A capital market solution to dairy margin insurance: a focus on cat-bond investor attractiveness and a feasibility study

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Abstract: Dairy commodities are subject to great variations of their prices, impacting producer margins. Because of the price component of such a volatility, insurance companies are challenged to design an adapted insurance coverage: the present study explores the way of Insurance Linked Securities (ILS), as a part of the solution. First, the study examines the return correlation between ILS and traditional asset classes. The findings show that ILS present a positive correlation with the stock market. Whatever, this article explores the feasibility of a "dairy-bond" to help insurance companies to cover French or European dairy producers margin. That dairy-bond has similar characteristics to a cat-bond in terms of expected-loss, so a pricing is possible using both a regression model and a Monte-Carlo simulation through an autoregressive-moving-average model (ARMA). The dairy volume and the cost for the producers, might be limits for such a structured product.

Keywords: asset class, cat-bond, dairy prices volatility, insurance securitization, portfolio diversification, risk management.

1 Introduction

In the dairy market, fluctuating prices and related production risks increase uncertainty for dairy producers: according to Schaper et al. (2010), huge price fluctuation on dairy products underlines that dairy producers are confronted to new dynamics in the milk market. In such a liberalized market, the insurance industry is under pressure to offer coverages that stabilize the dairy producer margin. The price volatility being a systematic risk, insurers cannot pool this risk as they are used to, and the corresponding financial exposure falls beyond their financial capacity. Insurers need to find partners who accept to bare this risk in order to propose an affordable and viable margin insurance product. Reinsurers are their traditional risk-sharing partners, but they may be unwilling or unable to assume the whole risk linked to market changes.

The recent development of alternative reinsurances opens new areas for the insurance industry. Securitized reinsurance allows the coverage of the systematic risk component of hazards, through insurance linked bonds, and especially cat-bonds; it has become a potentially valuable alternative to reinsurance over the last two decades (Götze & Gürtler, 2020). A greater financial capacity can be found on the financial markets, where investors may be attracted by weather-related risks, as suggested by the development of the cat-bonds market. The fields of action of this tool call to be broaden for new risks, as it happened in 2003 for the cancellation possibility of the football world cup in Germany (Artemis.bm, 2003), or in 2017 through the first catastrophe bond issuance providing financial backing and insurance protection to the World Bank's Pandemic Emergency Financing Facility (Lane Financial LLC, 2020).

For the dairy sector, there was a production quota in Europe; hence, there was no need for a dairy margin insurance. In 2015, the abolition of the production quota brought volatility to the dairy price and the French sector asked for an insurance solution. This work investigated a strategy of intermediation for the systemic risk management of the insurer, consisting in transferring the margin risk to the financial market, through cat bonds or similar products. It requires an index that can be trusted by investors and represents dairy producers' revenue.

This intermediation strategy is developed around three main lines. First, a new index of the dairy margin is created to both fit investors and the dairy producers. The investors' requirements are that the index must be comprehensive, transparent, and to have the greatest responsiveness. The comprehensiveness of the index comes with its simplicity; therefore, the dairy margin index is a gross margin, the difference of outputs and operating expenses, which disappear in the production act (feeding, energy, machinery and building upkeeps …). The dairy margin index must be transparent, meaning that the investor can verify and trust the data. A verifiable data is a data easy to access and a trustable data is a data that cannot be manipulated. Data from the future market correspond to such a characteristic, and moreover have a great responsiveness. Concerning the milk price, only the data from the European Commission is available for every European country. Their responsiveness requires a two-month period, hence the dairy margin index has a two-month lag. Concerning the dairy producers, there is a basis risk because the index captures the national margin including PDO and Organic Agriculture.

Second, the description of the dairy margin index allows the insurer to precisely quantify the systemic risk and facilitate its transfer through financial tools. In order to study its volatility, a dairy margin index modelling is made from the data from 2015 to 2020. The characteristics of the insurance studied is a 20% deductible with a 100% indemnification from the preceding three-year average.

The last aspect studied is the pricing of the risk transfer through a cat-bond. A cat-bond pricing model is developed from the issued cat-bonds through a multiple regression model as it was previously done in the literature, but with data that are more recent. Then, this model applies to the risk of dairy margin loss.

This paper broadens the insurance-linked securities to agricultural risks. The investors' appetite for a cat-bond over the dairy margin can be assessed by comparing it with financial markets, such as the stock markets or State bonds. Nevertheless, the dairy margin is only available since 2015 and no compensation would have been paid so a comparison of the past is pointless. Instead, the cat-bond market exists since 1997 and this comparison would have more interest.

The paper is organized as follows. Section 2 is a literature revue on the comparison of the relationship between the cat-bond market and the other financial markets. Section 3 investigates the investors' appetite for the cat-bond market. Section 4 creates a dairy bond with cat-bond characteristics.

2 Insurance linked bonds as an alternative asset class

2.1 The cat bond market

Hannover Re issued the first successful cat-bond in 1994 (Swiss RE, 2001); the cat bond market started growing slowly in 1997. Aon Securities LLC tracks cat-bonds since 2002. The market has shown a steady growth to reach more than $30b in 2021. The Figure 1 presents the evolution of the ILS market from 2002 to 2021.

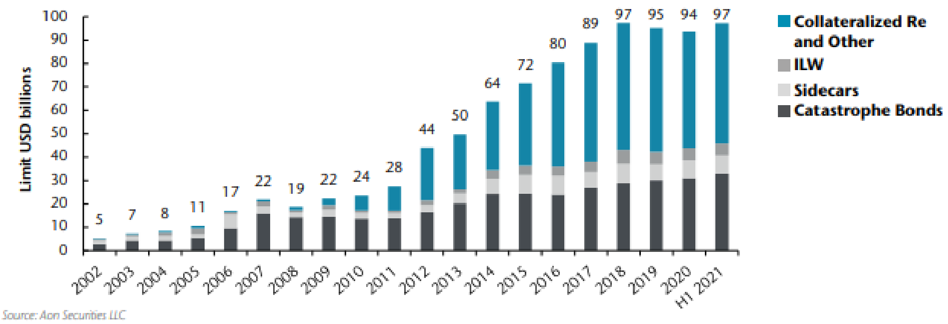

Figure 1 : Evolution of the ILS market from 2002 to 2021 (Aon Securities LLC, 2021)

From July 1st, 2020 to June 30th, 2021, the catastrophe bond market continues its strong growth with a record issuance year of approximately $13 billion placed in the period. There is innovation with market broadening geographic and peril coverage. An example is Fidelis' Herbie Re Ltd. 2021-1 transaction, offering coverage for US and Canada named storms and earthquakes, US and Canada severe thunderstorms, US and Canada winter storms, US wildfires, Japan typhoons and earthquakes, Europe windstorms, Italy earthquakes, Turkey earthquakes, Australian tropical cyclones and earthquakes, and New Zealand earthquakes, all on an index basis.

