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Securitization for common health

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ABSTRACT

Securitization is the process of turning a financial asset, such as a loan or a mortgage, into a security that can be bought and sold on the market. Insurance-linked securities have been developed in order to foster the risk-transfer from insurers to capital market. In the context of pandemics or health crisis, securitization has been used to raise funds for crucial healthcare infrastructure and resources. However, securitization can also play a role in lowering infectious rates of pandemics as a part of risk mitigation strategies. Securitization can be engineered at higher standards and levels involving different actors. In the current paper, we propose an operational securitization mechanism based on the previous work by Di Lorenzo and Sibillo (2020) where a bond with coupon linked to the infection rate is introduced in order to reduce the risk exposure of an insurer offering health coverage. The combination of bond and health policies is structured in such a way to foster the economic operators (insureds, insurer, investors on capital market) to reduce the pandemic risk. It follows that companies might guarantee collective health for their workers if they subscribe insurance policies. Indeed, issuing such a bond on the market is challenging, due to poor market liquidity and, then, due to difficulties in pricing. In these regards, we value the pandemic-linked bond via an approach based on an inter-temporal CRRA utility function that, in its turn, determines a certain equivalent financial bond. The comparison values the pandemic-linked bond at varying with investors' risk-aversion and sustainable-projects desirability. This provides an estimation of the risk-transfer cost for the insurers.

1. Introduction

The idea of the current paper is to promote a market-sustainable framework for the economics of a traditional common good: the collective health of a community during the effects of a disaster or a crisis [1–3]. The specific framework is based on innovative and recent mechanism coming from the world of mathematical insurance. Indeed, our effort follows a literature specifically based on considering "insurance as governance" [4]. The risk of new pandemics launched by the WHO requires not only treatment and prevention of disease, but also innovative policies to treat the multiple consequences of the pandemic impact [5–7].

First of all, not all disasters and associated crises are equal and can be equally dealt with. Disasters and their relative crises can be classified according to multiple factors. More specifically, the Covid-19 crisis has taught us about the multiple features of health disasters and crisis in modern ages. In this context, it is worthwhile to consider the role of the insurance sector in addressing the challenges posed by the demand for protection and prevention related to pandemic risks [8,9]; in fact, the pandemic from COVID-19 and the resulting restrictive rules aimed at limiting contagion led to huge economic losses worldwide. Indeed, one essential feature of Covid-19 disaster consists in its "contagious" nature. Pandemic risk falls within the macro-category of catastrophic risks, while differing from other categories of systematic risks by virtue of its expansion in space and time, and the extent of the losses caused [10–12]. It follows that the dynamics of the disaster depends on human factors: for instance, renewed, durable and time-continuous measures like social distancing, mask-wearing in social and working environments [13]. Conversely, natural disasters occur in one single random-shock and their consequences are immediate, dramatic and the produced crisis is quite visible and, to some extent, also more accountable [14]. As such, optimal and effective recovery strategies are the most relevant key issues for these "old-style" disasters. It is not a case that an extensive literature of recovery models has been recently developed so far from an optimizing angle [15–17].

It appears straightforward that the tool of risk mitigation is, specifically, more relevant for novel last-longing disasters; the effectiveness of mitigation strategies depends on how those strategies anticipate and provide coverage against the unethical individual action of humans, the negative social effects of the crowd reasoning and the sociological effects of inappropriate but widespread social norms in situations where

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each single individual is, financially, threatened by the ongoing crisis. Loosely speaking, individual might have incentives to maintain a secure behaviour, or to get vaccinated or to follow health central authorities' guidelines [18]; also, moral suasion plays a similar role in this framework [19]. This approach is based on the principle of "insurance as governance" and categorizes certain aspects of the insurance role, from the economic, ethical and social point of view [20]. The insurance mechanism itself influences the policyholders' behaviour. In light of this, the experience of Covid-19 pandemic suggests that an insurance cycle can be a driving force that promotes good behaviour.

Indeed, the joint protection of collective health and productive activities is a central issue for governments, requiring large-scale efforts and strategies, through public and private synergies [21]. It is specifically the role of insurance mechanisms the one that should mitigate the risk of pandemics within the boundaries of a less risky epidemics.

