A taxonomic approach to risk factors in derivatives pricing

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Abstract

The underlying cause of the 2007-08 crisis was the excessive leverage that had built up in the entire financial system. Synthetic leverage in the form of derivatives exposures augmented the overall level of leverage. One of the major regulatory responses to the crisis led to the introduction of "Minimum capital requirements for market risk", known as the "Fundamental Review of the Trading Book" or "FRTB". FRTB presents banks with their biggest change in market risk for two decades. One of the most challenging areas of FRTB is risk factors. FRTB defines a risk factor as "A principal determinant of the change in value of a transaction that is used for the quantification of risk". A number of authors called for more research into market risk factors and the need for a single risk factor taxonomy**.** While FRTB provides an improvement on the categorisation of derivative pricing risk factors it nonetheless lacks a single taxonomy. The purpose of this research is to address this gap. This study will review the different types of derivative pricing risk factors that exist and the relationships between them. The review will include an examination of the theory that underlies the assumption that FRTB makes about all risk factors, namely that they are risk-neutral market rates or derived from risk-neutral market rates.

Taxonomies are a necessary foundation for both researchers in theory building and for practitioners in organising, generalising, communicating, and applying research findings. This study argues that a derivative pricing risk factor taxonomy would consist of only two high level categories. The first is market risk factors, the second is parametric risk factors. Sub- categories, levels and definitions exist within these two broad categories. The study uses documentary analysis to create the high level categories then analyses risk factor data sets with the objective of creating the detailed sub-categories, levels and definitions that will act as a single coherent risk factor taxonomy. It argues that no taxonomy currently exists one of the categories, the parametric risk factors. The study addresses this gap by extracting from the literature a taxonomy of model parameters that exist within the wider risk factor taxonomy. The study concludes with an analysis of the inter-relationships of the different types of risk factors that exist within the broader taxonomy.

The research is warranted because of the centrality of the use of risk factors in trading book processes across trading, finance, risk and regulation in the investment banking world. Risk factors are central to processes such as market risk, independent price verification, product control, bid-ask reserving, marking to model, adjustments for illiquid positions, market risk limits, the monitoring of risk positions, the FRTB IMA and SA approaches, stress testing, internal model reviews, and interest rate risk in the banking book. A standardised definition of risk factors across all of these areas is merited from both an academic and practitioner perspective.

Introduction

Financial market volatility is one of the primary attributes of the modern global economy (Bryan and Rafferty, 2005). It can act as both a threat to economies and an agent of their change. Derivatives are a tool for managing volatility. They are financial instruments whose prices are “derived” from the prices of some underlying asset, index rate or event (FCI Report, 2011). Properly employed derivative contracts such as options, futures and swaps allow financial market participants to hedge financial risk (Schoen, 2017). The nature of the relationship between financial market volatility and derivatives is the subject of much research (Gorton and Rose, 1995; Stulz, 2005; Hull, 2015; Sotiropoulos, 2015). The development of the Black-Scholes-Merton (BSM) option pricing model (Black and Scholes, 1973; Merton, 1973) in the 1970s provided market participants with a consistent, generally accepted quantitative technique for option price discovery (Bezzina and Grima, 2012; LiPuma and Lee, 2005). Utilizing the theory of risk-neutral valuations the model resulted in a formula for calculating the prices of options (Wilmott, 2013; Hull, 2015). The success of the formula led to a dramatic increase in derivatives trading and liquidity. Today the notional amount outstanding of over-the-counter (OTC) derivatives globally is estimated to be $632 trillion (BIS, 2022a), over six times the size of estimated global GDP[1]

In the aftermath of the 2007-08 financial crisis the G20 countries initiated a wide-ranging program of regulatory reform in financial markets. One goal of the reform program was to make derivative markets safer (Bardoscia et al, 2019). The underlying cause of the 2007-08 crisis was the excessive leverage that had built up in the entire financial system. Synthetic leverage in the form of derivatives exposures augmented the overall level of leverage (Schoen, 2017). Between 2000 and 2008 there was a seven-fold increase in the notional value of OTC derivatives (FCI Report, 2011). In addition to allowing banks to increase their leverage, derivatives also allowed banks to reduce their value-at-risk[2] (Schoen, 2017) and therefore reduce the level of market risk capital they needed to hold (BCBS, 2016a). Market risk is defined as the risk of losses arising from movements in market prices. Unsurprisingly, derivatives trading was therefore seen as a major contributor to financial market instability and regulators found themselves under pressure to enhance their regulation of the OTC derivatives market (Awrey, 2010).

