Financial catastrophes are sometimes more endogenous *Nuclear Swans* than exogenous *Black Swans*

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There are two types of financial crises: 1) Exogenous types arising first in the real economy and then transferring to the financial markets, and 2) Endogenous types arising within the financial markets themselves (and then potentially transferring to real economies depending on their severity). In the current paper we examine the nature of the endogenous financial crises, and their common origins in over-reliance on financial models, and implementation via financial derivatives.

Introduction

There are two main categories of financial crises: 1) Exogenous types first arising in the real economy and then transferring to the financial markets, and 2) Endogenous types arising within the financial markets themselves (and then potentially transferring to real economies depending on their severity). The current Covid-19 crisis is a clear example of the exogenous type, whilst the 1987, 1998 and 2008 financial crises were examples of the endogenous type.

In the current paper we examine the nature of the endogenous financial crises, and in the related sister article we pursue the exogenous type. It is important to understand their differences as their nature, and their fiscal and monetary remedies are fundamentally different. This is particularly important now, as the current exogenous Covid-19 crisis is fundamentally different from the previous three that we have experienced in the last three and half decades, and which have thus potentially wrongly preconditioned our responses.

Endogenous financial crises

Endogenous financial catastrophes often arise from common over-reliance on a particular financial model, and investment pursued via financial derivates: *Derivatives' ability to isolate any part of the risk distribution, in highly levered fashion, makes them perfect in exposing any model's imperfections*. At first, a model inspired strategy can create high profits and encourage its wider and wider use. But ultimately this spiral is likely to turn and result in market crises: such as the 1987 market crash arising from *portfolio insurance*, the 1998 LTCM collapse induced by the *modern portfolio theory* and *value-at-risk* measure, and the 2008 credit meltdown effected by the wide use of the *Gaussian copula model*.

The above mentioned are not bad models, indeed they are some of the very best of financial theory. Similarly, it would be wrong to blame the derivate instruments as such. The same derivates – when correctly modelled and used – provide the most efficient and robust protection against any financial crashes. In analogy, as nuclear energy can create either destructive warheads or cheap non-polluting electricity, derivative instruments can be either the source of catastrophes or the salvation against them.

It is the combination of models & derivatives that can be dangerous, and one must be acutely aware of any model's limitations as the use of derivatives will magnify and expose them. In this light rather than considering financial market crises as undiscovered *black swans*, they can be better studied as self-induced *nuclear swans*.

Nature of derivative instruments

Derivative instruments, as to their name, are contracts that *derive* their value from an underlying security via a given pay-out formula. This gives them two special characteristics. First, rather than having to buy a costly primary asset, as mere contractual agreements they are highly capital efficient – i.e. they come with significant intrinsic leverage. Second, even simple derivatives can isolate specific parts of the return/risk distribution, this laser-focus being even more potent with complex tranches and exotic options.

This dual nature of derivatives – very low capital requirement combined with extreme ability to slice the return distribution – makes them perfect for transferring risk – in the good and in the bad.

For example, a buyer can efficiently protect his over-extended equity book via S&P500 put options. A well-capitalized seller may be perfectly positioned as well, for example by having a truly diversified basket of small positions generating steady income. This transaction is very much like an insurance company selling fire protection to its clients.

On the other hand, the derivatives can also be used for the bad – such as exploiting the failures of a risk or performance model – either accidentally or on purpose. For example, if an equity manager is judged solely by his Sharpe ratio (1), his best strategy is not to pick excellent stocks and protect downside by purchasing S&P500 put options. His optimal strategy turns out to be exactly the opposite: sell as many far-out-the-money put options as possible – and do little else.

Most of the time these options expire worthless, and the manager just collects the option premia. This creates steady and attractive returns. Naturally on rare occasion the market will fall significantly, and the sold options become liabilities. Given the position's high non-linearity, this results in catastrophic, bankruptcy type losses. However, when the risk is measured only via standard deviation (as is the case in Sharpe ratio), this effect on the denominator is not commensurate with the more frequent gains. In other words, the model fails by measuring risk solely via the second moment. This failure in turn can be exploited by even the simplest put option strategy – just sell the left-tails via put options.

Though manager selection is seldom done on Sharpe ratio alone, even this simple example illustrates the danger of blindly relying on models whilst using derivatives. And there are several examples where this danger has turned out to be anything but theoretical.

1987 market crash arising via portfolio insurance

Black and Scholes (1973) (2) *Option Pricing Model* in many ways created the modern derivatives market by introducing two main innovations: a closed form formula for pricing options, and a mechanism whereby options can be created via a self-financing, *replicating trading strategy* where the underlying security is bought and sold in pre-defined, market-level based amounts.