2.2 Cat bond structure, risk and return

The cat-bond is structured through a Special Purpose Vehicle (SPV) created by the cedant (insurer, reinsurer, sponsor). It is a risk transfer contract (reinsurance or derivative) from the cedant to the investor, against payment of a periodic premium. The objective of the SPV is to isolate the capital invested by the investor from his accounts to limit the risk of default on his part. The SPV reinvests the capital in risk-free assets such as the US three-month Treasury bills (Cummins, 2008) (Amundi, 2021), allowing to have liquid and risk-free returns for the duration of the cat-bond. In addition, the cedant pays the risk premium to the SPV. If the cat-bond has not been triggered, investors receive the total amount (principal + coupons) in the SPV. However, in the opposite case, the cedant recovers its claim from the SPV and the investor returns are adjusted downward partially or totally. Figure 2 schematizes how an SPV works for a cat-bond.

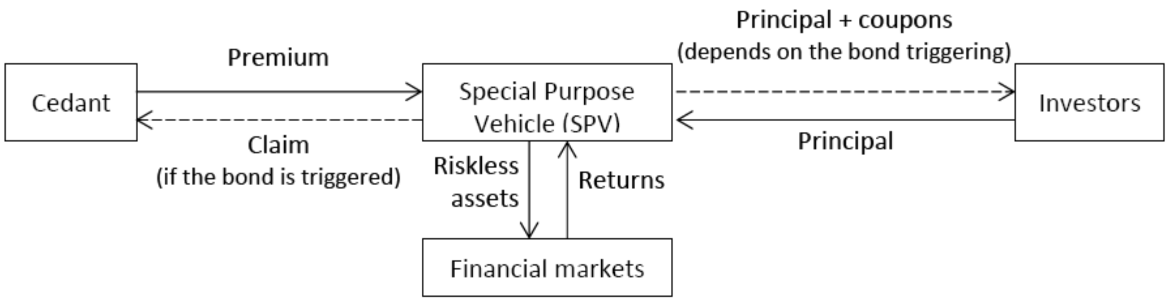

Figure 2 : Mechanism of a cat-bond (Cummins, 2008)

The characteristics of the cat-bonds are multiple: the risk and return; the period of coverage; the terms of payment; the nature of the catastrophic events covered and the compensation mechanism among others can be modulated. Buying a cat-bond, the investor expects a risk/reward related to the occurrence of the bond underlying event, not to the occurrence of the sponsor credit risk: that is the reason why the cat-bond proceeds are invested in safe assets, under the control of a trustee. According to market data (Artemis.bm, 2022), here are the recent characteristics of cat-bonds:

- *The cat-bond risk* is expressed with the expected loss and vary from 0.1% to more than 8%. It allows the comparison of each cat-bond independently of the nature of the catastrophic events;
- *The cat-bond return* is the coupon pricing. In 2020, the average coupon was 3 times the expected loss so a multiple of 3;
- *The period of coverage* is usually 3 years and varies from 1 to 5 years;
- The nature of the catastrophic events is 96% earthquakes or storms;
- *The compensation mechanism* relies on mainly three types of trigger. The indemnity trigger when indemnities are calculated by the policyholders. The index trigger when a disaster index such as wind speed (Saffir-Simpson) or earthquake magnitude (Richter scale) serves to calculate the compensation. And the hybrid trigger when the trigger threshold is using a predefined model based on various variables relating to the disaster.

Many authors studied the risk-return characteristics of cat bonds in an asset pricing context. They explain the risk spread of cat-bonds in function of various variables (expected loss, peril type, trigger mechanisms or macroeconomic factors) (Galeotti, et al., 2013) (Gürtler, et al., 2016) (Braun, 2016). Other studies focus on the issuing firms to evaluate the cat-bong pricing. (Hagendorff, et al., 2013).

2.3 Selective literature revue: focus on cat bond investors

Proponents of cat bonds have long argued that these securities provide a valuable new source of diversification for investors, and Cat bonds are often said to be “zero beta” investments (Litzenberger, et al., 1996). The work of Cummins and Weiss (2009) is among the first to support the claim that Cat bonds have low investment betas. It uses the Swiss Re Cat bond index to compare it to other financial assets before the financial subprime crisis and after it. The finding is that cat-bond total returns have almost no correlation with returns on alternative investments during the mostly normal market conditions between January 2002 and June 2007. Cat bond coupon returns are highly correlated with the LIBOR and U.S. government bond yields, but this is expected because Cat bonds are priced at spreads over LIBOR and SPV trust assets often consist of government bonds. Therefore, during normal conditions, cat-bonds are close to zero-beta with respect to stock and bond total returns. Nevertheless, during the subprime crisis, cat-bonds were not zero-beta; that is, like most other assets, they can be somewhat susceptible to systemic risk. However, even during the crisis, the bivariate correlations indicate the cat-bonds would be valuable for diversification.

Those findings were validated by Carayannopoulos and Perez (2015) who studied the beta of cat-bonds investments. CAT bonds were not immune to the effects of the subprime crisis. Indeed, four cat-bonds were structured by Lehman Brothers and its collapse did not make it possible to ensure the cat-bonds full payment. In consequence, CAT bond returns became significantly correlated with the market. However, the relatively small effect of the crisis on cat-bonds compared with other asset classes makes them a valuable source of diversification for investors. (Carayannopoulos & Perez, 2015)

Moreover, empirical evidence that catastrophes are uncorrelated with the stock market in Japan is provided in an event study by Yang, Wang, and Chen (2008), which shows no significant catastrophe effect for the Japanese stock market as a whole, although catastrophes negatively affect insurance stocks and positively affect construction firm stocks. (Yang, et al., 2008)

Sterge and Van der Stichele found that Cat-bond performance over 2001-2015 has been a steady 8.3% annual average return with volatility of 2.8%, for a realized Sharpe ratio of 2.4. However, this performance has in part been the result of lower-than-expected principal writedowns during this period. (Sterge & Van Der Stichele, 2016)

The most recent study that examines the relationship between cat-bond market and the other financial markets (Insurance Linked Securities (ILS) market, S&P 500, MSCI and Corporate Bonds market) is from Mouelhi (2021). (Mouelhi, 2021) It studies the 2012-2019 period. The main findings of this study showed that in the short-run, Cat Bonds are partially zero-beta assets while over the long-run they are entirely zero-beta assets. The correlation results are over 80% between ILS fund from eurekahedge and the Swiss Re Global CAT Bond Performance Index, but less than 20% between cat-bonds and the MSCI world index. These findings are in accordance with Drobetz et al. (2020) that cat-bonds serve as an effective diversifier against global stock, bond, real estate, commodity, private equity, and infrastructure markets. Nevertheless, cat bonds cannot act as a safe haven in phases of extreme market declines. (Drobetz, et al., 2020)

Finally, Demers-Bélanger and Son Lai investigate whether the inclusion of Cat Bonds in portfolios composed of traditional assets and common factors is beneficial to investors. They find that including cat-bonds increases significantly the time-varying Sharpe. (Demers-Bélanger & Son Lai, 2020)

This paper proposes to broaden the nature of the risk cover by a cat-bond as did Bouriaux and Scott (2004) for the terrorism risk. The results are that the lack of predictability in terrorist losses would result in a significant premium. (Bourriaux & Scott, 2004) The following part focus on the investors' appetite for the cat-bond market.

3 Investors' appetite for the cat-bond market

The analysis of the investors' appetite for the cat-bond market requires further sources of data to compare it with stock and bond markets.

