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Using Credit Risk Models for Regulatory Capital: Issues and Options

- Regulatory capital standards based on internal credit risk models would allow banks and supervisors to take advantage of the benefits of advanced risk-modeling techniques in setting capital standards for credit risk.
- The internal-model (IM) capital standards for market risk provide a useful prototype for IM capital standards in the credit risk setting.
- Nevertheless, in devising IM capital standards specific to credit risk, banks and supervisors face significant challenges. These challenges involve the further technical development of credit risk models, the collection of better data for model calibration, and the refinement of validation techniques for assessing model accuracy.
- Continued discussion among supervisors, financial institutions, research economists, and others will be key in addressing the conceptual and theoretical issues posed by the creation of a workable regulatory capital system based on banks' internal credit risk models.

In January 1996, the Basel Committee on Banking Supervision adopted a new set of capital requirements to cover the market risk exposures arising from banks' trading activities. These capital requirements were notable because, for the first time, regulatory minimum capital requirements could be based on the output of banks' internal risk measurement models. The market risk capital requirements thus stood in sharp contrast to previous regulatory capital regimes, which were based on broad, uniform regulatory measures of risk exposure. Both supervisors and the banking industry supported the internal-models-based (IM) market risk capital requirement because firm-specific risk estimates seemed likely to lead to capital charges that would more accurately reflect banks' true risk exposures.

That market risk was the first—and so far, only—application of an IM regulatory capital regime is not surprising, given the relatively advanced state of market risk modeling at the time that the regulations were developed. As of the mid-1990s, banks and other financial institutions had devoted considerable resources to developing "value-at-risk" models to measure the potential losses in their trading portfolios. Modeling efforts for other forms of risk were considerably less advanced. Since that time, however, financial institutions have made strides in developing statistical models for other sources of risk, most notably credit risk. Individual banks have developed proprietary models to capture potential credit-related losses from their loan portfolios, and a variety of models are available from consultants and other vendors.

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These developments raise the question of whether banks' internal credit risk models could also be used as the basis of regulatory minimum capital requirements. The Basel Committee on Banking Supervision is in the midst of revising regulatory capital standards and has in fact considered using credit risk models for this purpose. However, in a study released in April 1999 (Basel Committee on Banking Supervision 1999a), the Committee concluded that it was premature to consider the use of credit risk models for regulatory capital, primarily because of difficulties in calibrating and validating these models.

The purpose of this article is to build on this earlier work, by the Basel Committee and others, and to consider the issues that would have to be addressed in developing a regulatory minimum capital standard based on banks' internal credit risk models. In conducting this exercise, we consider how such a capital regime might be structured if the models were sufficiently advanced. This article is *not* intended to be a policy proposal, but rather to serve as a discussion laying out the issues that would have to be addressed in creating a capital framework based on credit risk models. In particular, we draw on the structure of the IM capital charge for market risk and examine how this structure might be applied in the credit risk setting.

As in the market risk setting, the overall objective of an internal-models regulatory capital charge would be to allow banks and supervisors to take advantage of the benefits of advanced risk-modeling techniques in setting capital standards for credit risk. Ideally, the framework should provide supervisors with confidence that the IM capital charges are conceptually sound, empirically valid, and

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reasonably comparable across institutions. At the same time, an IM framework should be flexible enough to accommodate—and perhaps even encourage—further innovation in credit risk measurement. The balance between meeting immediate prudential needs and fostering continuing, fruitful innovation is one of the key themes in the discussion that follows.

The remainder of this article lays out the issues that would be involved in structuring an IM capital regime for credit risk exposures. The next section contains a brief overview of the basic concepts underlying credit risk models. We then describe the basic components of an IM capital framework for credit risk—prudential standards, modeling standards, and validation techniques—and discuss a range of alternative approaches for these standards. At certain points in this discussion, we identify particularly difficult issues that would have to be addressed before an IM framework could be implemented. In such cases, we describe the scope of the issues and their importance, rather than make specific recommendations.

Overview of Credit Risk Models

This section provides a brief overview of credit risk models.[1] The purpose of this discussion is to provide background about the general structure and key features of credit risk models that will help explain the regulatory capital framework described in the next section. For this purpose, we will focus on the concepts that are common to all credit risk models, rather than present a detailed description of specific models. It is also important to note that the models described in this section are those that are usually applied to banks' wholesale and middle-market commercial lending portfolios. The models used for some other types of credits—for example, retail lending such as credit cards, auto loans, and small business loans—generally differ from the models described below.

In very general terms, the purpose of a credit risk model is to estimate the probability distribution of future credit losses on a bank's portfolio. The first step in constructing a credit risk model is therefore to define the concept of loss that the model is intended to capture, as well as the horizon over which the loss is measured. In terms of the definition of loss, models generally fall into one of two categories: models that measure the losses arising solely from defaults ("default mode" models), and models that incorporate gains and losses arising from less extreme changes in credit quality as well as from defaults ("multistate" or "mark-to-market" models). Clearly, the default mode paradigm is a restricted version of the multistate approach, and some models are designed to produce loss estimates based on both definitions of loss.

