TABLE 1.1 Components of derivative prices before and after the financial crisis of 2007–2009.

Pre-Crisis	Post-Crisis
Risk-neutral price (LIBOR discounting)	Risk-neutral price (OIS discounting)
Hedging costs	Hedging costs
CVA	CVA (DVA?)
Profit	Profit
	FVA (including cost of liquidity buffers)
	KVA (lifetime cost of capital)
	MVA/CCP costs
	TVA (tax on profits/losses)

marked. Competitive pressure on pricing also pushed banks to include DVA in derivative pricing as many corporate customers had CDS spreads that were significantly tighter than the bank counterparties they were trading with. Accounting standards moved to recommend bilateral CVA models because of the symmetrical valuation. Some banks chose to actively manage DVA, while others chose to warehouse some or all of the risk.

Unsecured funding costs became a focus as bank funding spreads widened significantly as their CDS spreads did and a number of models were produced (see for example Burgard and Kjaer, 2011b; Burgard and Kjaer, 2011a; Morini and Prampolini, 2011; Pallavicini, Perini and Brigo, 2012)). FVA remains controversial as will be discussed in detail in section 1.4; however, most practitioners accept that it must be included in pricing and accounting practice with most major banks now taking FVA reserves.

Post-Crisis, regulatory capital is a scarce and expensive resource that must be carefully managed by banks. Capital management is no longer a back office function and now resides firmly in the front office as a core activity for tier one banks. The cost of regulatory capital has to be priced into every new transaction to determine if a trade is expected to be profitable. Capital modelling is now based in the much more complex Basel II.5 and Basel III regimes (and their implementation by regional regulatory bodies).

In 2015 pricing a "vanilla" interest rate swap involves multiple projection and discount curves for the baseline valuation and a large-scale Monte Carlo simulation at counterparty level to calculate CVA, FVA and KVA; it is a long way from the single yield curve discount models of the mid-1990s (see Table 1.1). Indeed, as will become apparent in this book, single trades can no longer be valued in isolation and trade valuation is an exercise in allocation of portfolio level numbers down to individual trades.

1.3 TRADE ECONOMICS IN DERIVATIVE PRICING

1.3.1 The Components of a Price

Table 1.1 illustrates the components of pricing before and after the financial crisis of 2007–2009. Not all of these components apply to all trades and to understand the terms under which a derivative is transacted it is useful to divide counterparties into three types: unsecured, CSA and CCP. Of course, in reality the range of counterparty arrangements is a continuum between unsecured and an idealised CSA with full instantaneous transfer of collateral but it is useful to

separate them for the purpose of this discussion. Each of these three cases will have different pricing components.

Unsecured Pricing

- Risk-neutral valuation
- Hedging/management costs
- CVA
- FVA
- KVA
- Profit (Tax/TVA).

For trades that are unsecured the components of the price begin with the baseline risk-neutral valuation, although there remains industry debate about the appropriate choice of discount curve for this, with both OIS and xIBOR-based discount curves used in the market. Hedging and trading desk management costs should be charged and this includes effects such as bid-offer, lifetime re-hedging costs and cost of supporting infrastructure such as system maintenance and staff. A profit margin will also typically be charged. Given there is no collateral to mitigate the exposure to the counterparty, CVA will be calculated based on the full expected exposure profile. If a bilateral CVA model is used there will also be a DVA benefit term. The same expected exposure will give rise to FVA. The lifetime cost of maintaining regulatory capital, KVA, will also be included, although this might be a *hurdle rate* or minimum return level rather than a cash amount.

CSA Pricing

- Risk-neutral valuation: CSA-based (OIS) discounting
- Hedging/Management costs
- Residual CVA (including impact of collateralisation)
- Residual FVA (including impact of collateralisation)
- COLVA/Collateral effects
- KVA
- Bilateral Initial Margin MVA
- Profit.

For trades covered by a CSA the baseline risk-neutral valuation will be discounted using a curve appropriate to the terms of the CSA. Given that the CSA is imperfect in the sense that the collateral transferred to support the mark-to-market of the trade is done on a discrete periodic basis rather than a continuous basis, a residual counterparty exposure will remain. This residual exposure leads to *residual CVA* and *residual FVA*. There may also be a COLVA adjustment to account for collateral effects in pricing that cannot be captured by a discounting approach such as collateral optionality. Capital must be held against collateralised portfolios and this gives rise to KVA, although the presence of collateral significantly reduces the amount of capital that must be held through the counterparty credit risk and CVA capital terms. The *leverage ratio* comes into importance here, however, as while collateral reduces the CCR and CVA terms, it has a restricted impact on the leverage ratio. Market risk capital will be held unless there are other market risk offsetting trades. Hedging and trading desk management

costs should again be charged as should the profit margin. Under BCBS 226 (2012e) and BCBS 242 (2013e), trades supported by CSA agreements will also require bilateral initial margin to be held in a similar way to the way that CCP initial margin requirements operate.