3.1 Tracking cat bond asset class performance

The cat-bonds performance could be tracked through the Swiss Re Global CAT Bond Performance Index but the data are not available. Instead, thanks to the database of artemis.bm, a cat-bond index is created. 59 cat-bonds have been triggered, giving rise to a compensation since 1997. The index is a value-weighted index of every cat-bonds. The 2021 year for cat-bonds is too early to incorporate it in the index.

Individuals cannot directly invest in cat-bonds; he or she has to subscribe to an ILS fund. ILS fund can be tracked through the Eurekahedge ILS Advisers Index. It tracks the performance of 29 constituent funds which explicitly allocate to insurance linked investments and have at least 70% of their portfolio invested in non-life risk (Eurekahedge, 2022).

In order to compare with the stock market in its wholeness, the world stock market is captured with the MSCI World Index; it is the large and midcap representation across 23 developed markets countries through 1555 companies available on Boursorama (Boursorama, 2022).

Then the focus is on the Europe stock market and it is captured with the MSCI Europe Index; It is the large and midcap representation across 15 developed markets countries in Europe through 430 companies available on Boursorama (Boursorama, 2022).

As cat-bond are mainly in the United-States, the study uses the S&P500 for the US stock market. CAC40 will track the French stock market.

The bond market is tracked with the Bank of America BBB US Corporate Index Effective Yield available on the Federal Reserve Bank of St. Louis website (FRED, 2022).

As only monthly data are available for the cat-bond index, monthly data are required for the stock market and bond indexes. Therefore, the data used for the stock market and bond indexes are the monthly average of the opening quoting. The Figure 3 shows the evolution of the asset classes return growth, from 2010 to 2021.

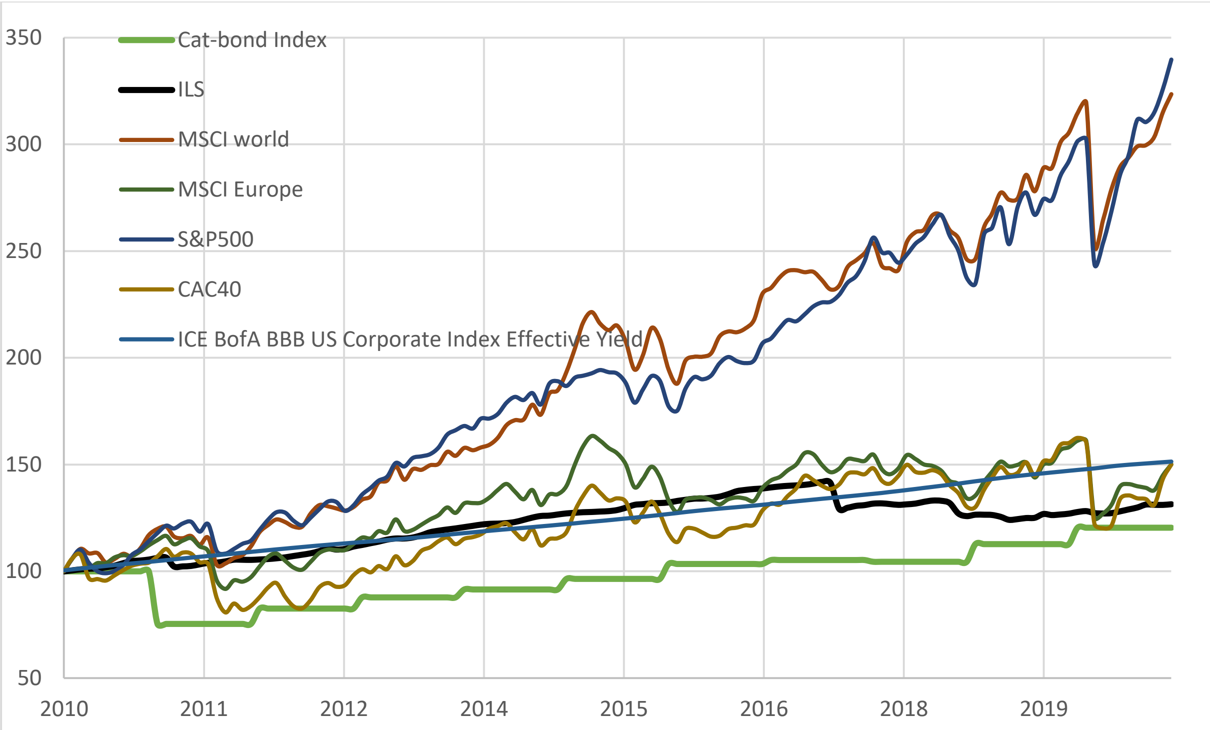

Figure 3 : Evolution of the asset classes from 2010 to 2021

3.2 Cat-bond correlation and profitability vs other asset classes

The Table 1 presents the correlation matrix. The average correlation between ILS index and other asset is 67.25% (except BBB bond) whereas the average correlation between the different asset classes is 91.33%. The diversification benefits are present, but limited. The zero-beta assumptions of cat-bonds can be discussed. A correlation coefficient with the cat-bond index is not possible because the values are on an annual basis.

Table 1 : Correlation matrix – Cat-bonds and Asset Classes (Authors)

Correlation coefficient (10 years)	ILS index	MSCI world	MSCI Europe	CAC40	S&P500	BBB Bond
ILS index	100%					
MSCI World	65%	100%				
MSCI Europe	75%	86%	100%			
CAC40	71%	94%	96%	100%		
S&P500	58%	99%	82%	91%	100%	
BBB Bond	-24%	-59%	-45%	-47%	-64%	100%

The Table 2 presents the beta of ILS for different assets. Indeed, the ILS index doesn't show a zero-beta but there is a diversification benefit due to the low Beta.

Table 2 : Beta of cat-bonds for different assets (Authors)

	β ILS index (10 years)
MSCI World	39,5%
MSCI Europe	31,3%
CAC40	46,1%
S&P500	47,6%
BBB Bond	-0,4%

The Sharpe ratio relates the performance and the risk of a portfolio, the higher the Sharpe ratio, the better the profitability of the asset. The Table 3 illustrates the Sharpe ratio for all the previously presented assets for December 2020. The higher the performance, the higher the Sharpe ratio is. The ILS index presents the lower Sharpe ratio due to a negative 5-year- yield. Whereas the cat-bonds index presents a positive 5-year- yield, therefore the Sharpe ratio is higher.

Table 3 : Sharpe ratio (Authors)

Dec-20	Sharpe ratio (1 year)	Sharpe ratio (3 years)	Sharpe ratio (5 years)	5-year- yield (annualized)
ILS index	1,61	-0,92	-0,27	-0,1%
Cat-bonds index	-	0,39	0,57	3,1%
MSCI World	0,11	0,45	0,71	10,7%
MSCI Europe	-0,28	-0,15	0,09	2,4%
S&P500	0,55	0,50	0,92	13,9%
CAC40	-0,28	-0,06	0,25	5,0%

The addition of ILS should lower the portfolio risk due to the diversification effect. Different portfolios are created, consisting in adding 10% of ILS or cat-bonds for the different assets. The Table 4 presents the Sharpe ratio for each portfolio. As the cat-bonds index, Sharpe ratio is higher than the

ILS index Sharpe ratio, each Sharpe ratio of the portfolio containing cat-bonds are higher than the one with the ILS index.