By the second half of 1980s many investors had begun using options to protect their increasingly equity weighted portfolios. Initially this was done via purchased put options, but given their cost, many investors started creating options in "DIY" manner. In this *portfolio insurance*, rather than buying put options at the exchange, they were self-created by using the *replicating trading strategy* reducing equity weights as markets declined. The amount of stock to be sold in turn was defined by the Black-Scholes model, i.e. the desired option's delta.

Initially this strategy worked very well: given the protected downside, investors were able to increase their equity holdings and earn high returns in bull markets. In downturns the put option provided the needed cover. As with any successful strategy, success breeds imitation and ever more investors joined in.

The unravelling spiral occurred in the market down-turn of 1987. As the markets started selling off, the DIY portfolio insurance became a *self-fulfilling* force. Instead of being long convexity, investors were actually short of it. As markets fell, more and more investors got the signal to sell, resulting in increased downward pressure. Worse still, the strategy assumed smooth/continuous trading, and with the now downward gapping prices, investors were faced with not linearly but quadratically increasing sell orders, facilitating even more violent price gaps, etc.

This self-destruction ultimately resulted in the largest one-day percentage fall in history, S&P 500 index lost 20.5% during the Black Monday, 19th of October 1987. The Federal Reserve itself was forced to intervene before any market stability were to be regained.

1998 LTCM failure induced by Modern Portfolio Theory and Value-At-Risk

Even more fundamental financial model was the *Modern Portfolio Theory* developed by Markowitz (1952), Sharpe (1964), and Lintner (1965). It answered the problem of how to create a portfolio from several correlated opportunities – i.e. how to optimise risk *vs* return. Related was the later Value-At-Risk model, which allowed the quantification of tail-losses of this optimally diversified portfolio. For example, it would tell that at 95% confidence the daily/weekly/monthly loss of a portfolio would be less than *x* dollars.

This model combination was particularly useful in creating diversified portfolios of convergence trades – highly correlated pairs of instruments that from time to time experienced small pricing discrepancies. In a convergence trade, one bought the cheap asset, sold the expensive one, and hedged out any remaining risks. Thus, each side of a trade was assumed to be tightly coupled, but as a group the trades were regarded as relatively independent.

As the dollar opportunity in these trades was generally quite small, efficient implementation required the use of derivates – with their unique ability to isolate the desired risk and their high embedded leverage. The most notable user of this strategy was Long Term Capital Management (LTCM), and the strategy's attractiveness was highlighted by the LTCM's extremely high returns, which for the first four years were 21%, 43%, 41% and 27% after fees.

The unravelling of this models & derivatives combination came on the 17th of August 1987 when Russia devalued its rouble and defaulted on $13.5 billion of debt. While LTCM suffered losses from its Russian domestic debt positions, these were relatively small and not fatal. However, the ripples that this unleashed were.

(1) Essentially the ratio of average returns over standard deviation of returns.
(2) Or more precisely the Bachelier (1900), Black and Scholes (1973), Merton (1973) option pricing model.

In particular, the strategy's high returns had attracted a number of bank proprietary desks and relative value hedge funds, each employing the same modelling and portfolio construction approach (Indeed, in many cases the entry of new players had induced the desired convergence contributing to the observed profitability). Now the system reversed, as the Russia shock simultaneously increased everyone's VaR coefficients, triggering risk reductions in every trading book. With everyone selling the same positions, the losses became ever wider, again increasing VaR measures, which in turn called for ever larger risk reductions, etc.

This simultaneous unwinding created conditions that were in perfect opposition to the model's assumptions: single trade's internal components became unhitched, and the trades themselves were almost perfectly correlated – and all parts loss making. As one of the partners at LTCM is noted to have said "it was as if there was someone out there with our exact portfolio... only it was three times as large as ours, and they were liquidating all at once (3)."

This self-fulfilling, across markets liquidation was critically contributed by the over-reliance on model assumptions and the above-mentioned heavy use of derivatives. Indeed, the inherent leverage of the positions was truly staggering. For example, for LTCM the 1998 starting equity of $4.7 billion was supporting derivate positions of over $1.25 trillion.

As with the portfolio insurance crisis of 1987, this was not an exogenous black swan, but an endogenous nuclear swan created by model simplifications/assumptions exploited by the heavy use of derivatives. Much like 1987, the crisis was only subdued by the intervention of the Federal Reserve: in this case forcing together a bank consortium with enough capital for a bailout, and a controlled unwinding of LTCM's portfolio (4).