[1] 2021 estimated global GDP is $97.1 trillion, www.statista.com

[2] Prior to the regulatory reform that came in the aftermath of the financial crisis of 2007-8, value-at-risk or VaR (Artzner et al, 1999; BCBS, 1996) was a primary approach for calculating that amount of market risk capital a bank had to hold.

One of the major regulatory responses to the crisis led to the introduction of "Minimum capital requirements for market risk" (BCBS, 2016a), known as the "Fundamental Review of the Trading Book" or "FRTB". It contains both qualitative (BCBS, 2016a, Appendices D and E) and quantitative requirements for regulatory compliance (BCBS, 2016a, pp1). The qualitative requirements detail the governance and control processes needed for the management of market risk and valuations. However, the primary focus of FRTB is the specification of the quantitative requirements, which articulated the rules and formulae for calculating and checking the adequacy of market risk capital. The quantitative requirements are divided into a standardised approach (SA) and an internal models approach (IMA). Originally scheduled for implementation in 2019, the timetable for full compliance now stretches out to 2025 for many regulatory jurisdictions[3].

SA primarily consists of a Sensitivities Based Approach (SBA) which aggregates risk sensitivities using risk factors that are prescribed in the FRTB document (BCBS, 2016a; Farag, 2017a; Zhan, 2020). In contrast to SA, the internal models that banks use under IMA require the use of their own risk factors (BCBS, 2016a; Orgeldinger, 2018). The option for a bank to use its own risk factors rather than use regulatory prescribed ones is central to FRTB (McCullagh et al, 2022). The BCBS argue that the internal model option is required in order to reduce opportunities for regulatory arbitrage. The use of internal risk factors ensures a level playing field across regulatory jurisdictions (BCBS, 2016a; McCullagh et al, 2022). To qualify to use internal models FRTB requires that banks perform a P&L Attribution (PLA) test and desk-level Value-at-Risk (VaR) back-tests (BCBS, 2016a, Aresi and Olivio, 2021). The PLA tests whether the distribution of trading desk profit and loss (P&L) is sufficiently close to the P&L distribution derived using the bank's risk management models (Pogliani et al, 2019; Mahfoudhi, 2017). The VaR back-tests check whether historical realised losses are close to what VaR models predict (Kratz et al, 2018).

FRTB presents banks with their biggest change in market risk for two decades (Farag, 2017a). Included as part of the Basel III reforms (BCBS, 2011), it specifies a more granular and onerous approach to market risk regulation. Banks have struggled to implement the changes required for compliance with its quantitative requirements (Orgeldinger, 2018a). One of the most challenging areas of the quantitative framework is risk factors. FRTB defines a risk factor as "A principal determinant of the change in value of a transaction that is used for the quantification of risk. Risk positions are modelled by risk factors" (BCBS, 2016a pp87). A number of types of risk factors and related concepts are noted

[3] For example full compliance is expected for banks under the jurisdiction of the European Banking Authority (EBA) by 1 January 2025.

in the FRTB document. These include risk factors defined in SA, the use of internal risk factors under IMA, component risk factors, primary risk factors, cross-cutting risk factors and real price observations. While the guidelines on the use and specification of risk factors have been in place since Basel I (BCBS, 2016a, Section B.3), FRTB adds further details and requirements. For example, under SA, high-level list of risk factors is provided (BCBS 2016a, Section B.3(i)). The document also includes a specification of risk factors under IMA (BCBS 2016a, Section C.7).