Even with low correlation and Beta, the addition of ILS in a portfolio does not raise the Sharpe ratio, hence it increases the risk of the portfolio. Nevertheless, the addition of cat-bonds increases the Sharpe ratio.

The reader should keep in mind that an individual can only invest in cat-bonds through an ILS fund. The Eurekahedge ILS Advisers Index used as the ILS tracker is following ILS funds which have at least 70% of their portfolio invested in non-life risk ILS.

The risks that are covered by ILS could be broadened and the dairy margin risk could be one of them.

Table 4: Sharpe ratio for different portfolios (Authors)

Dec-2020	Sharpe Ratio (1 year)				Sharpe Ratio (3 years)				Sharpe Ratio (5 years)				5-year-yield (annualized)			
	90% MSCI WR	90% MSCI Europe	90% S&P500	90% CAC 40	90% MSCI WR	90% MSCI Europe	90% S&P500	90% CAC 40	90% MSCI WR	90% MSCI Europe	90% S&P500	90% CAC 40	90% MSCI WR	90% MSCI Europe	90% S&P500	90% CAC 40
10% ILS index	0.13	-0.25	0.54	-0.25	0.44	0.15	-0.49	-0.05	0.70	0.09	0.89	0.24	9.7%	2.3%	12.5%	4.6%
10% cat-bonds	-0.04	-0.41	0.36	-0.39	0.61	0.01	0.65	0.09	0.76	0.14	0.96	0.29	10.6%	3.1%	13.5%	5.5%

4 The dairy-bond proposal: an alternative investment?

The EU dairy sector is the second biggest agricultural sector in the European Union, representing more than 12 % of total agricultural output. (European Paliamentary Research Service, 2018). The end of milk production quotas in the EU in April 2015 brought high price volatility in the dairy sector, accentuated by the Russian embargo on European agri-food products in 2014. In figures, the coefficient of variation of the French milk price from 2013 to 2014 was 6.9%, then 10.3% from 2015 to 2018, in addition to a drop in average prices of 11.5% between periods. Market risk management is a crucial issue at farm level but also at national level. For farmers, knowing ahead that their income is guaranteed would make it easier for them to invest because they would have less need to build up reserves for difficult years. These investments could increase their profitability and stabilize their income. For dairy collectors, it is essential to reduce price volatility in order to make the dairy farmer profession more attractive, which will allow dairies to secure their volume in the future. In France, the average age of farmers is increasing and this population is struggling to renew itself (MSA, 2018). At the national level, it is essential to limit the rural exodus and to maintain the agricultural model, the activity in the countryside and the food autonomous on dairy products. It is therefore in the general interest to stabilize the incomes of dairy farmers.

A dairy-bond would work the same way as a cat-bond but will be triggered by a fall in the dairy margin.

4.1 The dairy margin as bond underlying

The present subsection is adapted from Parrié (Parrié, To be published), to define and calculate a dairy margin, which is assessed with the dairy margin index (DMI) for France and Europe (the weighted average of Germany, Denmark, Ireland, Netherlands, France and Poland based on milk production). The DMI is a gross margin: sales of milk minus operating costs (feedings, herd renewal purchases, vet costs, machinery and building upkeep-, energy, contract work, and other direct inputs). It does not take into account the investment part of the farm activity as the materials and installations; buildings; or financial expenses.

In order to determine the DMI, a basket of inputs is calculated based on the "EU dairy farms report based on 2016 FADN data". Trackers are used to fluctuate this inputs basket to obtain a monthly index. The trackers are prices on future markets (Corn, wheat and rapeseed on EURONEXT; soybean on CBOT; oil on ICE) and also the consumer price index of each country. The only output of the DMI is the price of raw milk at real fat and protein content (PDO, Fat/protein content bonus, Organic Agriculture, etc.) from the European Commission data. These quotes are monthly but there is a two-month delay to obtain them. The Figure 4 illustrates the DMI for France and Europe.

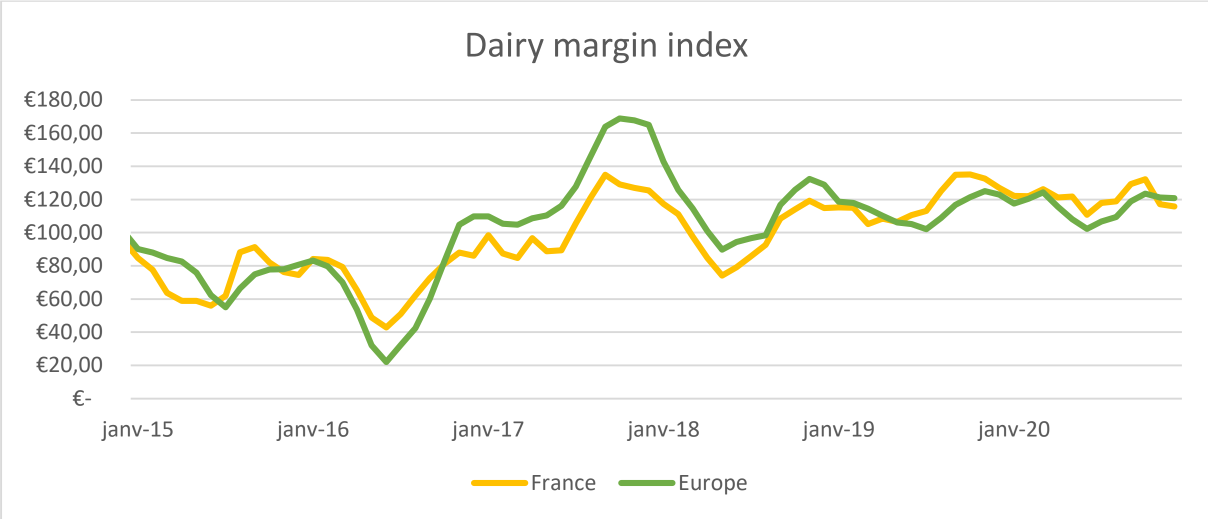

Figure 4 : Dairy margin index from 2015 to 2020 (Parrié, To be published)

4.2 The dairy-bond pricing by analogy with cat bond

The dairy-bond pricing will be the first limiting factor for the revenue protection tool. This pricing is assessed with an empirical analysis of cat-bond spreads applied to the dairy-bond. Another limiting factor is the size of the dairy-bond that needs to be large enough for its issuance. Finally, the dairy-bond should have characteristics that are similar to cat-bonds in order to interest investors.

The pricing of a cat-bond is a process organized by a broker who ask the ILS investment managers (52 according to Artemis.bm (Artemis.bm, 2021)) what are their appetite for the cat-bond in negotiation. ILS investment managers answer back with proposition of investment depending on the allocated risk premium. The broker gathers all the answers for the issuer. The issuer then decides the risk premium in function of the capital he wants. That information comes from an interview with Chin LUI who is the ILS investment manager of AMUNDI PIONEER. We are very thankful for the time he allotted us for this interview.