For both approaches, losses are measured over some future planning horizon. The most common planning horizon used is one year, meaning that the model will estimate changes in portfolio value—either from defaults or from more general changes in credit quality—between the current date and one year in the future. While a one-year horizon is most common

in practice, other choices are also possible, including fixed horizons other than one year and horizons that match the lifetime of the credits in the portfolio.

Once the definition of loss and the planning horizon have been selected, the model generates a distribution—a probability density function (PDF)—of future losses that can be used to calculate the losses associated with any given percentile of the distribution. In practice, banks concentrate on two such loss figures: *expected loss* and *unexpected loss*. Expected loss is the mean of the loss distribution and represents the amount that a bank expects to lose on average on its credit portfolio. Unexpected loss, in contrast, is a measure of the variability in credit losses, or the *credit risk* inherent in the portfolio. Unexpected loss is computed as the losses associated with some high percentile of the loss distribution (for example, the 99.9th percentile) minus expected loss. A high percentile of the distribution is chosen so that the resulting risk estimates will cover all but the most extreme events.

The first step in generating the PDF of future credit losses is to classify the individual credits in the portfolio by their current credit quality. Most frequently, this is done by distributing the credits across the bank's internal credit risk rating system, which provides a picture of the current state of the credit portfolio. Typically, a bank will have an internal rating system that assigns each credit to one of a series of risk categories according to the borrower's probability of default. The next conceptual step is to assess the probability that the positions might migrate to different risk categories—sometimes called "credit quality states"—during the planning horizon. In a default mode model, this process amounts to assessing the probability of default, while in a multistate model, it also incorporates assessing transition probabilities between internal rating categories. The accuracy of both the assignment and the quantification of banks' internal risk ratings is critical, as these ratings and transition probabilities have a very significant effect on the estimation of portfolio credit risk.[2]

The third step in constructing a credit risk model is to estimate the likely exposure of each credit across the range of credit quality states. For whole loans, exposure is simply the face value of the loan and is usually constant across risk categories, but for other positions—such as lines of credit or derivatives—exposure can vary over time and might be correlated with the particular credit quality state. Finally, given the risk category and the exposure in that category, the last element to be determined is the valuation of the position. For default mode models, this valuation is usually accomplished by specifying a loss-given-default (LGD) percentage. This is, essentially, the proportion of the credit's exposure that would be lost if the borrower defaults.[3] For multistate models, this process generally involves revaluing the position using credit spreads that reflect the default risk associated with the particular rating category.

Thus far, the discussion has focused on the treatment of individual positions in a bank's credit portfolio. Generating the PDF of future credit losses requires bringing these individual positions together to capture the behavior of the overall portfolio. From standard portfolio theory, this process essentially requires capturing the correlations between losses associated with individual borrowers. Correlations are vital in assessing risk at the portfolio level since they capture the interaction of losses on individual credits. In general, portfolio risk will be greater the more the individual credits in the portfolio tend to vary in common. In practice, incorporating correlations into a credit risk model involves capturing variances in and correlations between the risk category transition probabilities, credit exposures, and credit valuations.

Nearly all models assume that these variances and correlations are driven by one or more "risk factors" that represent various influences on the credit quality of the borrower (for example, industry, geographic region, or the general state of the economy). In some models, risk factors are economic variables such as interest rates and economic activity indicators, while other models derive default and transition probabilities from equity price data. In still other models, the risk factors are abstract factors that intuitively relate to business cycle conditions but are not tied to specific economic variables. In every case, the assumptions about the statistical process driving these risk factors determine the overall mathematical structure of the model and the shape of the PDF.[4] Thus, assumptions about the distribution of risk factors are a key element in the design of all credit risk models.

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Depending on the assumptions about the mathematical processes driving the risk factors, there are a variety of ways that the final PDF of future credit losses can be generated. In some cases, a specific functional form for the PDF is assumed and the empirical results are calculated analytically. In other cases, Monte Carlo simulation—generally involving simulation of the underlying risk factors that determine default and transition probabilities—is used to provide a numerical PDF. In either case, the final result is a PDF that can be used to derive estimates of the various percentiles of the loss distribution.

Framework for an Internal-Models Capital Charge

This section describes a possible framework for an internal-models regulatory capital charge for credit risk exposures. In developing this framework, we use the IM capital requirements for market risk as a model.[5] As a practical matter, the market risk standards provide a foundation that would be familiar to the many parties involved in developing and implementing any new credit risk standards. On a theoretical level, it also seems reasonable to use the market risk framework as a starting point because, fundamentally, both market and credit risk models have the same goal: to estimate the distribution of gains and losses on a bank's portfolio over some future horizon. The two types of models differ with respect to the underlying risk factors that generate these gains and losses, and these differences lead to significant differences in methodologies, modeling assumptions, and data requirements between the models. Nonetheless, the core similarity between the two types of models suggests that the framework used in the market risk setting can provide a workable beginning for a regulatory capital regime based on internal credit risk models.