Despite the additional specificity on risk factors outlined in FRTB, several studies note the challenges associated with complying with its risk factor-related requirements. These studies range from linking risk factors to trades (Aresi and Olivo, 2017) to assessing the modellability of risk factors (Orgeldinger, 2017; Farag 2017a; Farag 2018; Orgeldinger, 2018a; Slime, 2018; Aichele et al 2021) to the use of risk factors within expected shortfall models (Dalne, 2017; Menéndez and Hassani, 2021). IMA specifies allowable criteria for excluding risk factors from internal market risk models and the requirement for internal models to capture non-linearities in option products as well as correlations between risk factors (Zhan, 2022). IMA also requires that banks classify their risk factors as either modellable or non-modellable (Aichele et al, 2021; BCBS 2016a). For a risk factor to be classified as modellable, the bank must be able to observe a sufficient amount of "real" prices, i.e. trades or committed quotes that have a material exposure to the risk factor (EBA, 2019a). The EBA guidelines on risk factor modellability also allows model or function parameters to be used as risk factors where a mathematical function has been used by a bank to represent a curve or surface (EBA, 2019a, Section 3.6). These parametric risk factors add an additional layer of complexity to risk factor definitions and requirements contained in FRTB.

To address the challenges associated with complying with the FRTB risk factor-related requirements a structured approach to analysing risk factors is required. Azoulay et al (2018) discuss the benefits of taking such a structured approach. They argue that a single taxonomy for risk factors would allow for a more consistent approach to addressing the data challenges presented by FRTB. Such a taxonomy would allow for a holistic and pan-regulatory view of risk factors. A centralised and consistent view of its risk factors would allow the approaches used for FRTB compliance to be extended to related regulation such as stress testing (FRB, 2013a), internal model reviews (EBA, 2013a), and interest rate risk in the banking book (IRBB) (EBA, 2022b). Table 1 provides a summary of the various risk-related regulations that would be able to use a common taxonomy for derivative pricing risk factors.

Table 1: Regulations and trading book controls that use derivative pricing risk factors

Regulation / Control	Description / Reference
Stress testing	The EBA guidelines on institution’s stress testing (EBA, 2018a) provides a taxonomy of stress testing and discusses the benefits of having an institution-wide definition of risk factors that can be analysed at group level where the bank comprises of multiple legal entities. The guidelines define a stress testing scenario as containing of a set of risk factors and state that a bank’s risk factors should be aligned in an internally consistent way. The set of risk factors should reveal the nature of inter-related risks including risk factor correlations within and across portfolios, as well as system-wide interactions and feedback effects. The EBA guidelines on stress testing (EBA, 2018a, Section 4.6) discuss the importance in having quantitative methods for defining the link between stressed risk factors and risk parameters. Mechanisms that associate risk factors with changes in risk parameters should be understood.
BCBS 239	BCBS (2013) Principles for effective risk data aggregation and risk reporting, known as BCBS 239, states that banks’ information technology (IT) and data architectures did not have the capabilities required to manage financial risks during the 2007/08 global financial crisis (Orgeldinger, 2018b). Principle 8 requires that risk management reports include exposure data to all significant risk areas including market risk. Principle 8 states that supervisors may test a bank’s compliance with the principles by requesting exposures to the its risk factors.
Prudential valuations	The EBA regulatory standards on prudential valuation (EBA, 2015) requires that a prudent value of all positions is calculated by linking the prudent value to a range of rates/prices and a confidence level of 90%. The three main additional valuation adjustments (AVAs) are market price uncertainty (MPU) close-out costs (COC) and unearned credit spreads (UCS). Institutions are required to calculate the prudent value using market data and the bank’s valuation exposures. Financial instruments maybe combined into risk factors for this purpose.
Marking to market	The supervisory framework detailed in FRTB (BCBS, 2016a) describes how positions should be marked using observable prices from exchanges, screen prices, broker quotes, and other close out prices.