CCP Pricing

- Risk-neutral valuation: CCP methodology including CCP discount curves
- Hedging/Management costs
- Residual CVA (including impact of variation margin)
- Residual FVA (including impact of variation margin)
- COLVA/Collateral effects
- KVA
- Initial margin
- Liquidity buffers
- Default fund
- Profit.

For trades cleared through a CCP the components of a price include similar components to those of a trade supported by a CSA agreement. Residual exposure above the collateral provided as variation margin gives rise to CVA and FVA as with CSA pricing. Hedging and trading management costs are the same as is the addition of a profit margin. The lifetime cost of capital is also present although the risk-weight applied to qualifying CCPs is the relatively low value of 2% (BCBS, 2012c). As with CSA pricing a COLVA adjustment may be needed. In addition to variation margin, three other payments are often made to CCPS: *initial margin*, *liquidity buffers* and *default fund* contributions. The initial margin is designed to cover exposure that might arise due to market movements during a close-out period and hence prevent loss should a counterparty subsequently default. Liquidity buffers can also be applied if the risk position of a CCP member is large. All CCP clearing members are required to post default fund contributions which are designed to be used in the event of the default of a CCP member.

1.3.2   Risk-Neutral Valuation

In all three of the cases studied in section 1.3.1 a baseline risk-neutral valuation model is still used. The risk-neutral valuation is the value as seen by the derivative trader and is the value this trader is tasked with hedging. Normally this trader will be an asset-class specialist with experience of hedging in the markets underlying the derivative and so this is where the majority of the market risk on the trade is managed. The risk-neutral trade level valuation makes the usual assumptions of no credit or funding risk so in effect this valuation assumes that a perfect CSA agreement is in place. However, in general the choice of discounting curve varies depending on the arrangements under which the derivative has been traded.

Unsecured   The choice of discount curve is still a matter of debate in the industry and depends on internal factors. Many banks have left the baseline valuation of unsecured trades using xIBOR-based discounting models (Solum Financial Partners, 2014). In many cases this will be exactly the same multi-currency discounting model that was prevalent before the credit crisis, typically where all other currencies had cross-currency basis quoted against the US

TABLE 1.2 The possible choices of discounting for the baseline risk-neutral valuation of unsecured derivative trades.

Discounting	Motivation
xIBOR	■ Matches pre-crisis discounting (e.g. if this was USD based and included cross-currency basis) ■ Close-out reference value may be assumed to still be xIBOR based for unsecured trades
Single OIS curve	■ Central FVA management function ■ Single OIS curve discounting assumed to be reference close-out value (e.g. EONIA for European bank)
Multiple OIS curves	■ Central FVA management function ■ Single currency trading desks do not want cross-currency exposure ■ Multiple OIS curve discounting assumed to be reference close-out value
Funding discounting	■ Asset-class trading desks manage own funding costs ■ Discounting model of FVA adopted

dollar interest rates. Other choices are also possible including OIS discounting. The choice may be made to use a single currency discount curve for all unsecured trades, say for example Fed Funds. A further alternative might be to allow single currency derivatives to be discounted using the appropriate OIS curve for that currency and treat multi-currency trades differently. This has the advantage that single currency trading books would not be exposed to any cross-currency effects. If the bank elects to use funding discounting models for unsecured trades, then the discount rate will be the bank's internal cost of funds curve. The possible choices and motivating factors are listed in Table 1.2.

The choice of discounting depends on three key factors: organisational design, internal bank modelling of funding costs and the expected reference close-out in the event of default. Note that this reflects the practical reality of what happens in banks rather than theoretical correctness of any models used.

