

# Pandemic risk: Impact, modeling, and transfer

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## Abstract

COVID-19 has proven that pandemic risk deems to be the type of catastrophe risk that needs to be treated seriously, by both society and the insurance industry. A key element to measure, manage, and transfer pandemic risk is the modeling capability. This paper first reviews the insured loss from COVID-19 and the impact on the insurance industry. Then, current pandemic risk modeling capabilities and how insurance industry uses these models are evaluated. Some suggestions are made in terms of how these models can be improved in the future and how they can assist in insuring the pandemic risk. Finally, the nonmodeling elements of pandemic risk transfer and the government's role are discussed.

## KEY WORDS

insurance, model, pandemic risk

## 1 | INTRODUCTION

The COVID-19 global pandemic outbreak has created an unprecedented impact on global economies, local communities, and individual lives. Academic literature evaluating the impact of this global pandemic has been created. For example, Chetty et al. (2020) built an economic tracker to measure the impact of the COVID-19 crisis on economic activities and document the real-time impact. Baker et al. (2020) studied the impact of voluntary social distancing and government restrictions and argued that these actions led to extraordinary impact on the market, economies, and society that was not seen in the prior history, including the 1918 Spanish Flu. In the industry, Dan Glaser, the CEO of Marsh and McLennan Companies, has described the crisis as “two black swans that occurred at the same time.” As a public health crisis, COVID-19 has been a pandemic event most of the living population has never

experienced before. The 1918 Spanish Flu was the most recent pandemic comparable to COVID-19, but since then, few have expected the reoccurrence of a pandemic event of this scale in the modern world. The COVID-19 pandemic is ongoing; thus, it is not possible to predict the final number of confirmed cases and fatalities. However, the current levels of damages and losses will be sure to give this even a significant place in human history.

As an economic crisis, many governments' abrupt decisions to lock down societies, with the objective to slow down the spread of the virus, created an economic externality the economy was not prepared for. Social distancing and stay-at-home orders not only slowed down the economic activities in a material way but also reduced the overall demand for products and services. The number of job losses and the speed of economic decline quickly exceeded the 2008 financial crisis and have the potential of long-lasting effect on the global economy. Unfortunately, the economic crisis hit small businesses and low-income individuals disproportionately hard. Governments have taken unprecedented measures to counter the negative economic impact, incentivized companies to save jobs, and provided financial buffer. However, the broad-brush approach utilized by governments could not satisfy every business' and individual's needs.

In addition to the tail event like COVID-19, it should be noted that this type of risk also has a history of epidemic breaks or local breaks. SARS, MERS, and COVID-19 all occurred within the past 20 years, even though only COVID-19 has reached the global pandemic scale. These events created an impact on both human health and local economies (SARS and MERS were mostly in Asia, but also impacted the rest of the world such as Canada's hospitality industry). Therefore, researchers can reasonably use historical data to form a statistical distribution for this type of risk. It is also worthwhile mentioning the non-tail portion of epidemic risk should also be properly measured, managed, and transferred.

Insurance is naturally considered "the economic stabilizer," playing an instrumental role in uncertain times like COVID-19. The property and casualty (P&C) insurance sector and their products have responded well to indemnify the losses that were underwritten and insured explicitly, such as event cancellation loss, trade credit loss, and so forth. Meanwhile, coverage gaps and claim disputes, such as business interruption (BI) insurance, have also emerged from the crisis. These coverage gaps indicate the need for the insurance sector to become more relevant to the current and next similar economic crisis, especially as more insured assets would be intangible assets in the future. The P&C insurance sector must increase innovation of product offerings, have better tools to quantify pandemic risk and work with the broader society to create practical pandemic risk transfer solutions.