Marking to model	Banks will mark to model where observable market prices are not available for the position and therefore a mark to market approach is not possible (Derman, 2001; BCBS, 2016a, Section D). Marking to model, e.g. when using a derivative pricing model to value an illiquid OTC option means the valuation will be calculated using a mathematical model and the relevant market inputs (Cont,2010). Models are subject to model risk (Derman, 1996; Rebonato, 2002; Morini, 2011) and banks are required to validate their models and do periodic reviews to check the accuracy of its performance. FRTB requires that banks perform analyses of the P&L generated by the model cross-referenced to to changes in its risk factors (BCBS, 2016a, Section D).
Independent Price Verification (IPV)	The IPV process is separate from the daily mark to market process (BCBS, 2016a, Section D). The mark to market process is performed by the trading desk using prices and rates that are available to them. The IPV process is independent from the front office. The IPV function is especially important for illiquid long-term and complex OTC derivatives held on the books of investment banks (Derman, 2001). The success of these trades influences the careers of those who work on the trading desk. The independence of the IPV function is therefore critical. The IPV function is performed on a risk factor basis. Models are used to derive prices for OTC derivatives. Model parameters (parametric risk factors) such as volatilities and correlations should be implied from market prices of liquid traded securities (Loerx and Sachs, 2012; Cont, 2010; Derman, 2001). It is the responsibility of the IPV function to test that that market prices used to calibrate model parameters is relevant, timely and accurate (Derman, 2001; Nash, 2017). Note that the calculations which are done in the prudential valuation regulations (EBA, 2015), see above, on a risk factor basis can use the same market data (market risk factors) as those that are used by the bank's IPV function.

Bid-Ask Spread/ Close-out costs	Banks need to make valuation adjustments for close-out costs (BCBS, 2016a). For observable market rates, the bid–offer spread is calculated as the difference in price between what the buyer is willing to pay and what the seller is willing to receive. Risk sensitivities are exposures to positions built up in the risk factors associated with derivative positions. To close out or reduce the risks associated with a risk factor, the bank will be exposed to the bid-offer spread on that risk factor and will need to make a valuation adjustment for it (Nash, 2017).
Interest rate risk in the banking book (IRRBB)	The EBA guidelines on IRRBB metric and modelling (EBA, 2022c, Annex II) state that interest rate stress scenarios should be carried out. The scenarios should combine shifts of yield curves with changes in basis and credit spreads. There should be adequate tenors in all yield curves and daily updates of all risk factors.

Risk factor mapping is the process of mapping large portfolios of financial instruments to their risk factors. Mapping portfolios of derivatives to their risk factors and their risk sensitivities requires the use of Taylor series approximations (Alexander, 2008c). A Taylor series approximation can be used to calculate the value of an options portfolio because the portfolio's value is a non-linear function of its risk factors. The use of risk factors and sensitivities to calculate the value of a derivatives portfolio in this way is referred to as delta–gamma approximation (Alexander, 2008c). Mehta et al (2012) find that most banks use a risk factor mapping approach for market risk processes such as those used in FRTB. In their investigation of the impact of the FRTB PLA test and VaR back-test on trading-desk portfolios McCullagh et al (2022) call for further research examining the complex risk factor mapping techniques that are required for interest rate models. This study, which aims to produce a taxonomic analysis of market risk factors and parametric risk factors used in derivative pricing models, will include a taxonomic analysis of interest rate risk factors. Such an analysis could be part of and would benefit the research into the interest rate risk factor mapping process called for by McCullagh et al (2022).

A taxonomy or typology is an information storage and retrieval system whose major function is to order and make sense of the data (Rich, 1992). Taxonomies are artefacts used by researchers and practitioners to describe and classify objects within a domain (Szopinski et al 2020). The best classification systems combine information content with ease of access to that information (Rich, 1992). Different procedures for devising classification systems exist in the literature. Warriner (1984) divides these procedures into three separate types: common sense, a-priori / heuristic, a posteriori / arithmetic.