Organisation design Organisational design[4] determines which trading desks manage which risks. Broadly there are two main choices; either each individual trading desk manages their own funding (*distributed model*) or there is a central management desk for funding (*centralised model*). In the distributed model each trading desk will need to know the funding impact of all unsecured trades on their book. This would most likely be done using a funding discounting approach, although other models could be used. In the centralised model the asset-class trading desks will either wish to measure the funding risk and lay it off with the central desk or not be exposed to it at all. If the asset-class desks hedge out funding risks with the central desk then they will measure the funding cost and hedge it out through funding basis swaps, otherwise the asset-class desk would value all their unsecured trades either at xIBOR or OIS and be oblivious to funding considerations, with the central funding desk calculating and managing FVA directly.

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[4]See Chapter 22 for a broader discussion of organisational design.

Bank models of funding costs The bank model of funding costs also plays a role in determining the choice of discounting for unsecured trades. As will be discussed at length in Chapter 9 there are broadly two types of model for FVA, discounting approaches and exposure-based approaches. Discounting approaches simply adjust the discount curve, while exposure-based approaches use models similar to those used for CVA. Discounting-based approaches simply adjust the risk-neutral valuation by using the cost of funds as the discount rate and hence the risk-neutral valuation. Exposure-based approaches apply FVA as an adjustment to the portfolio valuation in the same way as CVA so the underlying risk-neutral valuation remains unchanged.

Reference close-out The reference close-out value is the final factor in determining the choice of unsecured discounting model. To be consistent with the CVA model the unsecured reference valuation should match that used in the CVA model so that in the event of default the risk-neutral valuation matches the claim value made against the administrators of the defaulted counterparty and the CVA becomes the realised loss on the trade once the actual recovery rate is known. Note that the use of funding discounting models implies that the CVA model *has to be changed to be consistent with this choice of FVA model*.[5]

CSA CSA and OIS discounting will be discussed in detail in Chapter 8; however, it should be noted here that the implications of Piterbarg (2010) and Piterbarg (2012) are that the appropriate discount rate for fully collateralised counterparties is the rate of interest received on the posted collateral. Hence the discount curve depends on the terms of the CSA agreement. In the simplest case where collateral can only be posted in cash in a single currency then the rate of interest received on posted collateral is normally the overnight rate in that currency. Hence the appropriate discount curve is the OIS curve in the same currency as this curve represents the market expected overnight rate extended out to longer maturities. In the case where cash in multiple currencies can be posted the appropriate discount curve is a blended curve which represents the rate earned on the cheapest-to-deliver currency.[6] Many CSAs allow a variety of securities to be posted as collateral and in this case the choice of appropriate discount curve becomes more complex.

CCP The discount curve used by CCPs to determine the value for the purposes of margin calls is determined by the internal models of the CCP. For single currency interest rate swaps cleared through LCH.Clearnet SwapClear this is currently a single currency OIS discounting methodology, having switched over from a LIBOR methodology during 2010 (LCH, 2010a). This can be viewed as the risk-neutral valuation of the interest rate swap, but there is no guarantee that a clearing member's own risk-neutral valuation will match that of SwapClear and this could become problematic because of the privileged position held by CCPs (Kenyon and Green, 2013c).

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[5]See Chapter 8.

[6]Chapter 8 discusses the construction of OIS discounting curves in more detail. It should be noted that collateral substitution where one piece of collateral is exchanged for another depends on the local legal framework and that collateral can be viewed as "sticky" in some jurisdictions. The pricing of the embedded cheapest-to-deliver option is not straightforward, therefore.

1.3.3 Hedging and Management Costs

The bid-offer spread quoted by trading desks has always been included in prices and reflects the trading desk cost of managing the trade. This is normally considered to include the cost of hedging the market risk on the trade at inception and any future re-hedging costs due to market movements and embedded nonlinear risk. There are however other elements that should be considered:

- *Staff costs* are a very significant fraction of the cost base of any bank. This includes trading and sales staff with primary responsibility for managing market risk and interacting with the customer. However, there are many other support functions involved including quantitative analysts, finance professionals and business controllers, risk managers, audit and operations staff.
- *Legal and other professional fees* are also a cost. Over-the-counter (OTC) derivatives are traded under the legal framework provided by ISDA (1992; 2002), which requires set-up and maintenance costs. Some transactions require external ratings, which means engagement with rating agencies and the payment of fees.
- *IT and other infrastructure costs* are also a significant part of the cost base of a bank. This covers everything from buildings, lighting and air conditioning through to the cost of IT system development, maintenance and hardware. For complex derivative products, even the cost of running the valuation and risk on a daily basis can be expensive due to hardware and the energy required to both power and cool it. Of course it is not just trading systems themselves, there are huge numbers of other risk systems for CVA, PFE, VaR etc that also consume resources.