The scientific literature on insurance contracts related to pandemic risks is still sparse and only recently, on the occasion of the pandemic by Covid-19, the debate on public and private policies and resources to tackle this issue has been considerably revitalized. Some researchers have shown perplexity about the role of pandemic insurances in incentivizing *insurance as governance*, due to moral hazard and the difficulty of collecting information related to the pandemic [22]. For instance, pandemic bonds are characterized as bonds aimed at bearing the expenses resulting from pandemics. The first issue dates back to 2017, when the World Bank decided to implement a financing system to help populations affected by global pandemics. Essentially, this system seeks to stimulate private investment, enticed by a bet on the development of pandemics based on some pandemic indicators [23]. However, the pandemic criteria were difficult to implement in countries that suffered from poor ability to retrieve the data required by these criteria. And this is why, during the Ebola epidemic that hit Congo in 2019, the pandemic bonds issued by the World Bank did not allow to find the necessary funds [24].

More "engineered" and more "market-sustainable" insurance mechanisms must be, then, proposed. Indeed, the preventive risk mitigation, provided by insurance mechanisms, should finally guarantee market-sustainability [25]. For instance, He et al. [22] advanced the idea of a tiered approach where, in addition to insurance and reinsurance, the government could have a role as re-insurer of last resort, as they say. The architecture of those insurance mechanisms might cover the costs associated with the initial phase of the disaster and then, might further reduce the duration of the disaster and, then, might even further reduce the final associated damage and economic costs. As such, insurance might help (ex ante) authorities in mitigating the spread of the ongoing disaster. Ideally, the latter should also bring into the economic principle of non-rivalry for collective health. In other words, insurance might also maintain the collective health as non-scarce resource for everyone.

In fact, some recent studies aim to a broader approach, including a multiplicity of roles in an extended insurance context: insurers, individuals, investors, public and private institutions may be involved. This vision becomes concrete in an organic market solution through a securitization process. According to the insurer's point of view, the risk associated with pandemics is catastrophic, characterized by low frequency of occurrence and high severity of impact. As with all insured catastrophic risks, as [25] argues, also in this case, insurability is based on the risk diversification by geographical areas, the use of reinsurance (as is the case with climate risk coverage) as well as using the non-insurance sector through insurance-linked securities (here too the experience of extreme climate risks is valuable). Haffar et al. [26] also explore the possibility of sharing pandemic risk between the insurance industry and the financial market; in this exchange several players are involved at various levels, that is insurers, financial investors, States, individuals.

Liu et al. [27] examine in depth the possible use of pandemic bonds in China during the SARS-Covid 19 outbreak; Huang et al. [28] propose a joint strategy by means of a pandemic bond and an endemic swap to hedge, respectively, a pandemic outbreak and recurrent endemic.

Chen et al. [29] consider a pandemic bond arising from a public–private partnership, aimed at mitigating the riskiness fronted by life insurers and other institutions suffering pandemic risks; Eggleton and Gürses [30] focus on the losses due to business interruption related to the pandemic; in this framework they suggest how an uninsurable risk related to the pandemic trend, can be managed in the insurance context through public–private partnerships. Moreover, Schmitt and Spaeter [31] also contribute to the study of pandemic-related business interruption losses; their analysis focuses on how qualified investors in CAT bonds can make an interesting contribution within a public–private coverage scheme.

Di Lorenzo and Sibillo [32] propose a virtuous securitization procedure: on one hand, insurance contracts signed by firms cover the employees/workers from health damage due to COVID-19 infection, thus encouraging the pursuit of good practices to protect the health of workers within the firm. On the other hand, the insurer buys through the Special Purpose Vehicle (SPV) the straight bond with fixed coupon, and issues the pandemic bond with stochastic coupon, so implementing a securitization process. The investors purchasing the securitized product, bet on the improvement of the contagion. In fact, if the infection decreases, the investors obtain a higher cash flow. The proposed health securities allow not only to share the risk of contagion, but also to generate a virtuous process in which all parties involved actively contribute to the improvement of public health.

The approach explored by Di Lorenzo and Sibillo [32] emphasizes the insurance response to pandemic risk also considering the inclusion of environmental, social and governance (ESG from now onwards) investments in the business of insurance companies [33]. The novel sustainable insurance aims at new strategies of public health protection and new policies involving the welfare of people and productive activities.

This topic is extensively explored in the actuarial literature, which has also deepened possible strategic lines shared by governments, firms, private and institutional investors [34]; moreover, novel contract profiles have been proposed, as insurance linked bonds related to the pandemic [20].