This paper intends to discuss where the P&C insurance sector can better serve the economy, the tools that are necessary for the sector to achieve these goals, and market mechanisms that can make the pandemic risk transfers practical. The second section of the paper offers an overview of the pandemic insurance market condition and the observations from the COVID-19 crisis, including where the P&C insurance sector is actively deploying their capital to cover losses and where the coverage gaps exist. The third section of the paper focuses on modeling and quantifications of pandemic risk, including a review of the current industry capabilities, key challenges around the pandemic risk modeling, and principles to establish a credible pandemic model for the future. The fourth section of the paper will discuss the nontechnical and nonmodeling elements that are necessary for a successful and functional pandemic (re) insurance market. Given the importance of insurance availability to the overall economy, this paper identifies opportunities for both technical analysis and policy research to facilitate a successful pandemic risk transfer scheme.

## 2 | REVIEW OF THE MARKET CONDITION BEFORE AND DURING COVID-19

Traditionally, insurance is a tool that individuals and businesses can use to manage uncertainties and transfer risks. There are considerations for “insurable” and “uninsurable” risks, although theoretically a risk can be insured as long as the premium is appropriate. From (re) insurance carriers’ perspective, an insurance product can be offered to the market if (a) the carrier understands the risk they are writing, most commonly through modeling or risk quantification, and (b) the carrier has sufficient financial resources to indemnify the losses even in an extreme loss scenario. When these conditions cannot be met, responsible carriers would either decline to offer the insurance coverage, or impose a reasonably low policy limit to control the overall risk, or transfer the risk to reinsurers if they can find reinsurance partners who are willing to take the risk. Such practical considerations can lead to an imbalance between insurance supply and demand, known as the “insurance availability issue.”

Historically, a number of insurance lines or products affirmatively cover the financial losses caused by pandemics, but others have clear exclusions in their policy language. Examples include:

- *Affirmative pandemics coverage:* Health insurance, life insurance, event cancellation insurance, travel insurance, trade credit insurance, workers compensation insurance if it is determined the workers become sick at the workplace, and so forth.
- *Pandemics losses exclusion:* The BI clause embedded in most commercial property insurance policies, workers compensation insurance if it is determined the workers become sick outside the workplace, and so forth.

Between affirmative coverage and clear exclusion, “silent coverage” sometimes exists. A classic example is property damage from a cyber attack. If a cyber event causes property damage (e.g., hacker makes a boiler become overheated and then explode), property insurance policy may be required to pay the claims if the cyber risk was not clearly excluded in the policy language.

Before COVID-19, the perception around pandemic risk mainly considered local outbreaks and health crisis, loss of lives, event cancellation, and trade disruption. As a result, insurance products existed for these types of losses. For example, Lloyd’s of London is known for covering nontraditional risks, such as event cancellation, although other carriers also wrote a significant amount of contingency insurance recently.

Few had expected the majority of the financial losses in a real global pandemic scenario, such as COVID-19, to be the BI losses caused by government orders to close down. This resulted in two important consequences:

- The affirmative pandemic coverage for BI was not widely available in the market. Additionally, there was little demand either. For example, in 2018, Marsh, Munich Re, and Metabiota introduced a pandemic risk transfer product named PathogenRx, which would cover BI loss from pandemics but had very little adoption before COVID-19. Few had expected a massive business lockdown triggered by a pandemic.
- Most property insurance forms (especially those in the United States) explicitly exclude communicable diseases, including pandemics, but this clause was not getting a lot of people’s attention until COVID-19. From the insurance carriers’ perspective, communicable disease risk was neither priced nor covered. From the policyholders’ perspective, they either mistakenly believed pandemics was a covered loss, or consciously decided to retain the risk.

These consequences led to a dramatic supply-and-demand shift of pandemic insurance for BI in the middle of COVID-19. Many companies, often driven by a mandate from the Board, are now seeking such coverage. However, they are either finding little to no insurance capacity for this kind of coverage or facing the reality that the price is unaffordable. Even insurers, who previously offered affirmative policy limits for BI caused by pandemic (such as FM Global), have significantly retreated from such product offerings since COVID-19 began. The current insurance market situation, in many aspects, is similar to the terrorism insurance availability and market post-9/11.