Earlier research has documented that a linear relationship is well suited to explain primary market cat-bond spreads (Galeotti, et al., 2013) (Braun, 2016). Due to the pricing process, the spread of a cat-bond might be affected by various factors that a multiple ordinary least squares (OLS) regression model will decompose to isolate the influence of each factor.

First, hypotheses have to be submitted in order to evaluate the determinants that improve the explanatory power of an econometric pricing model.

4.2.1 Hypotheses

The expected loss is the main measure for the riskiness of such transactions. In consequences, it is the most important driver of the cat-bond spread and previous study has already provided empirical evidence of it (Lane & Mahul, 2008) (Dieckmann, 2008) (Galeotti, et al., 2013)

The bond-specific characteristics can be determinant for the evaluation of the spread: volume, term, trigger type and the availability of tranches.

In line with Braun (2016) and Dieckmann (2008) or Berge (2005), the hypothesis concerning the size is that larger trade sizes are associated with lower transaction costs and also implies a higher fungibility and should reduce the spread. (Galeotti, et al., 2013). Braun (2016) highlight that it does not seem to be priced at all. Then this hypothesis is tested.

Hermann and Hibbeln have studied the trading and liquidity in the secondary cat-bond market. Their deductions are that there are strong evidence for a substantial liquidity premium on the secondary cat-bond market and cat-bonds are more often traded when they are closer to maturity and it is more expensive to execute trades of large volume. In addition, the cat-bond market is very illiquid with some cat-bonds going for months without a single trade taking place (Hermann & Hibbeln, 2020). Braun (2016) finds that the term of security gives no indication of the spread in the primary market. But the recent development of the secondary market, a longer maturity term of the cat-bond could provide more opportunities to exchange it on the secondary market, hence investors could lower their spread asking for a longer cat-bond.

Concerning the trigger type, it gives the possibility of moral hazard by the sponsor. Investors could demand compensation with higher spreads in case a cat-bond exhibits an indemnity trigger.

Also, the availability of tranches indicate that the expected loss was calculated to have a better fit for the tranche than a unique one for the whole cat-bond. No documentation was found on this fact. The supposition is that the availability of tranches would lower the cat spread.

Four hypotheses are formulated on the bond-specific characteristics:

- H1(a): Cat-bond spreads decreases with its size.
- H1(b): Cat-bond spreads decreases with the maturity term.
- H1(c): Cat-bond spreads increases if pure indemnity trigger is used.
- H1(d): Cat-bond spreads decreases if there are tranches on the cat-bond.

In second, the type of peril and the covered territory could also play a part in the determination of the spread.

This effects have already been documented (Lei, et al., 2008) (Bodoff & Gan, 2009) (Papachristou, 2009) (Galeotti, et al., 2013) even in the latest study (Braun, 2016). It reveals that cat-bonds covering North America carry larger spreads than transactions exposing investors to the same natural hazards in the rest of the world. This phenomenon is attributed to the fact that the vast majority of risk capital in the cat-bond market relates to events on North America territory. On the contrary, transactions covering other zones, such as Europe or Japan should have lower risk premiums because they are sought-after for diversification of ILS portfolios.

In addition, sponsors may like to insure as many peril types as possible by one cat-bond due to reduced transaction costs and the sharing of limits for several risk regions. On the other hand, investors may prefer single peril Cat-bonds, that enables them to buy the cat-bond which fits best to their investment strategy (Banks, 2004) (Guy Carpenter & Company, 2007). Empirical evidences were that the premium of the Cat-bond declines if only one risk type is insured (Berge, 2005).

Another hypothesis can be formulated concerning the risk insured. 31% of cat-bonds in the sample concern windstorm perils. Still for the diversification of ILS portfolios, cat-bond spreads for windstorm may be larger than for other perils.

Perils that are not earthquake or windstorm lack of cat-bond history, hence the risk premium for those perils may be larger. But many studies detect lower Cat-bond premium for the “exotic” risks that contribute to portfolio diversification (Lane & Mahul, 2008) (Papachristou, 2009) (Gütler, et al., 2012).

Apart from separate effects, there might also be a combined impact of territory and peril, since, in practice, these two factors are commonly considered together (Braun, 2016).

Five hypotheses can be formulated concerning the type of peril and the covered territory:

- H2(a): Cat-bonds spreads for USA are larger than for other territories.
- H2(b): Cat-bonds spreads for windstorm are larger than for other perils.
- H2(c): Cat-bonds spreads for other perils than windstorm and earthquake are larger than all other perils.
- H2(d): Cat-bonds spreads increase with an increasing number of peril types or peril regions.
- H2(e): Interaction effects between territories and perils increases the spread.

Exterior factors can also have their importance in the determination of the spread, as reinsurance pricing and the investors' other possibility of financial investments.

(Lane & Mahul, 2008) are the first to point out the relevance of the underwriting cycle with regard to cat-bond pricing. The reinsurance business is subject to periods of soft markets with plenty of coverage and rather low premiums as well as hard markets with restricted risk-bearing capacities and higher premiums (Cummins & Weiss, 2009). Cat-bonds can be regarded as an alternative to traditional reinsurance (Finken & Laux, 2009). Cat-bonds as a direct substitute for traditional reinsurance contracts, should follow the same pricing patterns over time.

Yields for corporate and government bonds vary over time and can be substitute investments for investors. A link is to be suspected between the spread of a cat-bond and the corporate or government bond spread. The same way, the share market is a possible investment for investors, it may have influence on their behavior. The impact of the stock market has not been considered in the empirical literature before.

Therefore, four other hypotheses can be formulated on the influence of different markets on the cat-bond spread:

- H3(a): Corporate bonds spreads have a positive influence on cat-bond spreads.
- H3(b): Government bonds spreads exert a positive influence on a cat-bond spreads.
- H3(c): Cat-bonds spreads have a similar fluctuation as the reinsurance underwriting cycle.
- H3(d): The stock market revenue exerts a positive influence on a cat-bond spread.

4.2.2 Empirical analysis

Only one source of information his publicly available on the cat-bond issued, the Artemis Deal Directory on the website Artemis.bm (Artemis.bm, 2021). The information related can be trusted as it is used on different scholar publications (Braun, 2016) (Cummins, 2008) (Lei, et al., 2008) (Gütler, et al., 2012) and even by leading actors of cat-bond market (Aon securities Inc., 2017) (S&P Global Ratings, 2020). The resulting data set comprises 871 cat-bond tranches issued between June 1997 and December 2020. Only the data with the spread, expected loss, issue date, size, term, trigger type, covered territory, reference peril were kept. 485 data had to be removed due to missing fields or because the peril was not due to a non-life insurance (Medical benefit claims levels, mortgage insurance risks …). 386 observations remain for the study from Mars 2011 to December 2020.

The environmental factors require further sources of data. The general level of reinsurance premiums will be proxied by the Guy Carpenter Global Property Catastrophe Rate-On-Line Index (henceforth RoL index, or rate on line index), which is published by the Guy Carpenter & Company, LLC on a yearly basis (Guy Carpenter & Company, Llc, 2021). Because many cat-bonds collected (74%), relate to risks in the USA territory, the study will focus on environmental factors of USA. The US 3-month Treasury bill yield is collected on the economic data of the Federal Reserve Bank of St. Louis and is available on a monthly basis (fred.stlouisfed.org, 2021). Braun (2016) report that the vast majority of cat-bonds exhibit a BB rating. In consequence, Merrill Lynch U.S. High Yield option-adjusted spread (henceforth BB spread) which is the calculated spreads between a computed option-adjusted spread (OAS) index of all bonds in a given rating category and a spot Treasury curve. (fred.stlouisfed.org, 2021). Finally, the stock market is collected through the S&P 500, which is available on a daily basis on boursorama.com (boursorama.com, 2021). In order for it to be usable, the 3 month-variation is used. As only the month of cat-bond issuance is available, the data use the monthly mean of the open quotation of each day.