Several authors have described criteria for an effective taxonomical process. Olken (1984) offers six criteria for efficient information storage and retrieval in a data management system: efficiency, data semantics, standardisation, integrity preservation, security and usability. Rich (1992) states that one of the key criterion for a taxonomy is that it has to be an exhaustive classification of the phenomena being categorised. In their survey of literature on taxonomies Szopinski et al (2020) examine a sample of 446 articles investigating the criteria employed in evaluating taxonomies. They produce a frequency distribution of 43 different taxonomy evaluation criteria identified in articles within the sample. The most frequent criteria are "usefulness", "comprehensive", "applicability", "concise", "robust", "explanatory" and "understandable". Szopinski et al (2020) also describe a number of guidelines for researchers who build and/or evaluate taxonomies.

While FRTB provides an improvement on the categorisation of derivative pricing risk factors over what was provided in Basel I (BCBS, 1996) and Basel II (BCBS, 2004) including references to concepts such as real price observations (RPOs), cross-cutting risk factors, component risk factors and parametric risk factors, it nonetheless lacks a single taxonomy covering the different categories of risk factors that exist and that could be used in other regulations impacting the trading book. The purpose of this research is to address this gap. This study will review the different types of derivative pricing risk factors that exist and the relationships between them. Taxonomies are a necessary foundation for theory building (Szopinski et al, 2020). The objective of this study is to conduct a taxonomic analysis of risk factors that will benefit future researchers in the areas of market risk, derivatives, derivatives pricing models and related regulation. Equally practitioners require an organizing framework to generalize, communicate, and apply research findings (Glass and Vessey, 1995). As argued above, a single taxonomy will benefit practitioners involved in implementing FRTB and also those involved in ensuring compliance with related regulation. A common taxonomy of risk factors would straddle not only the different approaches to market risk prescribed by FRTB, but it would also span the various other trading book-related regulations outlined in Table 1.

This study will investigate the argument that there are two categories of risk factor referred to in the FRTB document and related regulatory documents. The two main types are market risk factors and parametric risk factors. Table 2 describes the two types. A third sub-type is added for real price observations. FRTB places much importance on the concept of the liquidity of risk factors (BCBS, 2016a pp87) and it requires banks to perform a modellability check using real price observations to prove the risk factors are sufficiently liquid. While real price observations are not technically risk factors, their importance in the definition of risk factors within FRTB warrants their inclusion as a top-level category in the holistic taxonomy of risk factors.

Table 2: Risk Factor Categories

Risk Factor Category	**Description**
1 Market risk factors	"A principal determinant of the change in value of a transaction that is used for the quantification of risk. Risk positions are modelled by risk factors" (BCBS, 2016a pp87). The definition is closely related to the concepts of observable market prices, marking to market, and market data (Jouini, 2000; BCBS, 2016a 718(ciii); Plantin et al, 2005). Market prices and rates such as risk-free yield curves and implied volatilities are used as inputs to derivative pricing models. These market prices are referred to extensively in the derivative pricing literature (e.g. Hull, 2015; Wilmott, 2013; DeRosa, 2011). FRTB (BCBS, 2016a) defines seven classes of risk factors: interest rates, foreign exchange, equities, commodities, credit, structured credit, and credit correlation.
2 Parametric risk factors	One of the purposes of derivative pricing models is to generate curves and surfaces that closely fit to the market data that is used to generate them. These curves and surfaces can be seen therefore as being created by mathematical functions or models that take parameters as inputs. They are referred to as parametric curves or surfaces (EBA, 2019a) or more generally as parametric risk factors The model parameters that are used to generate parametric risk factors need to be calibrated using a market implied calibration technique under the risk-neutral valuation principle (BCBS, 2016a, Section D, 718cxi; Aresi and Olivo, 2017, Section 2.1). The use of observed market prices that are consistent with the risk-neutral approach is the standard assumption when calibrating model