1.3.4 Credit Risk: CVA/DVA

Part I of this book discusses CVA and DVA in detail, including models for unsecured and secured portfolios. Here I examine the CVA impact on pricing in each of the three cases.

Unsecured   Unsecured portfolios represent the standard case for CVA as both counterparties are fully exposed to each other. In most cases, close-out netting will apply meaning that the exposure on default will be to the netted value of the portfolio. If unilateral models are used then the CVA is only calculated on the exposure to the counterparty. In theory this would give rise to asymmetry in the price obtained by both counterparties as each would only charge for the credit risk of the other and take no account of their own risk of default. It is this theoretical asymmetry that has been one of the key drivers behind the introduction of bilateral CVA models and DVA. If bilateral models are used then both counterparties can agree on the credit valuation adjustment as the two terms in the calculation, CVA and DVA, are mirror images of each other. Counterparty A calculates CVA_A and DVA_A, while B calculates CVA_B and DVA_B with the following symmetry holding:

$$CVA_A = DVA_B$$
$$DVA_A = CVA_B.$$

Of course in practice this symmetry would certainly not hold as both counterparties would operate different CVA models and may be operating under different accounting regimes. For

example, one could be a bank with the derivative held in its trading book using mark-to-market accounting while the other might be a corporate using IAS 39 hedge accounting rules (IASB, 2004). There are also a number of other issues to be addressed when pricing unsecured derivatives such as including the impact of right-way or wrong-way risk and dealing with illiquid counterparties. Counterparties that deal on an unsecured basis are more likely to be smaller names with no traded CDS contracts, although some will be larger corporates or governmental entities.

CSA In the case of perfect collateralisation, where any change in mark-to-market is instantaneously covered by a transfer of collateral to support it, there is no credit exposure and hence no CVA or DVA. In practice, of course, even the strongest of bilateral CSA agreements do not display this behaviour and have a daily collateral call. In general all CSAs have a minimum transfer amount (MTA) and many have non-zero thresholds. Many CSAs will also have asymmetric thresholds giving *one-way CSAs*. Some CSAs have credit-rating dependent features such as thresholds that reduce on downgrade, volatility buffers or a requirement to novate the trade if the derivative issuer falls below a certain rating. CSAs can have a much lower call frequency such as weekly or monthly and this is particularly true of non-bank counterparties who do not have the operational capacity to manage collateral on a daily basis. In general, a default is not recognised immediately and often there is a recognised *cure* or *grace* period where a counterparty that has failed to make a collateral payment is allowed time to make the payment. In general, a *margin period of risk* is included when modelling collateral to allow an estimate of the realistic expected exposure. In the Basel III regulatory framework this is set at ten days unless the counterparty is a significant financial institution in which case the margin period is increased to twenty days.[7] During the margin period of risk no collateral is assumed to be transferred by the counterparty but often it is assumed that the bank must continue to make collateral payments, even if the counterparty has previously failed to make a collateral payment. Collateral disputes can also give rise to exposure and to the regulatory margin period of risk if more than two disputes occur in the previous two quarters (European Parliament and the Council of the European Union, 2013a; European Parliament and the Council of the European Union, 2013b).

CSAs are imperfect and give rise to residual exposure and hence there is credit risk and so CVA can be calculated and charged. However, not all banks mark CVA on collateralised names, particularly those with low or zero thresholds and a daily call frequency.

CCP CCP *variation margin* arrangements are very similar to a strong CSA with a daily call frequency and in some circumstances collateral can be called intraday. Given the presence of initial margin the residual expected exposure to the derivative trades themselves will be very small or zero.[8] However, there remains the possibility of exposure to the CCP itself through the initial margin and the default fund. If the initial margin is bankruptcy remote then the exposure generated by posted initial margin can be excluded from CVA. However, this is not the case for the default fund contributions which are designed to be used in the event of the default of a member. The default fund certainly generates exposure and hence credit risk.

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[7]Except for repo transactions where the margin period of risk is set at five days.
[8]Of course with sufficiently large market moves, almost any initial margin can be exceeded as is clear from the removal of the CHF-EUR peg by the Swiss National Bank on 15 January 2015.