This work proposes securitization as a tool to protect collective health. The derivative financial instrument is analysed in its quantitative structure, and its ESG product qualities are highlighted. The attractiveness of the product is analysed following the approach of the certain equivalent, identifying the deterministic product perceived as equivalent by the investor. A numerical application presents some relevant results that consolidate the proposed theoretical design. The remaining of the paper is organized as follows: in Section 2 the securitization process is described and formalized; Section 3 deals with the certain equivalent of the proposed product; to this aim the probabilistic structure of the payouts is presented, the product is clearly defined as an ESG one, and a utility function involving the specific investor's profile is introduced. Section 4 provides some meaningful results concerning the certain equivalent analysis aimed at defining the product attractiveness.

2. Financial synergies and collective health: the securitization process

We recall the securitization process introduced by Di Lorenzo and Sibillo [32], that is the starting point of the whole analysis.

The leitmotiv of the scheme is to involve three economic players in a chain that aims to enhance the community's well-being. The chain starts from a firm seeking to protect its employees from any potential health damages caused by a pandemic, for instance the COVID-19 pandemic. The insurance policy aimed at such coverage also provides for a reduction in premiums over time, if the pandemic shows a tendency to mitigate the number of infected. The scale of this reduction

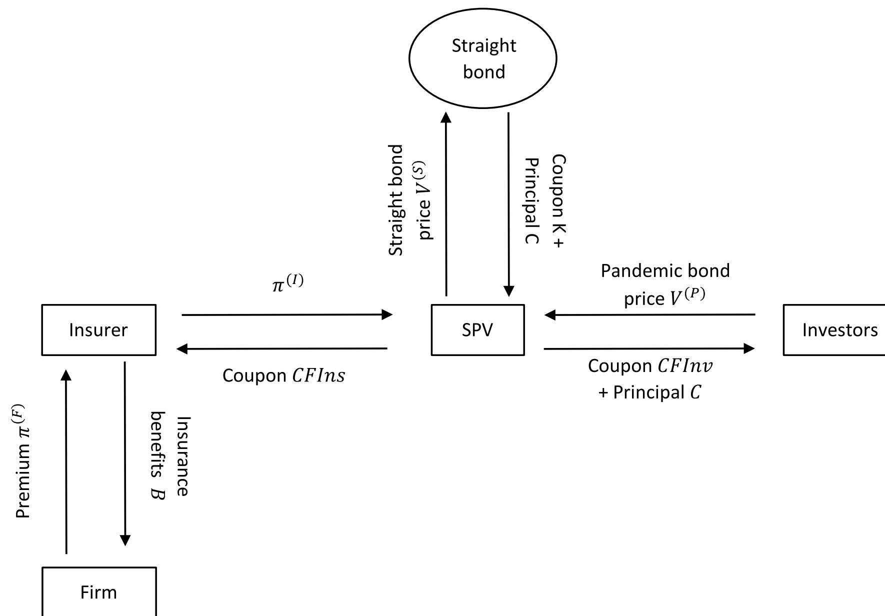

Fig. 1. Economic players and cash-flows of the proposed scheme.

identifies a new protagonist of the cycle, that is the insurer, indeed a co-protagonist, since the firm itself is interested in taking all the necessary actions to limit the contagion in its workplace.

The overall strategy requires further action on the part of the insurance company (which intends to finance itself for the burden arising from the reduction of premiums); this action consists in issuing bonds linked to the pandemic trend, using, as is the practice, a *special purpose vehicle* (SPV) to which the insurer pays the corresponding premium. In addition to the insurer company and the insured firm, there is another player, namely the investor who buys the securitized product, whose coupon flows are linked to the bet on the good performance of the number of infected. As pointed out in the Introduction, the securitized process is a circular process leading to economic-social impact based on collective health. For its part, the investor who buys the securitized product, in addition to achieving diversification of its portfolio, is characterized as an investor involved in the prevention of collective risks and serious about fostering the collective well-being. From the side of the common health, firms can provide coverage for their workers if they subscribe insurance policies. In their turn, workers' health is protected and positive health spillovers also fall on the whole society. Moreover, health-conscious firms take advantage of lower premiums. In a broader context, the whole cycle promotes and increases good practices to protect the health of workers and, in cascade, the collective health, reiterating the process over time.

In order to describe the above-mentioned cycle, we consider an insurance policy whose benefits, let us say B, cover the employees of a firm from possible health damages of a pandemic crisis. The contract provides the payment of a premium by the firm to the insurer, let us say $\pi^{(F)}$. Moreover, it includes a reduction in the premium over time, if the number of infected people decreases. This clause constitutes an incentive for the firm that buys the policy, so that measures are taken to protect the reduction of contagion. The first part of the cycle is described in the left part of Fig. 1.