(Re)insurance sector's cautious behavior to provide future pandemic coverage is partly caused by uncertainty around the loss potentials from COVID-19. Some prominent insurance industry figures have voiced their pessimistic views on the possible losses to the P&C insurance sector.

- (a) "This event will be the largest event in insurance history."—Evan Greenberg, Chairman and CEO of Chubb Ltd.
- (b) "We believe Covid-19 will be the single largest CAT loss the industry has ever seen."—Brian Duperreault, CEO of American International Group Inc.

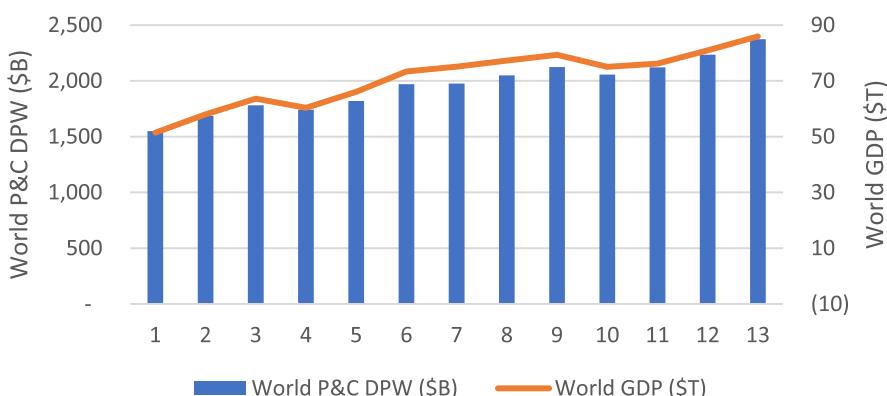
Additionally, capital market analysts and banks also shared the quantitative assessments of the potential insured losses from COVID-19, as part of their evaluation of insurance carriers' financial strength, such as Barclays (\$40B–\$80B), Bank of America (\$30B–\$97B), Wells Fargo (\$44B–\$110B), Moody's (\$56B–\$90B), and JP Morgan (up to \$100B).

It is important to note the figures and statements above were made with the assumption that the pandemic exclusion in BI insurance would generally be honored, and legislations would not be passed to retroactively force insurers to pay for BI claims. Otherwise, the insurance industry would face a loss on a different scale. American Property Casualty Insurance Association preliminarily estimated that business continuity losses for small businesses, with 100 or fewer employees, could fall between \$220B and \$383B per month. The cumulative policyholder's surplus of the United States P&C industry is just over \$800B, meaning that the entire P&C industry could be easily bankrupted if such losses were imposed on them.

Even without significant BI claims, the P&C insurance sector is still facing a COVID-19 loss potential that is significant enough to materially change the market. The hardening of market conditions for insurance and reinsurance was clearly evidenced and widely spread. Below is a summary of the loss potentials for each P&C line of business.

Likely COVID-19 claims	Possible increase in loss activities	Possible decrease in loss activities
<ul style="list-style-type: none"> <li>• Workers compensation</li> <li>• Employment practices liability</li> <li>• Trade credit</li> <li>• Event cancellation</li> <li>• Travel</li> </ul>	<ul style="list-style-type: none"> <li>• General liability</li> <li>• Directors and officers</li> <li>• Errors and omissions</li> <li>• Cyber</li> <li>• Commercial property (business interruption)</li> </ul>	<ul style="list-style-type: none"> <li>• Personal auto</li> <li>• Commercial auto</li> <li>• Some specialty lines</li> </ul>

Future premium projection and the pattern of cash flows are also crucial to insurance operations. These can also be significantly impacted by COVID-19. Overall insurance is considered a nondiscretionary spend, meaning the demand should not be very elastic; however, COVID-19 is an unprecedented event. In the short term, multiple states in the United States



**FIGURE 1** World P&C DPW and GDP. *Source:* The World Bank, Insurance Information Institute, Inc. DPW, direct premium written; GDP, gross domestic product; P&C, property and casualty

have required insurers to allow delay in premium payments and prevented them from canceling the policies. These actions clearly will impact the insurance carriers' cash flow. Additionally, initiated by GEICO, personal auto insurers have started to refund their auto insurance policyholders to account for the disuse of cars due to the government close-down orders. These refunds, amounting to billions, will influence the pattern of insurance carriers' cash flow in a meaningful way.