4.2.3 Focusing on the outliers

To prepare the analysis, outliers are identified, meaning that they have abnormally large impact on the least squares coefficients. In this purpose, a full model (model 1) including all considered predictors is estimated, externally studentized residuals[1] and Cook's distances[2] are calculated. The figure 5 presents a visual presentation of these statistics and shows 18 cases outside the bottom center box, meaning **they are heavily influential**.

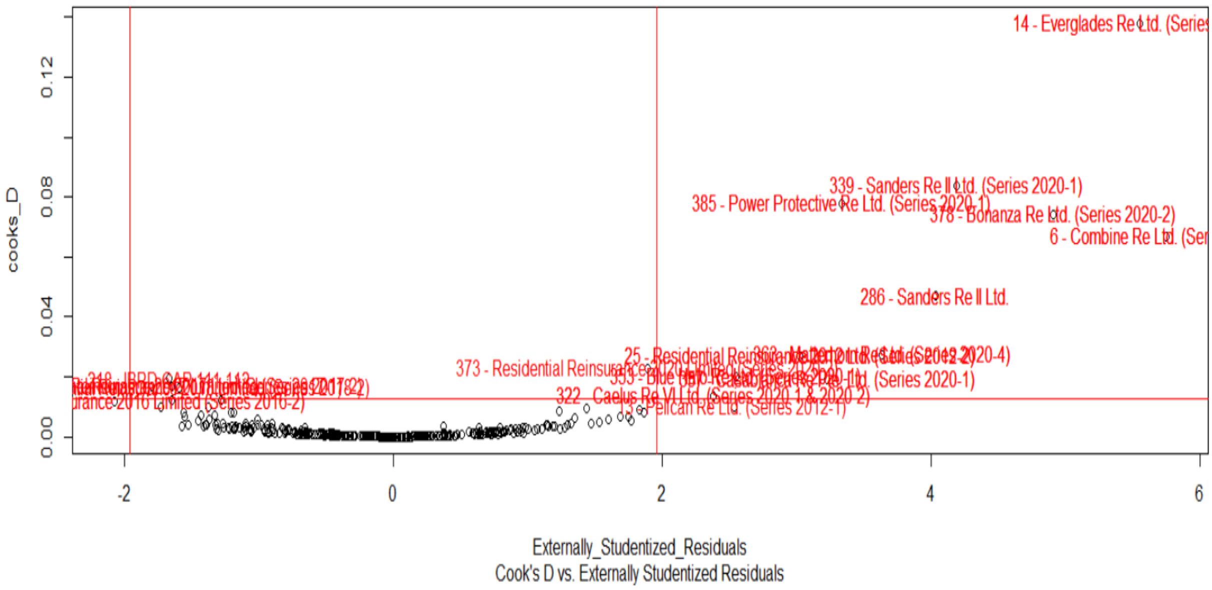

Figure 5 : Identification of Outliers

Four of the 18 outliers can reasonably be rejected as they have an expected loss above 14% making them the riskiest cat-bonds (only one with an EL above 14% is not detected as an outlier). Therefore, the model does not fit for cat-bonds with an expected loss above 14%.

Eight of the 18 outliers were cat-bonds issued during the 2020. The sanitary crisis that outbreak during this year made it special and need some attention. In this purpose, only the cat-bonds from

[1] The externally studentized residuals is the comparison of the observed response values to their fitted values based on the models with the i^{th} observation deleted. Standardizing the deleted residuals produces studentized residuals

[2] Cook's distance measures the effect of deleting a given observation.

2019 and 2020 were kept remaining 106 data for the same analysis. The eight previously outliers cat-bonds from 2020 stayed as outliers. The residuals of these outliers are mainly positive. Meaning that the spread was higher than expected. No theory can explain this phenomenon; further investigations must be conducted later with more data.

After removing the four outliers with an expected loss greater than 14%, 382 tranches remain for the study. (1)

4.2.4 Determinants of the Cat-bond Spread at issuance

The first model includes all factors, hence it can be formulated as follows:

$$Spread_i = \beta_{EL} * EL_i + \beta_{Size\_Tranche} * Size\_Tranche_i + \beta_{Tranche} * Tranche_i + \beta_{Size\_CAT} * Size\_CAT_i + \beta_{Term} * Term_i + \beta_{Wind} * Wind_i + \beta_{Earthquake+windstorm} * Earthquake+windstorm_i + \beta_{Multiperil} * Multiperil_i + \beta_{Others(peril)} * Others(peril)_i + \beta_{Indemnity} * Indemnity_i + \beta_{North\_America} * North\_America_i + \beta_{Worldwide} * Worldwide_i + \beta_{North\_America\ x\ windstorm} * North\_America\_x\_Windstorm_i + \beta_{S\&P\ 500} * S\&P\ 500_i + \beta_{US\_3months} * US\_3months_i + \beta_{BBspread} * BBspread_i + \beta_{RoL} * RoL_i + \varepsilon_i$$

The spread of cat-bond *i* measured in % ($Spread_i$) is function of the expected loss (EL_i in %), the size of the tranche ($Size\_Tranche_i$ in million USD), if there are tranches on the cat-bond ($Tranche_i$ as a dummy[3]), the size of the cat-bonds ($Size\_CAT_i$ in million USD), the term ($Term_i$ in months), if the peril is a windstorm ($Wind_i$ as a dummy), if the peril is windstorm and earthquake ($Earthquake+windstorm_i$ as a dummy), if the perils are multiple ($Multiperil_i$ as a dummy), if the peril is other than windstorm, earthquake and multiperil ($Others(peril)_i$ as a dummy), if the trigger rely on indemnity ($Indemnity_i$ as a dummy), if the peril localization is in North America ($North\_America_i$ as a dummy), if the peril localization is worldwide[4] ($Worldwide_i$ as a dummy), if the peril is in North America and a windstorm ($North\_America\_x\_Windstorm_i$ as a dummy), the 3 month variation of the S&P 500 ($S\&P\ 500_i$ in %), the US 3-Month Treasury Bill (US_3months in %), the BB spread ($BBspread_i$ in %), the Guy Carpenter Rate on Line (RoL_i in point) and an error term (ε in %).

The Table 5 contains the unstandardized and standardized[5] coefficient estimates and corresponding significance levels for the considered model specifications. In the bottom part, there are the adjusted coefficient of determination[6] (R^2) and the standard error of the estimate (SEE) as measures for explained variance and goodness of fit. If the Breusch–Pagan test detects heteroscedasticity and autocorrelation-consistent (HAC) standard errors, the Newey–West HAC covariance matrix will be used.