	parameters (BCBS, 2013a, pp 62). Hull (2015). Model parameters, e.g. parameters used in a model for the estimation of a volatility surface, are determined from market data, i.e. determined from market risk factors. Such market data includes broker quotes on actively traded options such as caps or swaptions in the interest rate world (BCBS, 2016a, 718(cvii)). These actively traded instruments are referred to as the calibrating instruments. The objective of the calibration exercise is to choose the model parameters so that the difference between the prices generated by the model and liquid market prices are minimized using a goodness-of-fit measure (Loerx and Sachs, 2012; Cont, 2010). Goodness-of-fit measures can be minimised using the appropriate numerical procedure, e.g. the Levenberg–Marquardt procedure (Flannery et al 2007).
2.1 Real price observations	To calculate market risk regulatory capital a trading desk can use either the SA or the IMA ((Farag, 2017a). A new aspect of FRTB as compared to Basel I (BCBS, 1996) and Basel II (BCBS, 2004) is the risk factor eligibility test (RFET) which includes a modellability assessment of each risk factor. The purpose of the modellability assessment is intended to ensure that the risk factors included in their Expected Shortfall (ES) model under IMA, are sufficiently liquid and observable (EBA, 2019a). To be deemed modellable there must be a sufficient quantity of real price observations for the risk factor (BCBS, 2016a, Section C.5).

The study will conduct a documentary analysis of the FRTB document along with related documents from national regulators and other sources to examine whether the three categories in Table 2 are exhaustive in terms of the universe of derivative pricing risk factors. The output of this analysis will be the construction of a dictionary of terms focused on regulatory references to risk factors. Sub-categories that fit within the three main categories will also be identified. The resulting overall classification system will be analysed using one of the procedures for devising analysing classification systems described in Warriner (1984), i.e. common sense, a-priori / heuristic, or a posteriori / arithmetic. The objective will be place each risk factor term into one of the three categories (or sub-categories within the three). If the analysis concludes that more than three categories are required to allocate all of the risk factor terms then additional categories will be added (and may lead to additional research questions). The starting assumption however will be that a high level taxonomy exists with the three categories of risk factors described in Table 2. Having this high level taxonomy in place leads to the research questions.

The first research question is:

RQ1: Examine the extent to which a taxonomy of FRTB-compliant risk-neutral market risk factors (Category 1) can be extracted from existing data sources?

In answering this research question the study will examine a three data sets containing instrument identifiers for risk-neutral market rates:

- the GoldenSource database[4]
- the Refinitiv database[5]
- the OpenFIGI database[6]

Each data set will be examined using criteria on effective taxonomies obtained from the literature (Szopinski et al 2020; Rich, 1992; Olken, 1984). Codification adequacy, naming standards, completeness of the instrument set, inter-relationships between risk factors, and the ability to map to the FRTB categories will be among these criteria. The aim will be to determine whether each data set contains an over-arching taxonomy that supports the reporting, aggregation and analysis of market risk factors as defined in FRTB. Each data set will be examined also using criteria on financial instrument instruments (Young, 1996; Poltoradneva, 2014; Denga and Jain, 2016). These financial instruments represent the constituents of derivative pricing market risk factors. The taxonomy criteria will require that these instruments be analysable by maturity (tenor), moneyness, underlying index, price or rate. The taxonomy will also need to contain definitions of interest rate curves (Bouchaud et al, 1999; Björk and Christensen, 1999) and volatility surfaces (Cont and Da Fonseca, 2002; Gatheral, 2011) again linking back to the definitions of curves and surfaces defined in FRTB. The ability to cross-reference instruments between the different databases will also be investigated. The adequacy of the

[4] https://www.thegoldensource.com/solutions/banks-brokers/market-data-management-solutions/
[5] https://www.refinitiv.com/en/financial-data/eikon-datasets
[6] https://www.openfigi.com/about/symbology

database as a potential source for market risk factors will be supported with a statistical analysis of the data set.

The second research question is:

- RQ2: Investigate the extent to which a taxonomy of risk-neutral parametric risk factors is possible by categorizing and codifying derivative pricing models and identifying the model parameters in each model.