In the long term, as P&C insurance premium volumes have tracked with overall economies closely (see Figure 1), it suggests that how soon the economies recover and whether global trades resume as normal will determine the long-term prosperity of the P&C insurance sector. The low-interest-rate environment, anticipated to continue to support the economy, means lower investment income. This subsequently adds pressure on underwriting operations and requires more underwriting profitability. As a result, it is conceivable that the insurance market will both harden and become more competitive simultaneously. Insurance carriers' capabilities to innovate, close the coverage gap, and identify new revenue sources become critically important for their growth and profitability in the future. This contrasts with the fact that much of the financial losses from COVID-19 was not covered by the P&C insurance sector. The rest of the paper will discuss the necessary technical and nontechnical conditions for the insurance sector to take on pandemic risk in the future.

### 3 | PANDEMIC RISK MODELING FOR P&C INSURANCE

Academic literature focusing on pandemic risk models and their applications on insurance exist, but mostly either attempts to tackle the technical aspect such as mortality risk (Cox et al., 2010) or specific computer modeling algorithm (Rozell, 2019). These literature have made significant contributions and helped push the boundary of academic research. Meanwhile, the COVID-19 crisis has called for a more comprehensive review of the actual pandemic risk models used in the insurance industry, as well as an assessment of how these modeling capabilities can be further improved to facilitate pandemic risk transfer. These topics are going to be the focus and contributions of this section.

### 3.1 | Overview of current pandemic models

Modeling capabilities for pandemic can be categorized by their ultimate applications. For healthcare and disease control, pandemic models were widely used to estimate the number of COVID-19 confirmed cases and deaths since the global outbreak began in early 2020. For risk transfer and insurance, life and health insurance sectors have historically considered pandemic a “catastrophe risk” and attempted to model the pandemic risk to the extent possible. For example, stress tests were performed to ensure the insurer's balance sheet could endure a significant pandemic scenario. Such analyses often focus on the number of fatalities. The economic impact on both sides of an insurer's balance sheet is then derived accordingly. These event-based analyses are deterministic, and they can model either historical or hypothetical scenarios. The advantage of such a deterministic analysis is that the results are intuitive to understand, and sensitivity analysis can be performed to determine how various factors can influence modeling results. The disadvantage is that the number of scenarios is usually limited and does not necessarily cover all future possibilities. Product design and pricing requires a reasonable idea of the complete loss distribution curve. Therefore, stochastic models were developed to tackle the full loss distribution. These models usually employ simulations to generate a large number of hypothetical scenarios for the future, assign a probability to each scenario, and combine all scenario losses and their probabilities to calculate loss distribution. The results from the stochastic models can be more meaningful statistically and inform business decision-making in a comprehensive way. These results include annual average loss, value at risk, tail value at risk, and so forth.

In addition to deterministic and probabilistic events that represent possible influenza and infectious disease scenarios, pandemic models also often explicitly consider factors such as demographics of the exposed population, transmissibility, mobility and fatality rate, and counter-spreading effects such as government intervention and vaccine. When insured human exposures and their demographics are entered into the models, each event's impact on these exposures will be calculated based on the above factors, and ultimately a loss distribution can be calculated. Risk assessment and risk transfer price can be developed based on such loss distribution.