1.3.5 FVA

FVA was initially controversial in the quantitative finance community as is clear from the series of papers by John Hull and Alan White (2012b; 2012c; 2014b) and the responses to them by Castagna (2012), Laughton and Vaisbrot (2012), Morini (2012) and Kenyon and Green (2014c). The debate around FVA is discussed in section 1.4.1 and FVA models are presented in Part II; however, it is clear that most market practitioners believe a pricing adjustment should be made for the cost of funding unsecured derivative transactions. In this context FVA represents the costs and benefits from managing the collateral on hedges used to eliminate market risk from the unsecured transactions. FVA and CVA together can be viewed as the cost of not trading under a perfect CSA agreement. The accounting status of FVA is now in transition with increasing numbers of banks taking reserves.

Unsecured   As with CVA, unsecured trades are the standard case for FVA as both counterparties are fully exposed to each other. Symmetric models with both funding cost and benefits as well as asymmetric models with only funding costs have been proposed with a key determining factor being the potential overlap with DVA benefit. Broadly speaking, methodologies for FVA are either based on discounting, as noted earlier, or on exposure-based models that are extensions of CVA.

CSA   The discussion on residual exposure from CVA also applies in the context of FVA so that deviations from a perfect CSA could give rise to *residual FVA*. If we view FVA as the cost of providing an effective loan or the benefit of an effective deposit through a derivative then the residual exposure just gives rise to a residual funding cost or benefit. However, as will be discussed later, if we view the FVA as the cost of maintaining collateral on a hedge trade then the argument for residual FVA on CSA trades is much weaker, although funding costs and benefits will still arise from mismatches in collateral requirements due to differing CSA terms. What is clear is that FVA does not apply to the secured portion of the exposure unless the assets provided as collateral cannot be rehypothecated. Lack of rehypothecation may be due to legal terms within the CSA or because the asset provided as collateral may be ineligible under other CSAs.

CCP – Variation Margin   Given the degree of overcollateralisation for trades cleared through CCPs any residual exposure is likely to be small to zero. With this in mind the FVA component due to a mismatch between valuation and variation margin is likely to be close to zero.

Other Sources of FVA   Central counterparties also require that initial margin be posted in addition to variation margin. Large net risk positions can give risk to volatility buffers and all members of the CCP are required to contribute to a default fund that will be used to cover any losses in the event of the default of a member. All of this additional collateral needs to be funded through unsecured borrowing and hence gives rise to *Margin Valuation Adjustment (MVA)*. Modelling the exposure at future times arising from these collateral buffers is complex. Initial margin is generally calculated using VaR models which means estimating expected future VaR. The volatility buffers use risk multipliers based on estimates of market depth so that large risk positions that cannot be quickly closed are penalised. The default fund, in the case of LCH, is based on all positions of all clearing members and so is very difficult to estimate

as the positions of other members are unknown. In addition the methodology used by central counterparties is not always public, making models difficult to build.

The Basel Committee proposal on bilateral margin for financial counterparties BCBS 226 (2012h) and BCBS 242 (2013e) would similarly give rise to a funding requirement to maintain the initial margin collateral buffer.

Regulatory liquidity frameworks including FSA047/048 as applied in the UK (Financial Conduct Authority, 2014, section 12) and the liquidity framework under Basel III (BCBS, 2013b) also require the maintenance of an internal liquidity buffer to protect an institution from outflow in the event of a credit downgrade. This *liquidity buffer* has to be held in liquid assets by the bank against a two-notch downgrade of long-term rating by credit rating agencies. Many CSAs and ISDAs contain provisions for additional collateral in the event one or more rating agencies downgrade the counterparty below certain certain rating levels. In addition non-derivative products such as deposits may contain provisions to allow the counterparty to withdraw the deposit if the bank's credit rating falls below a certain level. The liquidity buffer must be funded through unsecured borrowing and hence is a type of FVA. Trades with counterparties that have embedded *downgrade triggers* in their documentation should include the cost of funding any additional liquidity buffer in the price of a new transaction.

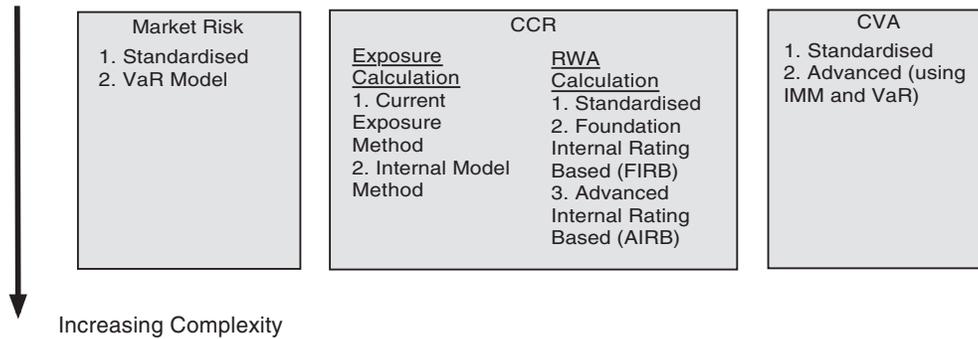### 1.3.6   Regulatory Capital and KVA

Under the Basel III framework (BCBS, 2011b) there are three key contributors to regulatory capital requirements:

- Market risk
- Counterparty Credit Risk (CCR)
- Regulatory CVA.

In addition some transactions will be subject to other capital provisions through *Specific Risk*, *Incremental Risk Charge (IRC)* and *Wrong-way Risk*. The incremental cost of capital due to a new trade is significant and has to be included in the price of a new derivative. This is not a funding cost, however, as there is no requirement to hold collateral or an asset return, rather there is a requirement to hold shareholders' capital against the risk of loss on the derivative portfolio. This capital is not free and shareholders require a return on this capital. Often bank management will state a target return on capital or direct staff within the bank to accept transactions that exceed a minimum return on capital. The Basel framework requires an amount of capital to be held based on the application of the capital rules to the current portfolio, giving a *spot capital requirement*.[9] However, the spot capital requirement is not necessarily a good measure of the expected capital requirement throughout the life of a transaction. An interest rate swap, for example, will be entered at close to zero value but will then diverge away from it, given additional CCR and CVA capital requirements during its lifetime. Hence the cost that

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[9]Note that sometimes this spot capital requirement is referred to in terms of *RWA* or *Risk-Weighted Assets* as this is the regulatory asset value against which the capital must be held. In reality the Basel framework is written partially in terms of RWA and partly in terms of direct capital requirements but RWA is frequently used in finance as a shorthand way of describing all capital requirements.

Market Risk	CCR		CVA
1. Standardised 2. VaR Model	Exposure Calculation 1. Current Exposure Method 2. Internal Model Method	RWA Calculation 1. Standardised 2. Foundation Internal Rating Based (FIRB) 3. Advanced Internal Rating Based (AIRB)	1. Standardised 2. Advanced (using IMM and VaR)

Increasing Complexity

FIGURE 1.1 The different calculation methodologies available for market risk, counterparty credit risk and CVA under the Basel III framework. The more complex methodologies requiring regulatory approval are lower down the figure.

needs to be priced into to new derivatives is the *lifetime cost of capital* which measures the cost of all future capital requirements. Part III discusses approaches to how this lifetime cost of capital can be estimated.

Once we have a measure of the lifetime cost of capital, KVA, then new transactions can be priced in such a way as to achieve the desired minimum profit to achieve the desired return for shareholders. However, this will not remain constant as market moves can lead to higher or lower capital requirements. Both the CCR and CVA terms are driven by the portfolio mark-to-market and so the lifetime cost of capital will have market risk sensitivities in a similar way to CVA and FVA. This leads to the question as to whether or not capital can be managed in a manner similar to CVA and FVA. It certainly can be managed passively through managing the back book of trades through novation and trade cancellation. Counterparties with large trade portfolios between them may find that capital as well as operational costs and risks can be reduced through compression trades that seek to replace a large portfolio with a smaller number of trades with the same risk profile. Active management of the CVA and CCR terms is embedded into Basel III through the capital mitigation that is available from the use of single name and index CDS trades to hedge counterparty risk. In theory trades could be used to hedge the market risk sensitivities of the lifetime cost of capital. Such trades would be in place to generate retained profits at exactly the time additional capital would be needed. In reality, however, these transactions would likely attract additional capital themselves making hedging involve iteration/optimisation rather than simply constructing a trade to offset the risk directly.

One further point to note here is that the amount of capital required depends on the regulatory approvals that the institution has in place. For each of three main contributors to regulatory capital listed above, the calculation method depends on status, with more advanced institutions allowed to use internal modelling subject to appropriate approvals and oversight. The different approaches are illustrated in Figure 1.1.

It should be immediately clear that regulatory capital will not be the same for all market participants because the methodology in use in each institution is different. The cost of capital of each institution will also be different as each will set individual target returns. Even in the absence of book-specific effects, such as netting, the cost of capital embedded in the derivative price can be significantly different between different banks.