To answer this question the study will follow a number of steps. The first step will be to categorise and codify commonly used derivative pricing models. There is an extensive list of authors that summarise and describe these models, e.g. Rebonato (2004), Wilmott (2013), Kwok (2008); Hull (2015). The model categories resulting from the first step will be cross-referenced and consolidated into a single derivative pricing model taxonomy. It is envisaged that this cross-referencing of models and the resulting model taxonomy will be a contribution for use in future research. The second step involves a review of the literature associated with each model to identify the model's parameters. The third step will be the classification and codification of each model parameter into a model parameter taxonomy that aligns with the definitions provided in FRTB. The assumption that all model parameters can be classified using the model parameter taxonomy from step 3 will be tested by randomly choosing a number of less common derivative pricing models (i.e. derivative pricing models that do not fall into the model taxonomy resulting from step 1) from the literature.

The third research question is:

- RQ3: What are the inter-relationships between the two different types of risk factors, i.e. market risk factors and parametric risk factors, and their associated real price observations? Can a statistical relationship be identified which relates model parameters to the market prices that they are calibrated to? And is there a relationship between real price observations and the parametric and market risk factors?

To test whether a statistical relationship exists between market risk factors, parametric risk factors and real price observations, it is envisaged at this stage that a documentary analysis with accompanying regression models will be used. The first step with this approach involves the creation of a dictionary of terms associated with model parameters. The study will derive the dictionary of terms using words and terms extracted from the literature on derivative pricing models. There are many examples of dictionaries in the literature including market risk dictionaries (BCBS, 2016a, Glossary), financial crisis dictionaries, and corporate filing risk factor disclosure dictionaries (Campbell et al, 2014, Appendix 3). Next will be a count of each term in the dictionary to allocate weights indicating the relative importance of each model parameter. Google scholar or the Scopus database will be used to perform counts of the dictionary of terms. The same dictionary-of-terms approach will be used to calculate weightings for the different types of real price observations. Codes and standards for real price observations already exist in the form of taxonomies for financial markets transactions and derivative transactions including the Classification of Financial Instruments (CFI) (ISO 10692, 2021) and the ISDA 2.0 taxonomy (ISDA, 2019a) from the International Swaps and Derivatives Association.

An approach is also needed to allocate weightings to market risk factor types. To achieve this a count will be performed of the instruments contained in the market risk factor database (e.g. the Refinitiv or the GoldenSource database from RQ2). Sub-totals of instrument count by risk factor type will be calculated which will be used to assign weights to market risk factor types indicating their relative importance. The final step will be a regression model which will be used to determine whether relationships exist between the different weightings assigned to the different types of market risk factors, parametric risk factors and real price observations. The hypothesis under test for this RQ will be that a statistical relationship does exist between market risk factors, parametric risk factors and real price observations.

Theoretical framework

The theoretical underpinning of risk-neutral market prices is risk-neutral valuations. Gottesman (2021) explains the concept of risk-neutral valuation, the standard approach for pricing derivatives. The cash flows of a derivative can be exactly replicated with a synthetic asset where the synthetic asset is a combination of its underlying security and a risk-free security. This means that both the derivative and the synthetic asset must earn the same rate of return. If all instruments in the portfolio, i.e., the derivatives and the synthetic assets, earn the same rate of return, then there are no opportunities to invest in risky assets so all assets must earn the same risk-free rate of return. This is the risk-neutral world that derivatives are valued in and the foundation for derivatives pricing theory. The use of the risk-neutral pricing approach was the key insight into the BSM model (Black, 1989; Arnold, Nixon and Shockley, 2003). Under the risk-neutral pricing approach the underlying stock price is not required to calculate the price of an equity option.