In order to reduce its risk exposure, the insurer uses a securitization process. As explained before, the pandemic-linked bonds are issued by the insurer throughout a SPV. The proposed bond can be designed either as a principal-and-coupon-at-risk bond or as a coupon-only-at-risk bond. We consider the case of a coupon-only-at-risk bond, keeping certain the principal payment at the bond maturity.

An easy way to build such a pandemic bond is through the decomposition of cash-flows of a straight bond. The SPV buys, at price $V^{(S)}$, a straight bond paying a fixed annual coupon K at each time t, $t = 1, 2, \dots, T$ (with T the bond maturity) and the principal C at maturity. Simultaneously, the SPV issues a pandemic bond with the same principal and a stream of coupons linked to the pandemic trend. Every year t the SPV will split the coupons K paid by the straight bond into the two pandemic linked cash-flows: the coupons $CFInv_t$, acquired by the investors, and $CFIns_t$, acquired by the insurer. Note that $CFIns_t$ is the mirror part for the payments $CFInv_t$. In exchange for coupons $CFIns_t$, the insurer pays to the SPV the sum $\pi^{(I)}$, while investors pay the price $V^{(P)}$ to purchase the pandemic-bond. The SPV meets his obligations and has a profit if $V^{(P)} + \pi^{(I)} > V^{(S)}$. For a representation of this cycle see the central part of Fig. 1.

The coupon amount $CFInv$ depends on the percentage of infected i_t of the reference population, detected at each coupon maturity date t, and two threshold values ($Q_1(i_t)$ and $Q_2(i_t)$) given by two prefixed quantiles of i_t distribution. The coupon amounts for the investor and the insurer in t, $t = 1, 2, \dots, T$, with T the bond maturity, are described as follows:

$$CFInv_t = \begin{cases} K & E_1^{(t)} \\ 0 & E_2^{(t)} \\ K\frac{Q_2(i_t)-i_t}{Q_2(i_t)-Q_1(i_t)} & E_3^{(t)} \end{cases} \tag{1}$$

K being the amount of the coupon cap. In the same way:

$$CFIns_t = K - CFInv_t = \begin{cases} 0 & E_1^{(t)} \\ K & E_2^{(t)} \\ K\frac{i_t-Q_1(i_t)}{Q_2(i_t)-Q_1(i_t)} & E_3^{(t)} \end{cases} \tag{2}$$

At bond issue time, $t = 0$, the event of an ongoing pandemic at a generic time $t > 0$ is not certain. Therefore, the events in (1) and (2) can be described as follows: $E_1^{(t)}$ occurs if $\{i_t \le Q_1(i_t)\}$. This happens if there will be no pandemic in t or if, given the existence of an ongoing pandemic in t, the indicator will take values below the threshold $Q_1(i_t)$. It is sum of two incompatible events. $E_2^{(t)}$ occurs if $\{i_t \ge Q_2(i_t)\}$. This happens if a pandemic exists in t and, in this case, the indicator will take values greater than $Q_2(i_t)$. It is the product of two dependent events. $E_3^{(t)}$ occurs if $\{Q_1(i_t) < i_t < Q_2(i_t)\}$. This happens, similarly to the previous case, if a pandemic exists in t and, in this case, the indicator will take values between the two thresholds $Q_1(i_t)$ and $Q_2(i_t)$. It is the product of two dependent events.

3. The health-based product and its certain equivalent

The approach we will take in this section is that of the investor, with the aim of analysing the desirability of the product in a market where investors come with their own degree of risk aversion and their personal impatience with liquidity. Alongside these investor-specific characteristics, our analysis also considers the influence of the personal investor's preference for investment in a sustainable financial product, in particular the health-based financial product we propose (in this regard, we refer to the subsequent Section 3.3). We will aim the analysis at determining the certain equivalent that an individual, considering the personal characteristics that influence his or her financial choices, is willing to exchange for the security proposed in the paper. We will identify a risk-free bond with the same characteristics as the product under study, which the investor will perceive as "equivalent", in the sense that it confers on the investor the same level of utility.

3.1. The probabilistic structure of the payouts

We start by describing the probabilistic structure of the random flows of the proposed health-based product, and then move on to the utility function we choose to design the investor's behaviour.