[3] A dummy variable takes only the value 0 or 1. One represents the presence of the qualitative attribute, and zero otherwise.

[4] Europe, Japan and other territories have been reunited in order to have a group with an occurrence higher than 10% (15%).

[5] The standard data allows the comparaison of all the factors even with different units.

[6] Provides a measure of how well observed outcomes are replicated by the model, based on the proportion of total variation of outcomes explained by the model.

Table 5 : Determinants of the Primary Market Cat-bond Spread (Authors)

	Model 1		
	Coeff.	**Stand**	**P-value**
(Interception)	0		
Expected loss	1.2600	0.8064	0
Size of the tranche	0	0.0519	0.58
Is there a tranche on the cat-bond ?	0.0040	0.0922	0.15
Size of the cat-bond	0	-0.0203	0.30
Term	-0.0004	-0.0489	0
Windstorm	0.0043	0.0633	0.31
Windstorm + Earthquake	0.0107	0.1572	0.0012
Multiperil	0.0119	0.1344	0.0014
Others (peril)	0.0314	0.1711	0
Indemnity	-0.0042	-0.0115	0.0592
North America	0.0133	0.1839	0.0001
Worldwide	0.0046	0.041	0.26
North America X Windstorm	0.0004	0.03456	0.92
S&P 500	0.0376	0.0520	0.04
U.S. Treasury bill 3 month	-0.0534	0.1582	0.69
BB spread	0.5971	0.2537	0
Guy Carpenter.RoL.Index	0.0001	0.2456	0.0048
Df	365		
SEE	0.01741		
R^2	0.8319		
Adjusted R^2	0.8246		
BP test	12.82		0.0003

The Breusch–Pagan test (BP test) is significant then it is accurate to use Newey–West HAC covariance matrix for all standard errors and p-values.

The previously information is derived in the purpose of establishing an econometric pricing model for cat-bonds which aim to be the most statistically robust. To this end, a stepwise regression is operated by delating all statistically insignificant factors (backward elimination). The model 2 is derived from the model 1 with a limit of p-value of 0.01 which results are available in Table 6; the remaining factors are:

- Size_Tranche
- Wind
- Size_Cat
- Indemnity
- Worldwide
- North _America_X_Windstorm
- S&P500
- US_3months

Hence, the second model is formulated as follows (equation 2) and the Table 6 presents the result:

$$Spread_i = \beta_{EL} * EL_i + \beta_{Term} * Term_i + \beta_{Wind} * Wind_i + \beta_{Earthquake+windstorm} * Earthquake+windstorm_i + \beta_{Multiperil} * Multiperil_i + \beta_{Others(peril)} * Others(peril)_i + \beta_{North\_America} * North\_America_i + \beta_{Worldwide} * Worldwide_i + \beta_{BBspread} * BBspread_i + \beta_{RoL} * RoL_i + \varepsilon_i \quad (2)$$

Table 6 : Determinants of the Primary Market Cat-bond Spread (Authors)

	Model 2		
	Coeff.	**Stand**	**P-value**
(Interception)	0		
Expected loss	1.296	0.8372	0
Size of the tranche			
Is there a tranche on the cat-bond ?			
Size of the cat-bond			
Term	-4.462e-04	-0.0506	0
Windstorm			
Windstorm + Earthquake	1.015e-02	0.1247	0
Multiperil	8.085e-03	0.0857	0.0035
Others (peril)	2.81e-02	0.1624	0
Indemnity			
North America	1.179e-02	0.1653	0
Worldwide			
North America X Windstorm			
S&P 500			
U.S. Treasury bill 3 month			
BB spread	0.5792	0.1645	0
Guy Carpenter.RoL.Index	9.443e-05	0.1836	0
Df	373		
SEE	0.4465		
R^2	0.9499		
Adjusted R^2	0.9488		
BP test	10.56		0.0011

By deleting all nine statistically insignificant factors, the adjusted R^2 only dropped at 0.8006. Meaning that this model is highly significant.

The experimental uncertainties are assessed with the function *confint()* of R which performs student test for the model 2 with confidence level of 5% and summarized in Table 7.

Table 7 : Uncertainties for the coefficients with confidence level of 5% (Authors)

	Uncertainties	
Model 2	**2.5%**	**97.5%**
(Interception)		
Expected loss	1.219	1.374
Term	-9.128 e-04	-2.797 e-04
Windstorm + Earthquake	5.841 e-03	1.445 e-02
Multiperil	5.841 e-03	1.350 e-02
Others (peril)	1.871 e-02	3.749 e-02
North America	7.676 e-03	1.591e-04
BB spread	3.776 e-01	7.807 e-01
Guy Carpenter.RoL.Index	4.703 e-05	1.418 e-04

The model 2 can be used in the purpose of calculating the spread of a potentially new cat-bond.

The dairy bond is calibrated as 20% deductible of the income losses compared to a triennial historical income with 100% of compensation.

The end of production quotas took place in April 2015. Prior to that date, the milk price was regulated and there was no necessity for a dairy-bond. Therefore, the study focuses on an analysis after the end of quotas. Six years of DMI historical data (2015-2020) are not enough to have a statistical approach for the dairy bond. In order to get more data of the dairy margin, we operate a Monte-Carlo simulation through an autoregressive-moving-average model (ARMA).

ARMA (p,q) for a centered series is defined thereby (equation 3):

$$X_t = \varepsilon_t + \mu + \sum_{i=1}^{p} (\varphi_i X_{t-i} - \mu) + \sum_{i=1}^{q} \theta_i \varepsilon_{t-i} \tag{3}$$

Where φ_i corresponds to autoregressive parameters; θ_i as moving average parameter; and μ is the expectation of X_t. φ_i; θ_i and μ are constant. The terms of error ε_t is the white noise and obeys a normal distribution with a variance of σ^2.

The parameter p of the ARMA (p, q) is the order of the autoregressive part, it corresponds to the number of previous observations of the time series X_t that are taken into account to determine the next value. The parameter q of the ARMA (p, q) is the order of the moving average part; it corresponds to the number of previous observations of white noise ε that are taken into account to determine the next value.

The parameter ARMA (p, q) is chosen to minimize the AIC[7] coefficient with p∈[1;3] and q∈[1;3]. Therefore, it is an ARMA(1,1) for France and an ARMA(3,1) for Europe. The Table 8 presents the ARMA coefficients.

Table 8 : Coefficients of the ARMA function for the dairy margin (Authors)

	France	Europe
AIC	512	479
AR_1	0.8891	0.8252
AR_2		0.5468
AR_3		-0.5265
MA_1	0.4005	1.0000
σ^2	62.28	35.15
Average	99.0702	103.0279

With 200 000 years of DMI simulation data, the dairy-bond characteristics are calculated and presented in Table 9. The expected loss for France or Europe is between 6 and 7%. The average cat-bonds & ILS issuance expected loss in 2021 is 2.43% according to artemis.bm statistic database (Artemis.bm, 2022). In the artemis.bm database from 2016 to 2020, there are 26 cat-bonds with the expected-loss higher than 7% among the 226 listed cat-bonds. The expected loss remains high for a cat-bond but it should not be limiting for its issuance.

[7] The Akaike information criterion (AIC) is an estimator of prediction error and thereby relative quality of statistical models for a given set of data.