Prior to COVID-19, the commercially available pandemic models for the insurance sector included:

<b>Model name</b>	<b>What is modeled?</b>	<b>Methodology</b>
Metabiota®	human outbreak + live events	1-million-year simulation
RMS LifeRisks®	Influenza, infectious diseases	Event based methodology
AIR Pandemic Model	Influenza, emerging infectious diseases	500-K-year simulation
<b>Model name</b>	<b>Deterministic analyses</b>	<b>Stochastic analyses</b>
Metabiota®	Y	Y
RMS LifeRisks®	Y	Y
AIR Pandemic Model	Y	Y

As the basis for risk modeling, public and commercial data sources were often used to develop models or simulate scenarios. These data sources can also be used to perform statistical analysis and make inferences. Examples of such data sources include

- WHO Disease Outbreak News (<https://www.who.int/csr/don/en/>)
- GIDEON Informatics (<https://www.gideononline.com/home/case-studies/>)
- CDC COVID Data Tracker ([https://covid.cdc.gov/covid-data-tracker/#cases\\_totalcases](https://covid.cdc.gov/covid-data-tracker/#cases_totalcases))

### 3.2 | Key challenges to model pandemic risk for P&C insurance

Despite the existence of pandemic models as discussed above, their applications to P&C insurance have been limited. Prior to COVID-19, the pandemic risk was not perceived as a catastrophe risk at a similar level to a hurricane, earthquake, terrorist attack, or cyber attack. The P&C insurance sector was confident that pandemic loss was excluded by their policy languages in many cases (e.g., BI loss). Therefore, the pandemic stress test for P&C carriers was not a common practice in the industry and regulators and rating agencies did not require them. Additionally, the pandemic models also had certain features that led to their underutilization in the P&C insurance sector, summarized below.

- Models were not built for specific P&C insurance products: Different P&C lines of business offer very different insurance products, for which the loss triggering and financial mechanism are also very different. Workers' compensation losses might be directly determined by the pandemic outcome, but liability insurance loss might be more correlated with social and government measures taken to deal with the pandemic situation. For example, essential workers must continue to work, which can lead to employer liability; such liability is driven by the government and business policies during the pandemic.
- Model output is not insured loss: As discussed above, current pandemic model outputs often focus on the number of fatalities or casualties. There is a very significant gap between these models and the ultimate insured losses for the P&C carriers. For example, even in the same pandemic death scenario, the liability insurance indemnities can be hugely different depending on the litigation process and court decisions. Without the ability to address this additional layer of uncertainty, models cannot provide a reliable distribution for the ultimate insured losses.
- Model resolutions are not refined enough for risk identification and price differentiation: A key requirement for any model used for P&C insurance is that it can tell high risks from low risks, and, therefore, actuarial prices will be differentiated accordingly. Unfortunately, the resolutions of the existing pandemic models are not refined enough to achieve this objective. For example, if a model's resolution is at the country level, an insurer would charge the same price for risks located in the Northeast and the Midwest. The type of businesses may not influence the modeling results either, meaning the hospital workers and office workers may be charged the same insurance rate despite differences in underlying risk.

To the P&C insurance sector, the current market environment for pandemic risk, in certain aspects, is similar to the market environment for terrorism risk post-9/11 attack. The sector suddenly realized a material risk and significant loss potential that was never predicted before. Additionally, the sector entered a situation where lacking an effective tool to model the "new" risk or quantify the insurance carriers' exposures simultaneously. Prior to 9/11, terrorism models did not exist, and terrorism coverage was often included without charging additional premiums. Post-9/11, terrorism models were developed to address the market gap and their capabilities continue to improve. Now it is an industry common practice to manage terrorism

accumulations, price terrorism risk separately and explicitly, and provide terrorism risk exposures and loss potentials to rating agencies and regulators. It is conceivable that the P&C pandemic insurance market and modeling capabilities will progress similarly post COVID-19, especially given the vast amount of business opportunities in this unchartered area for insurance carriers. However, there are a few principles and key elements needed to establish a credible pandemic model for the future.

### 3.3 | Principles to establish a credible pandemic model for the future

It is fully expected that pandemic models will become more robust post-COVID-19. Insurance carriers, brokers, consulting companies, and model vendors all have the incentives to invest in this area, likely meaning multiple model versions will be developed. Competition will incentivize the development and improvement of pandemic modeling capabilities, but there are a few principles that are crucial for credible pandemic models, listed below.