On the base of the model in (1), two preliminary remarks are necessary:

- the quantity K, which is crucial in the design of the bond and as consequence in the following calculations and results, is determined a priori and is therefore to be considered fixed. It can be regarded as a strategic variable, which the issuer will have to carefully evaluate, bearing in mind the financial profile with a view to balancing the control and transfer of risk and its mitigation and the attractiveness of the product itself;
- we must imagine a future in which the pandemics will be recurring events, states that will occur at random intervals and will proceed with equally random durations. Consequently, we will describe a product launched on the market both in the presence of a pandemic and in the absence, presumably temporary, of pandemics.

Considering the payout of the bond at the generic time t, $0 < t \leq T$, and following the approach in [35], we express the uncertain payout in t at the issue time:

$$CFInv = K\,\mathbf{1}_{\{\tau<t\}\cap E_1^{(t)}} + K\,\mathbf{1}_{\{\tau\geq T\}} + \left(K\frac{Q_1(i_t)-i_t}{Q_2(i_t)-Q_1(i_t)}\right)\mathbf{1}_{\{\tau<t\}\cap E_3^{(t)}} \qquad (3)$$

recalling that the definition of the indicator function of an event A is as follows:

$$\mathbf{1}_A = \begin{cases} 1 & \text{if A is true} \\ 0 & \text{otherwise} \end{cases}$$

according to the following probabilities, under a risk-neutral probability measure $\mathbb{Q}$:

$$\mathbb{Q}\left[\{\tau<t\}\cap E_j^{(t)}\right] = \mathbb{Q}\left(E_j^{(t)}/\tau<t\right)\mathbb{Q}(\tau<t) \quad j=1,2,3$$

$$\mathbb{Q}\{\tau \geq T\}$$

such that:

$$\sum_{j=1}^{3}\mathbb{Q}\left[\{\tau<t\}\cap E_j^{(t)}\right] + \mathbb{Q}\{\tau\geq T\} = 1.$$

3.2. On the context of ESG investments

The product we propose can be considered in the macro-area of socially responsible investments, investments made with ESG (Environmental, Social and Government) objectives [33]. An investor can strategically consider ESG criteria in his/her investment choices by following different approaches, as in an official report from [36] are listed: Best in class, engagement and voting, ESG integration, exclusions, norm based screenings, sustainability themed, impact investing. For instance, the last two, which we report here with the description of Eurosif [37], seem to fully match the characteristics of the product.

3.2.1. Sustainability themed

Investments or assets in themes are linked to the development of sustainability. Thematic funds focus on specific or multiple issues related to ESG. Sustainability themed investments inherently contribute to addressing social and/or environmental challenges such as climate change, eco-efficiency and health. Funds are required to have an ESG analysis or screen of investments in order to be counted in this approach.

3.2.2. Impact investing

Impact investments are investments made into companies, organizations and funds with the intention to generate social and environmental impact alongside a financial return. Impact investments can be made in both emerging and developed markets and target a range of returns from below market-to-market rate, depending upon the circumstances. Investments are often project-specific, and distinct from philanthropy, as the investor retains ownership of the asset and expects a positive financial return. Impact investment includes micro-finance, community investing, social business/entrepreneurship funds and French *fonds solidaires*.

The product falls within the scope of impact finance. It not only mitigates the negative effects resulting from the spread of the virus, but also encourages virtuous behaviour on the part of the community interested in the product itself. It generates an ex-ante planned effect, therefore *intentional*, *additional,* because it is obtained thanks to the actions implemented directly by the company, and last but not least, it is *measurable*, by monitoring the trend of contagion. It is therefore rightful to associate an impact generated by the bond itself.

3.3. On the certain equivalent analysis

The aim of this Subsection is to associate the proposed financial product with a comparable bond that can be interpreted as its certain equivalent. As is well known, the certain equivalent is the amount of money that, with certainty, produces the same utility for the investor as the uncertain situation. In our context, the certain equivalent that we will derive will take the form of the risk-free bond that the investor will judge to be equivalent to the uncertain payout linked to the product. In other words, the investor will be indifferent to the two securities.