Table 9 : Specification of dairy-bond compensations with a 20% deductible (Authors)

	France	Europe
Frequency	17.59%	19.67%
Pure premium (contribution in €/t)	1.86	2.49
Pure premium / margin	1.9%	2.4%
Maximum = VaR(99.5%) (in €/t)	30.55	37.30
Expected Loss	6.09%	6.68%

The table 10 gives an outlook for investors of the triggering characteristics of the dairy-bond with these parameters. They seem appropriate with the currently available cat-bonds list.

Table 10 : triggering characteristics of dairy-bonds (Authors)

	France	Europe
Expected loss	6.1%	6.68%
Attachment probability	17.6%	19.7%
Detachment probability	0.5%	0.5%

In annex, a practical application as July 2021 presents the dairy-bond cost for the dairy producer.

4.3 The 20-year dairy-bond return

The past period since 2015 and the end of dairy production quota would not have given any compensation from the dairy-bond. Hence, it is not relevant to study its retroactive effect. Instead, a 20-year simulation is processed and compared to the return on asset classes.

As it was run for the dairy margin simulation to assess the dairy-bond characteristic, a 20 year simulation of the France and Europe dairy margin is processed with an ARMA(1,1) for France and ARMA(3,1) for Europe. The dairy-bond would have compensated twice for €/t 32.23 to French dairy producers and 4 times for €/t 93.10 to European dairy producers. On the same period with the parameter of July 2021 (annex), the premium of a dairy-bond would have been €/t 78.20 for French producers and €/t 101.2 for European producers (ANNEX).

In consequence, an investor would have had a return of -78% for the European dairy-bond and 212, 6% with the French dairy-bond over 20 years. The Figure 5 presents all dairy-bond returns. In comparison, the CAC40 did 211% over the last 20 years (dividends reinvested), 304% for the S&P500, 83% for the MSCI Europe and 205% for the MSCI World.

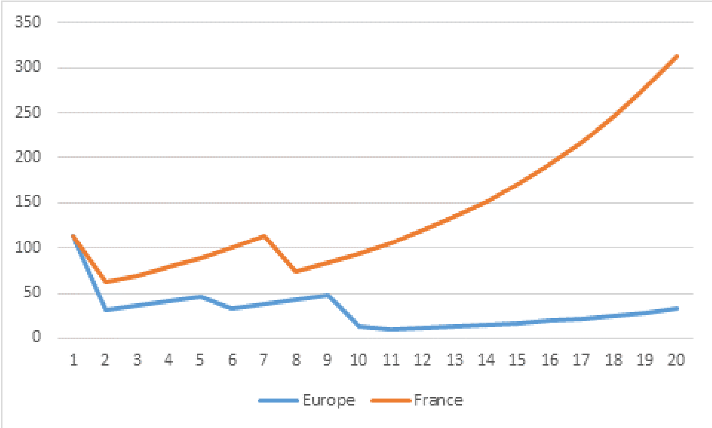

Figure 5: representation of a dairy-bond investment over 20 years (Authors)

5 Conclusion

Previous studies focused on data until 2019 and found a correlation of less than 20% between cat-bonds and the MSCI World index (Mouelhi, 2021). Nevertheless, 74% cat-bonds capital is provided by ILS funds, 11% from institutions and 11% from reinsurers (S&P Global Ratings, 2020). Therefore, one can only invest in an ILS fund to have cat-bonds assets. The Eurekahedge ILS Advisers Index tracks the performance of 29 constituent funds that explicitly allocate to insurance linked investments and have at least 70% of their portfolio invested in non-life risk.

Moreover, the zero-beta assumption from Litzenberger and al. (1996) for the cat-bonds or the clue provided by Cummins and Weiss (2009), Carayannopoulos and Perez (2015) does no longer stand for investments in ILS funds. The β of the ILS index and the MSCI World is around 40% from 2011 to 2021.

Nevertheless, the cat-bond market has been growing over the last two decades. It allows insurances to cover catastrophic risks that are systematic. The use of cat-bond could be an option to protect producers against a drop of their margin, which is called dairy-bond, in order to cover their revenue. The dairy sector is subject to volatility causing recurring income crises at a farm level. This price volatility concerns both incomes and expenses. The latest one is the abolishment of production quota in April 2015 changing the market by providing volatility to the dairy prices. The farmers may need a tool to cover their revenue. The dairy bond risk level (expected loss) corresponds to the ones that commonly securitized through a cat-bond, so a cat-bond is adequate for the securitization. However, the volume and the price to issue could be a problem for the dairy sector.

This analysis uses a cat-bonds pricing that may not be very accurate because 96% of cat-bond covers risks for windstorm and earthquakes; however, the novelty of cat-bonds invites to broaden its spectrum of action. Also, the margin simulation is based only on a 6-year-history (2015-2020), it will gain in accuracy with a longer DMI history.

The dairy bond could seek subsidies through the income stabilisation tool of the European CAP if the regulation of the later change. In fact, the DMI doesn't correspond to the definition of the agricultural income according to the article 39 of Regulation (EU) N° 1305/2013 of the European Parliament and of the Council. Also, an insurer probably won't issue a dairy bond, but more likely a government fund could do so in order to reach critical size and insurers could sell the products as is done in the United States for the crop insurance or the dairy margin protection program.

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AIC. *: Akaike information criterion*
BB spread. *: Merrill Lynch U.S. High Yield option-adjusted spread*
CAP. *: common agricultural policy*
DMI. : Dairy Margin Index
HAC. : heteroscedasticity and autocorrelation-consistent
henceforth RoL index. *: Guy Carpenter Global Property Catastrophe Rate-On-Line Index*
ILS. *: Insurance Linked Securities*
OAS. *: option-adjusted spread*
OLS. *: ordinary least squares*
R^2. *: coefficient of determination*
SEE. *: standard error of the estimate*

7 Annex

7.1 Practical application as July 2021

As the triggering of the dairy bond is the three-year margin average, the dairy producer will have to commit for a three-year period and the dairy bond will have a three-year term. The BB spread is of 3.2%, and the Guy Carpenter Rate on Line is of 199.9 in July 2021. Then this data is used for the spread calculation resulting in equation (3):

$$Spread\ (in\ \%) = 1.296 * Expected\ Loss\ (in\ \%) + 0{,}049 \quad (3)$$

5% experimental uncertainties assess with a student test (table 7) : 1.296 ± 0.077 and 0.049 ± 0.021

A cat-bond should at least be 75 million €, therefore, it is set to be the minimum capital. By applying the economic pricing model of the equation (3) for the dairy-bond, its cost is summarized in the table 10.

Table 10 : Cost of a dairy-bond

	France	Europe
Spread	12.81% (± 2.5)	13.56% (± 2.5)
Minimal capital required (in €)	66,483,000	66,044,000
Minimal production (in t)	2,176,000	1,771,000
% of national production	8.8%	1.2%
Cost of a dairy-bond (in €/t)	3.91 (± 0.76)	5.06 (± 0.93)
% of margin	4.0%	4.9%

The results for France are that volumes might be limiting with almost 9% of the production needed in order to issue a dairy-bond. The volume should not be an issue for an Europe dairy-bond but then the price is €/t 1 higher than France.