- **Insurance product-specific model:** As discussed, a model needs to focus on the insured loss for a specific product line to be applicable. Different insurance products' claims are affected by different factors, and these factors must be properly incorporated into the model. Uncertainties will always exist and can be significant (e.g., litigation outcome), but this is not a valid reason to exclude such factors. If insurance carriers' claims and pricings are influenced by certain elements, such as business type and pandemic risk mitigation measures, the model should also reflect these elements and their uncertainties. It is through these quantitative analyses, often simulation-based approaches, that insurer carriers can properly design and price a product.
- **Correlation:** It is justifiable that pandemic risk, such as COVID-19, is a systematic risk. Therefore, it is important to address the correlations between pandemic risk and other types of risks. Pandemic risk may trigger a higher volume of insurance claims across multiple insurance lines of business simultaneously (e.g., workers compensation and event cancellation). Sometimes, the other lines' claim activities may be reduced, such as less reduced driving and its impact on auto insurance. More importantly, pandemic risk will affect both sides of the insurance balance sheet simultaneously, caused by the capital market plunge and the low-interest-rate environment as observed during COVID-19. This dual effect means insurance carriers may not only experience above-average claims but also be negatively impacted by investment income and surplus shrinkage. Such correlations are critically important elements for enterprise risk management or risk capital modeling. Meanwhile, despite individual policy pricing focuses more on the underlying risk of exposure, it should also consider the necessity of accumulation risk loadings for pandemic risk.
- **Transparency and customizability:** Natural catastrophes, such as hurricane and earthquake, can be modeled based on meteorology and seismology. Physics and engineering knowledge can be used to inform the vulnerabilities from natural catastrophes. Therefore, catastrophe models for natural perils are often based on scientific foundations. In contrast, the outcome of pandemic risk is determined by the timing and effectiveness of disease control measures, resources for the healthcare systems, and many other "human factors." These factors cannot be predicted with scientific research and consequently cannot be modeled to a high level of accuracy. As a result, it is particularly important that the pandemic models are transparent and allow users to customize the model to form their own view of risk. It is possible for the

pandemic models to have default parameters, which will probably facilitate market risk transfers, but the parameters should be adjustable to model a fluid risk like a pandemic.

With hundreds of years of history, the insurance market evolved with the market needs. Risks considered “uninsurable” in the past can be insured today. The modeling and risk quantification capabilities also evolved, especially with the recent advancement of data and technology. The COVID-19 crisis will trigger the industry to become innovative again. Though the availability of pandemic insurance (e.g., BI caused by pandemics) is partially a technical issue, some nontechnical considerations are also crucial to a functional pandemic insurance market.

## **4 | NONMODELING ELEMENTS FOR SUCCESSFUL/ FUNCTIONAL PANDEMIC (RE)INSURANCE MARKET**

### **4.1 | Unique considerations of pandemic risk from the insurance perspective**

The unique features of pandemic risk and how they impact insurance should be highlighted to understand why P&C insurers hesitate to offer a pandemic product such as BI insurance. Generally, successful insurance operation relies on the Law of Large Numbers, where risk is diversified among insureds or across time. As a result, the annual average claims and the uncertainty around these claims can be reasonably quantified and forecasted; from these values, the insurance products can be priced appropriately. Catastrophe risks would challenge the Law of Large Numbers by their low frequency and high severity natures. However, catastrophe risks still can be insured because

- Insurers can diversify catastrophe risk across geographies and time so that they can still be profitable over the long run.
- Insurance and reinsurance industries have sufficient capital to cover a worst-scenario catastrophe loss (e.g., a Florida cat-5 hurricane making landfall in Miami and causing \$100B insured loss)
- Insurance-linked security (such as catastrophe bonds, collateralized reinsurance, and side-cars) with capital supplied by the non-insurance sector has provided a large amount of capacity for catastrophe risk transfer. As of the end of 2019, alternative reinsurance capital accounts for around 20% of the total reinsurance capital globally, according to AM Best. The underlying rationale is that natural catastrophe risk does not correlate with the capital market and, therefore, can diversify the investment portfolios of pension funds and hedge funds.