2008 credit meltdown effected by the wide use of Gaussian Copula

The Modern Portfolio Theory noted above optimizes risk/return trade-off under normal market conditions where risk can be proxied via small price movements and assets' covariance. A much more fundamental notion the risk of default. This deeper portfolio problem was addressed at the turn of the century by the Gaussian Copula Model (Li (1999,2000)), where asset characteristics could now include credit risks, and where defaults could be correlated (5).

Modelling joint failures had historically been mostly an art, and always the weakest link in pricing and measuring credit portfolios. Gaussian copula model provided an intuitive, simple answer and was enthusiastically embraced by all market participants: banks, investors, rating agencies, and even regulators. Because of the model's simplicity – not despite of it – Gaussian copula became the lingua franca of credit markets (ABS, MBS, and CDOs). In particular, all the rating agencies incorporated it into their rating methodologies – and all did so with relatively low correlation assumptions. These two choices were to have wide ranging consequences. In particular, in sub-prime mortgage securitization the combination of Gaussian Copula Model with a new derivative instrument, Collateralized Debt Obligation (CDO), facilitated large-scale creation and transfer of mortgage default risk.

On the supply side the set model allowed banks to take advantage of an apparent credit arbitrage: For their given credit-rating sub-prime mortgages were trading at very wide spreads. However they could be first pooled and packed into a Mortgage Backed Security (MBS), and then the tranches of MBS in turn could be split into various CDOs. The apparent diversification benefit in a pool of poor credits, as computed via Gaussian Copula model and low correlation assumptions, ensured that a very large portion of the resulting final products received AAA and AA ratings. Crucially the returns remained unchanged, so you had AAA & AA credits with high positive yield spreads in comparison to any other alternative. So attractive was this business that many banks moved wholesale from "originate to hold" to "originate to distribute" business models. Contributing factor was that on the demand side this period was characterized by lack of alternatives, and the achieved high yielding AAA and AA rated products allowed investors who otherwise would not have participated in this asset class at all, to become its main buyers.

This demand for CDOs even created a backward demand for the underlying mortgages, in turn inducing a credit boom and a housing bubble. The positive spiral was self-fulfilling since as long as house prices increased, defaults remained low. Any failing loans could be covered via re-mortgaging or a simple house sale, re-enforcing the model's assumptions of low mortgage default probability and low correlations.

Ultimately, this spiral reached its peak with increasingly questionable underwriting practices and starting in 2006 declining housing prices. Increased occurrences of negative equity created defaults and the main unwinding started in 2007 when the two hedge funds ran by Bear Sterns failed and their collateral turned out to be practically worthless. In the ensuing panic, mortgage issuance disappeared, housing prices fell further, defaults increased etc. As with the LTCM crises, the original model assumptions turned onto their heads – default occurrences were actually very high and correlations nearly one. Again, the Federal Reserve had to intervene with the very well known, and still ongoing effects.

(3) As a historical detail, the two main contributors to the Option Pricing Theory – Myron Sholes and Robert Merton – were at the centre of the 1998 crisis as partners of LTCM.

(4) Interestingly, the two banks that declined to participate in the LTCM bailout consortium were Bear Sterns and Lehman Brothers – decision that came to revisit them 10 years later.

(5) Copulas in general describe dependencies between random variables. Based on Sklar's theorem, any multivariate joint distribution can be expressed in terms of univariate marginal distributions and a copula function giving the dependency. Gaussian copula function is the simplest copula representation, giving in this case a one factor, one parameter model for joint defaults.

Conclusion

The above crises briefly illustrate the dangers of simple models and their implementation via derivatives. On the surface, all three cases highlight a common failure – their reliance on normal (elliptical) distributions and stable correlations. For example, Gaussian copula's failure to capture tail dependencies is very similar to Black-Scholes model's inability to consider heavy-tails of equity returns. Similarly Modern Portfolio theory explicitly relies on variance as the measure of risk and constant covariances. Even in a non-parametric VaR model, returns have to be stable enough to be estimated from relatively recent price history. In other words, all these standard models of finance fail to model extreme events and any evolution of dependency.

One partial solution has been improved modelling and testing of models' assumptions and limitations, such as is done at Methodology. For example, the undesirable property of asymptotic independence in Gaussian Copula can be remedied by other copula functions, portfolio construction can be done via much more robust Methodology Measure, and Extreme Value Theory tools in turn can incorporate effects of heavy-tails.

However, it is unlikely that this is a complete solution. Models will always be simplifications of reality – "All models are wrong, some of them are useful". The above crashes illustrate the very endogenous nature of the financial crises: the self-fulfilling initial ramp-up, failure and reverse, and the self-destroying rapid melt-down. Rather than considering endogenous market catastrophes as mere unknown/undiscovered black swans, they may better be studied as self-induced nuclear swans. This is in contrast to exogenous crises, such as the current Covid-19 impact on the real economies.