The idea is thus to describe the risk-free bond that the investor perceives as *indifferent*, from the point of view of the utility he/she derives from it to the health-based product we propose; this security will have to replicate the time structure of the health-based product. Like any greedy, risk-averse investor, he/she will measure the utility of acquiring the uncertain cash flow from the product through a risk aversion parameter and a parameter of impatience in repurchasing the cash. In addition to these, which are the traditional characteristics of the rational investor, the investor will be influenced by his/her liking for a fair, ESG-type investment. To the aim of determining the certain equivalent of the health-based product, we will use a time additive CRRA utility function. A Constant Relative Risk Aversion (CRRA) function is characterized by a constant risk aversion measure for all levels of wealth and a decreasing absolute risk aversion. In our case we have [38]:

$$U = E\left(\sum_{t=1}^{T}\phi(t)\frac{[CFInv(t)]^{1-(\gamma-\rho)}}{1-(\gamma-\rho)}\right) \qquad (4)$$

in which $\phi(t)$ is the impatience parameter, a financial function decreasing with increasing time, γ represents the risk aversion, and ρ is the investor's liking of a virtuous investment, which mitigates the impact of γ. The constant amount $CFconst$, certainly payable throughout the

life of the health-based product and with the same temporal regularity, that the investor with this utility function associates with the uncertain flows represented in (1), is calculated by the following equation:

$$U = \sum_{t=1}^{T} \phi(t) \frac{[CFconst]^{1-(\gamma-\rho)}}{1-(\gamma-\rho)} \tag{5}$$

from which:

$$CFconst = \left[\frac{U\,(1-(\gamma-\rho))}{\sum_{t=1}^{T} \phi(t)} \right]^{\frac{1}{1-(\gamma-\rho)}}. \tag{6}$$

$CFconst$ represents the constant certain amount, due on the same maturity dates as the eventual coupons of the random security and for the same duration, which will describe the certain equivalent of the proposed product.

4. Numerical application

In this section we develop a numerical application with reference to a possible pandemic-linked bond in the perspective of investors. Specifically, we determine the price at which they would be willing to purchase it according to their personal characteristics in terms of risk aversion. We also determine the certain equivalent of the bond. This amount allows us to determine the cost that would be borne by the insurer (the sum $\pi^{(I)}$) to obtain the risk coverage resulting from receiving the coupons $CFIns$. We also observe how the sustainable investment nature of the bond leads investors to demand a lower risk premium and thus reduces the cost of coverage for the insurer. A sensitivity analysis concludes the section, deeping the role of the attractiveness of the product due to its sustainability characteristics.

4.1. Bond structure and data

Let us consider a pandemic-linked bond with the following features:

- We assume that the issue is at pandemic inception, therefore $\tau = 0$ and $\mathbb{Q}\{\tau < t\} = 1 \quad \forall t > 0$. The aim is not to introduce a bond designed to cover the risk of incurring a pandemic but a bond aiming at covering the risk of spreading of the infections when the pandemic has already been declared.
- We assume $T = 3$. The maturity is chosen consistently with the duration of major pandemics observed in the past (Spanish flu, COVID-19).
- We consider a coupon-at-risk bond, keeping certain the principal payment.
- $Q_1(i_t)$ and $Q_2(i_t)$ are fixed as the first and the ninth deciles of the i_t distribution, respectively.
- We assume annual coupon at a coupon rate, k, equal to 4% and the principal is assumed equal to 1000 euros, therefore $K = 40$.

We assume a flat and deterministic term structure, with an annual interest rate equal to $r = 4\%$, while the impatience parameter is determined as: $\phi(t) = (1+r)^{-t}$. Note that under these assumptions on the interest rates structure a bond with certain coupons and annual coupon rate $k = 4\%$ would be quoted at par, therefore in this case $V^{(S)} = C$.

The distribution of the infection rate i_t has been obtained from the observed number of infected in the 107 Italian provinces from February 24, 2020 (pandemic inceptions) to October 11, 2023.[1] The observed data were divided into 3 periods of annual breadth, and annual infection rates were calculated for each province. The main features of the obtained empirical distribution of i_t, separately for 3 annual periods, are shown in the Table 1. From the table, we can observe the variability of the contagion rate across provinces and from year to year. The heterogeneity of the contagion rate across provinces allows us to represent the uncertainty faced by an insurer offering insurance coverage against a pandemic. Differences in the distribution of the infection rate from year to year show the highest incidence from the second year and the peak in the third year, with decreasing coefficients of variation. We use the empirical distribution of the contagion rate to determine the expected distribution of pandemic-bond coupons.[2]

Table 1
Contagion rate across Italian provinces-years 20–21, 21–22, 22–23.