For many reasons, pandemic risk challenges Law of Large Numbers to a greater level than natural catastrophe risk, and, therefore, presents unique challenges to insurance. Pandemic risk is not limited by physical parameters, such as geography or time. A large hurricane and earthquake can be “catastrophic” to the landfall or epicenter areas, but such areas are geographically limited, and such events only last for a few days at most. In contrast, pandemic events like COVID-19 can impact a whole nation or even the whole world, creating a significant challenge for insurers to diversify the risk. Additionally, a pandemic event can easily last for

months or even years, with possibilities of multiple waves of infections, which materially increases the risk exposures of the insurers who underwrite such risks.

Another unique challenge of pandemic risk is the insurance industry has insufficient financial resources to cover the worst-case pandemic loss, such as BI loss from COVID-19 because historically insurers did not price or cover such pandemic risks. Consequently, the insurance industry did not accumulate the capital corresponding to pandemic risk. Without such capital, a practical approach for insurers to take is to start writing pandemic risk, with a small limit and little premium income. Through accumulating the profit and capital across many years, the industry will be able to gradually build up the capital base to underwrite a larger amount of pandemic risk. However, this approach inevitably will result in insurance availability issues in the short term. Meanwhile, actuarially sound risk premium will lead to affordability issue, which is a focus of the political debates. As a result, both insurance availability and premium subsidies should be the key considerations of future design for pandemic risk transfer.

An additional challenge is pandemic risk can lead to turmoil in the capital market, presenting a positive correlation with investment risk. This reduces capital market investors' appetite for backing the pandemic insurance product. Presenting further challenges to the capital market solution of pandemic risk is capital market investors are more comfortable taking the insurance risk that can be modeled well, so they can roll up the risk with their overall investment portfolio in a quantitative fashion. However, this does not mean the capital market solution is not possible: Before COVID-19, a limited number of catastrophe bonds for pandemic risk existed. For example, in 2017, The World Bank launched the first-ever pandemic bond to support a \$500 million pandemic emergency financing facility.

Further to the above practical considerations from the industry perspective, risk management and insurance literature also started to explicitly address the unique characteristics of pandemic risk and its insurability. For example, Hartwig et al. (2020) built a model to quantify the capital requirement in the context of pandemic insurance, compare the result with natural catastrophe and concluded the private insurance industry does not possess sufficient capital to insure pandemic risk on its own. Richter et al. (2020) provide a firm-level examination of how insurance companies think about pandemic risk prior to COVID-19, as well as resilience and contingency planning. In summary, both academia and industry have an abundance of reasons to argue that pandemic risk must be treated differently than traditional insurance risks, including natural catastrophes.

## 4.2 | Governments' role and their own need to quantify the financial loss from pandemics

On the basis of the unique characteristics of pandemic risk, one can argue that not all of the pandemic losses are insurable, or the P&C insurance sector is not yet ready to take on the risk alone. The government also has a vested stake in managing and mitigating pandemic risk. COVID-19 has proven that when people are affected by pandemics on a large scale, governments will have to intervene. In economic theory, managing pandemic risk has strong positive externalities, supporting governments' involvement in managing and transferring pandemic risk.

The governments can play a significant role by contributing in a number of different ways, such as (a) providing postevent financing, similar to what the governments did for COVID-19, (b) providing pandemic insurance directly, (c) providing pandemic reinsurance to insurance companies and serving as their backstop, (d) imposing social insurance for pandemic risk which

is similar to a tax scheme, and so forth. It is outside the scope of this article to examine the advantages and disadvantages of the potential public policy designs (interested audience can refer to Hartwig et al., 2020), but it is worthwhile to point out that these potential schemes will score differently from different perspectives. Unfortunately, there are many elements to look at when evaluating future policy designs, such as impact on the overall economy, affordability, and sustainability, incentives for risk mitigation, appropriate matching between funds and losses, operational efficiency, and so forth. The complexity of this issue, plus the enormous impact it may have on the whole society, warrants serious academic research, full industry involvement, and thorough political debate.