This surprising conclusion that the stock price variable was not required in the BSM model led to its authors winning the Nobel prize in economics in 1997 (Shah, 1997; Duffie, 1998; Jarrow, 1999). In probabilistic terms, the risk-neutral measure[7] is a probability measure that means a share price is equal to the discounted expectation of its future share price (Dennis and Mayhew, 2002). The fundamental theorems of asset pricing (Harrison and Pliska, 1981; Delbaen and Schachermayer, 1994) capture the importance of the risk neutral concept for derivatives pricing. They state that in a complete market (Jarrow, 2012), a derivative's price is also equal to the discounted expected value of its future payoff under the unique risk-neutral measure – i.e. under discounting with the risk-free rate. However, such a measure can only exist if there are no arbitrage opportunities in the market.

Standard finance theories such as state preference theory (Arrow and Debreu, 1954), the efficient market hypothesis (Fama, 1970), replicating portfolios (Merton, 1973) and complete markets (Harrison & Pliska, 1981) were precursors to the risk neutral approach (Rubinstein, 2006; Ross, 2009). This study will review these foundational theories and their link to risk-neutral market prices. Risk-neutral valuations continued to be the underlying assumption of the many and varied models, e.g. the stochastic volatility models and jump-diffusion models of Merton (1976), Hull and White (1987) and Heston (1993), that were introduced to account for the flawed assumptions in the BSM model. Market prices and rates such as risk-free yield curves and implied volatilities are referred to extensively in the derivative pricing literature (e.g. Hull, 2015; Wilmott, 2013; DeRosa, 2011). As noted, parametric risk factors are calibrated to these market prices and rates.

Contribution of this research

The research is warranted given the centrality of the use of risk factors in trading book processes across trading, finance, risk and regulation. Risk factors are the principal determinants of the change in valuations and risk capital (BCBS, 2016a pp87). They are therefore central to processes such as Independent Price Verification (Derman, 2001; (BCBS 2016a, Section D, 718 cvi)), Product Control (Nash, 2017), bid-ask reserving (BCBS 2016a, Section D, 718ciii), marking to model, (BCBS 2016a, Section D, 718 cv), adjustments for illiquid positions ((BCBS 2016a, Section D.2), market risk limits ((BCBS 2016a, Section D.2), the monitoring of risk positions ((BCBS 2016a, Section D.2), the FRTB IMA and SA approaches, stress testing (FRB, 2013a), internal model reviews (EBA, 2013a), and interest rate risk in the banking book (IRBB) (EBA, 2022b). A standardised definition of risk factors across all of these

[7] Also referred to as an equilibrium measure, or equivalent martingale measure

areas is merited from both an academic and practitioner perspective. The research is expected to contribute in a number of areas.

The first contribution is to theoretical knowledge. The theoretical foundation for both market risk factors and parametric risk factors is risk-neutral pricing (Jacod and Protter, 2010; Rásonyi, 2004). No prior study has examined the universe of market and parametric risk factors from a theoretical finance perspective, tracing their risk-neutral assumptions to underlying finance theories. The second contribution is to the classification of derivative pricing models and their parameters. While classifications of derivative pricing models exist in various journals and texts (Hull, 2015; Wilmott, 2013; Rebonato, 2004), a structured classification of these models with the objective of producing a taxonomy of model parameters does not currently exist. The third contribution is to the classification of risk factors. Because taxonomies are a necessary foundation for theory building (Szopinski et al, 2020), researchers in the areas of market risk and derivative pricing models will benefit from the taxonomical analysis of this study. Practitioners require an organizing framework to generalize, communicate, and apply research findings (Glass and Vessey, 1995). The taxonomy for risk factors will benefit practitioners responsible for ensuring compliance with FRTB and related regulation. A common taxonomy of risk factors sitting across the regulations outlined in Table 1 will lead to efficiencies in implementing regulation and trading book controls.

The remainder of this paper is organised as follows. Section 2 examines the institutions and actors involved in derivatives trading and its regulation. Section 3 presents the theoretical framework that underpins derivative pricing and the risk-neutral prices that are used as inputs to derivative pricing models. Section 4 describes the conceptual framework used to illustrate the taxonomy for risk factors and where it fits in the derivative pricing world. Section 5 summarises the different types of derivatives trading and the main derivatives pricing models. Section 6 describes the proposed data and methodology and Section 7 concludes.

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