	24/02/2020–23/02/2021	24/02/2021–23/02/2022	24/02/2022–23/02/2023
$E(i_t)$	3.84%	6.44%	31.84%
$\sigma(i_t)$	1.54%	1.75%	4.88%
$Min(i_t)$	1.07%	2.92%	22.17%
$Q_1(i_t)$	1.92%	4.53%	26.34%
$Q_2(i_t)$	5.86%	8.30%	39.74%
$Max(i_t)$	8.56%	13.38%	42.40%

Table 2
Expected values and expected present values of coupons.

t	$\phi(t)$	$E(CFInv_t)$	$\phi(t)\cdot E(CFInv_t)$	$E(CFIns_t)$	$\phi(t)\cdot E(CFIns_t)$
1	0.9615	18.93	18.21	21.07	20.26
2	0.9246	16.07	14.86	23.93	22.13
3	0.8890	21.18	18.83	18.82	16.73
Σ			51.89		59.11

Note that the choice of an index underlying the determination of pandemic-bond coupons is the key point. It is essential to ensure the independence and transparency of the index. It must be an index calculated on a population known to all stakeholders in the process, and it must be available at a time-frequency comparable with the contractual deadlines; and there must be no excessive delay between the date of release of the data and the date to which they relate. The index considered in our numerical application is processed directly on the official data of the National Observatory of the National Health Service, which were provided on daily basis for each Italian province. Some necessary remarks for the well-functioning of the proposed financially-engineered mechanism are necessary. First, when considering a pandemic-bond written on the contagion index of the workers of a firm, the definition of contagion and the workers' samples shall be taken into account. Moreover, an independent company, responsible for the calculation of the index, should be clearly indicated. Finally, the time frequency and the moment of measurement of the number of infected persons and the methods of communication of the data to the parties involved in the securitization process should be specified before the bond issue.

4.2. Results

Table 2 shows expected values and expected present values of cash-flows received by investors and insurer.

As a consequence of the way the bond coupons are split between investors and insurer, the sum of the amounts in the third and fifth columns is always equal to 40 (K). If investors were risk-neutral, and thus random flows were valued according to the principle of expected value, the value of the bond to investors would be sum of the expected present value (51.89) plus the present value of the certain principal (889.00): $V^{(P)} = 51.89 + 889.00 = 940.89$. The value obtained is equal to what a non-risky bond with a coupon rate of 1.87% would have.

[1] Data were extracted from the site https://github.com/pcm-dpc/COVID-19 last consulted on October 15, 2023.

[2] Alternatively, and as a possible development for future research, the number of infected people can be modelled as a stochastic process. A proposal for a stochastic model of the number of infected people has been made by Hainaut [39] to whom we also refer for a review of the literature on mathematical models developed to represent the evolution of a pandemic.

Always adopting the expected value principle, the cost of coverage for the insurer would be given by the sum of the expected present values of $CFIns_t$: $\pi^{(I)} = \sum_{t=1}^{T} \phi(t) \cdot E(CFIns_t) = 59.11$. The sum of $V^{(P)}$ and $\pi^{(I)}$ is equal to the non-risky bond price, $V^{(S)}$: $940.89 + 59.11 = 1,000$.[3] Therefore, the SPV can purchase the straight bond with a coupon rate of k and split the coupon stream between investors and insurer. The cost of the straight bond would be repaid by the sum of the price paid by investors for the pandemic-bond and the premium paid by the insurer for insurance coverage. In the absence of transaction costs and taxes, the cost to the insurer would be equal to the fair premium.

If we take risk aversion into account, $V^{(P)}$ is reduced. Let assume a value of the risk aversion parameter γ equal to 0.5. Through Eq. (4) we obtain the expected inter-temporal utility and then, through Eq. (6) the constant coupon flow certain equivalent to the at-risk coupon: $CFconst = 14.71$. This implies that investors would find a bond with a certain coupon rate of 1.47% equivalent to the pandemic bond. A risk-free bond with $k = 1.471\%$ would be quoted 929.83 on the market.

From the previous results we can get two different information:

- A risk-neutral investor considers the pandemic-bond equivalent to a risk-free bond with a coupon rate of 1.87%, while a risk-averse investor with $\gamma = 0.5$ considers the pandemic bond equivalent to a risk-free bond with a coupon rate of 1.47%. The cost of risk for the second operator is then equal to 40 basis-points (bp).
- A risk-neutral investor prices the pandemic-bond 940.89, while a risk-averse investor with $\gamma = 0.5$ prices the pandemic bond 929.83. In order to buy the straight bond, the SPV asks the insurer for the difference (11.06). Therefore, this value has the meaning of security loading, Λ, applied to the fair premium paid by the insurer: $\pi^{(I)} = \sum_{t=1}^{T} \phi(t) \cdot E(CFIns_t) + \Lambda$. In relation to the fair premium the loading is 18.7%.