Meanwhile, it is important to keep in mind that government involvement may tend to lead to subsidy, as well as the mismatch between risk and risk premium. Therefore, a risk-revealing mechanism generally would benefit the overall risk transfer scheme in the long run. Even in the scenario that government provides insurance coverage directly or launches a social insurance program, it is worth considering a private insurance program for a specialty or niche market (e.g., an insurance consortium for airline industry) that runs in parallel. This will help reveal free-market information and pricing.

From the modeling perspective, whatever role governments play in the future risk transfer scheme, being able to quantify the pandemic risk and loss potential will continue to be a key factor for success. Not only the scheme design needs to make financial sense, but it also will have a trickle-down effect on business and individuals in terms of how they view, manage, and transfer pandemic risk. Any future pandemic insurance, whether provided by the government or private sector or a combination of the two, is better to be properly priced and reflect the underlying risk, which will provide incentives for the insureds to perform risk mitigation. Meanwhile, affordability and fairness are equally important. All of these elements rely heavily on risk quantification capabilities. Therefore, whether it is the government providing pandemic insurance directly, serving as the insurance industry's backstop, or creating a tax scheme for social insurance, it will benefit the whole society for the government to have the capabilities to model their risk exposures, stochastically and deterministically, so that they can create appropriate incentives for all the participants of the pandemic risk scheme.

Governments already have employed several pandemic models to manage responses to COVID-19. These pandemic models are not insurance models, and generally do not focus on economic impact, but can be extended to assist governments in making informed decisions. For example, governments' emergency funding can be distributed more effectively if the models can output the relative severity of pandemic loss by geography or by the business sector.

If governments intend to insure or reinsurance pandemic risk in the future, their financial resource planning can be beneficially informed by pandemic models. Unlike the insurance industry, the government pandemic model output does not have to be insured loss of specific insurance products. Instead, the output can be an overall economic impact based on which governments can deploy financial resources. From this perspective, a macro model, instead of a micro model, can be suitable for government needs.

## 5 | CONCLUSION

As a health and economic crisis, COVID-19 is an important lesson for the P&C insurance industry. Significant coverage gap for the majority of the economic loss, such as BI, emerged despite certain lines of business expected to pay claims for the risk they had underwritten. This contrasts with

insurers' strong desire to grow profitably, which has been a consistent theme for the sector in the past decade. It is natural to think that insurers' desire to grow profitably and the strong needs for pandemic insurance would match perfectly. However, numerous obstacles exist, a critical one being the ability to model and quantify the insured loss from pandemics.

This paper reviews the existing pandemic models for the insurance industry and concludes that they have been mainly designed for and used by the health and life insurance sectors. The conclusion was driven by a few factors, including (a) the pandemic models were not built for specific P&C insurance products, (b) model output are not insured losses, and (c) model resolutions are not sufficiently refined for risk profiling and price differentiation. Without the ability to reasonably quantify the pandemic risk, P&C carriers would find it difficult to design new products and price them. COVID-19 has demanded the P&C insurance industry to be innovative again. Developing modeling capabilities to understand pandemic risk in a quantitative manner is a critical step to achieve innovation.

It is also important to highlight the key elements and principles required to establish a credible pandemic model for the future. These include the necessity for pandemic models to be specific for certain insurance products, the ability to address correlations among insurance product lines and between two sides of the insurance balance sheet, and the importance to be transparent and customizable.

Some unique characteristics of pandemic risk and the government's vested stake in society's stability determine that government will need to play a role in the future pandemic risk transfer scheme. Therefore, the government will also need to develop capabilities and skills for pandemic modeling, although their perspectives would be different from the private sector. To incentivize risk mitigation and prevent adverse selection, the pandemic insurance and reinsurance price should reflect underlying risk and differentiate risk profiles, which also require strong modeling capabilities.

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