In the analysis carried out so far we ignored the ρ parameter, the investor's liking of virtuous investment. Let us introduce a ρ value equal to 0.2. Given that $\gamma = 0.5$, the introduction of ρ implies a reduction in risk aversion and that the investor behaves as if he had a γ equal to 0.3. Under the new set of parameters, the constant coupon flow certain equivalent to the at-risk coupon is 16.62. This implies that investors would find a bond with a certain coupon rate of 1.66% equivalent to the pandemic bond. A risk-free bond with $k = 1.66\%$ would be quoted 935.23. Accordingly, the cost of risk for the second operator is equal to 21 basis-points (bp). In this scenario, the security loading applied to the insurer is 5.66 (or 9.57% of the fair premium). In other words, the attractiveness of the bond results in a reduction of the extra-return required by the investor of 19 bp compared to the scenario with $\rho = 0$ and a reduction of about half of the cost of coverage for the insurer. Obviously, if we had assumed a value of ρ equal to γ the extra return required by investors and the security loading for the insurer would have been zero.

Interestingly, the amount of ρ that measures the attractiveness of the investment can also be derived implicitly from the reduction in the additional return required. Assuming we know the return reduction that an investor is willing to accept from a sustainable investment, it is possible to estimate the risk reduction ρ to be applied to γ. For example, accepting a reduction in yield of 30 bp is equivalent to a reduction of γ from 0.5 to 0.41 or a value of $\rho = 0.09$.

4.3. Sensitivity analysis

In this section we analyse the sensitivity of the results to the variation of the risk aversion parameter net of the propensity to sustainable investments. Denoting with γ' the difference between γ and ρ, the results are reported directly as a function of γ'. The results are reported in Table 3.

[3] As previously observed, if $k = r$ the non-risky bond is quoted at par.

Table 3
Sensitivity analysis when γ' varies.

γ'	$CFconst$	Extra-return for the investors (bp)	Safety loading for the insurer (% of fair premium)
0	18.70	0	0.00%
0.1	18.09	6	2.84%
0.2	17.42	13	6.00%
0.3	16.66	20	9.57%
0.4	15.78	29	13.72%
0.5	14.71	40	18.70%
0.6	13.38	53	24.97%
0.7	11.57	71	33.47%
0.8	8.84	99	46.29%

It is immediate to observe that with increasing values of risk aversion (net of ρ) the extra-returns demanded by investors and the charges applied to the premium paid by the insurer increase more than proportionally. High levels of γ' would make the cost of insurance coverage unacceptable. However, if the desirability of the investment is high, costs can be significantly reduced.

5. Conclusions

In the context of pandemics or health crisis, we present a securitization operational model involving different private actors. In our own spirit, securitization plays a role in enforcing fair behaviour in the context of pandemics and, then, in lowering infectious rates of pandemics themselves. Indeed, the proposed architecture can be seen as a tool for risk mitigation for the dynamic and ongoing spreading of pandemics. The insurance trick lies in transferring important features of collective health, such as rivalry, to risk on capital markets. Indeed, the practical functioning of the financially engineered system is detailed in Fig. 1 (in Section 3) and allows for risk sharing among different private actors. We price the pandemic-linked bond despite of lack of liquidity in those types of markets. The latter is one of the first attempts at describing the potential sustainability of the proposed financially engineered system for insurers.

CRediT authorship contribution statement

Francesco Ciardiello: Writing – original draft, Supervision, Methodology, Formal analysis, Data curation. **Emilia Di Lorenzo:** Writing – original draft, Supervision, Methodology, Formal analysis, Conceptualization. **Massimiliano Menzietti:** Writing – original draft, Supervision, Methodology, Formal analysis, Data curation. **Marilena Sibillo:** Supervision, Methodology, Formal analysis, Conceptualization, Writing – original draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Declarations; including that for Generative AI and AI-assisted technologies in the writing process

We have no declarations to make with regard to funding or conflicts of interest/competing interests etc. In particular, this research did not receive any specific grant from funding agencies in the public, commercial or the non-profit sectors. Further, we have not used any Generative AI and AI-assisted technologies at all.

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