Perhaps the most appealing approach would be to base an internal-models regime on a multistate loss concept, *because it takes account of the probability of changes in credit quality as well as the probability of default.*

As noted above, the basis of the market risk requirements is a risk measurement model that estimates the distribution of gains and losses on the bank's portfolio over some future time horizon. The market risk capital charge is based on a certain percentile of this distribution. In particular, the capital charge is based on the 99th percentile loss amount over a ten-day future time horizon. This amount represents the maximum that the bank could lose over a ten-day period with 99 percent probability. Such estimates are often interpreted as measures of the degree of risk inherent in a bank's portfolio, since they reflect the portfolio's potential for future losses.

A regulatory capital requirement for credit risk could be based on the output of credit risk models in a similar fashion. Just as in the market risk setting, the capital charge could be based on a particular percentile of this loss distribution over a given time horizon. These parameters would differ from those used in the market risk capital framework, for reasons that are discussed below. Nonetheless, the basic structure of the framework—a capital requirement based on a statistical estimate of the distribution of future gains and losses on the bank's positions—could be applied to credit risk exposures.

As in the market risk setting, the IM framework for credit risk could have three general components: a set of prudential standards defining the risk estimate to be used in the capital charge, a set of model standards describing the elements that a comprehensive credit risk model would incorporate, and validation techniques that could be used by supervisors and banks to ensure that model estimates are reasonably accurate and comparable across institutions. These three general components could be specified in a variety of ways, and the discussion that follows generally highlights a range of alternatives. The goal of the discussion is to provide a sense of the features that an IM approach to regulatory capital would likely incorporate and to raise issues requiring further analysis and comments.

Prudential Standards

The first component of an IM regulatory capital regime would be a set of prudential standards intended to establish the basic degree of stringency of the capital charge. As such, these standards would be specified by the supervisor to ensure that the regulatory capital requirements provide a suitable degree of prudential coverage and would be the same for all banks subject to the capital charge. Mirroring the basic elements of credit risk measurement models described in the previous section, these prudential standards would include the definition of loss, the planning horizon, and the target loss percentile. Each of these elements is discussed below.

Definition of Loss

As noted, the first step in specifying a credit risk model is to determine the definition of loss and the planning horizon. Similarly, in constructing a minimum capital requirement based on internal models, the first step would be to specify supervisory standards for these concepts. In particular, an IM approach to regulatory capital would need to specify whether the minimum capital requirement would be based on a default mode or multistate loss concept and the horizon over which these losses would be measured.

From a prudential perspective, the two standards are linked, since there is something of a trade-off between the length of the planning horizon and the definition of loss. Specifically, longer planning horizons appear appropriate for the default mode approach since the impact of defaults that occur beyond the end of the planning horizon is ignored. Conversely, somewhat shorter planning horizons may be acceptable in a multistate paradigm because some of the impact of these long-term defaults is captured by credit rating downgrades.

Perhaps the most appealing approach would be to base an internal-models regime on a *multistate loss concept*, because it takes account of the probability of changes in credit quality as well as the probability of default. This approach is appealing because it recognizes economic gains and losses on the credit portfolio and, from a supervisory perspective, it holds the promise of requiring additional capital for credit weaknesses well in advance of their full development as losses. In addition, this approach is consistent with the growing tendency of many of the largest banking institutions to treat credit risk as something that can be traded and hedged in increasingly liquid markets. These considerations suggest that a multistate loss definition would be the soundest basis for a regulatory capital regime based on internal credit risk models.

Nonetheless, this choice would raise some issues that are worth noting. The most significant of these is that many models currently used by banks incorporate a default mode approach, which means that these models would have to be changed—and in some cases, entirely reconstructed—to be eligible for regulatory capital treatment. In addition, default mode models correspond in straightforward ways with the book value accounting used by many financial institutions, while multistate models are more consistent with market-value accounting. Thus, although some evidence suggests that the trend in the industry is moving away from default mode models and toward multistate approaches, the question remains whether a regulatory standard based on a multistate approach would place a significant burden on banks or whether it would merely provide them with the incentive to move more quickly in the direction that they were already going.

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Planning Horizon

As indicated above, the choice of a supervisory planning horizon is very much linked to the definition of loss. We have argued that a multistate loss definition that recognizes changes in credit quality short of default would provide the soundest basis for an IM capital regime for credit risk. Given this choice, we now consider several alternative planning horizons, including a fixed horizon of one year, a fixed horizon of more than one year, and a "lifetime" horizon that would cover the maturity of credits in a bank's portfolio.

At one end of the spectrum, a lifetime horizon would be consistent with the conceptual approach to a traditional banking book in which credits are held to maturity.[6] By looking over the full maturity of positions in the portfolio, the potential for all future losses would be captured by the capital requirement. In that sense, the lifetime assumption can be interpreted as requiring that capital be sufficient to ensure that, with a certain probability, the bank will be able to absorb any and all losses, even if it is unable to raise additional capital or to mitigate its troubled credits.

For this reason, the lifetime horizon would provide a very high degree of comfort that capital would be able to withstand quite significant negative credit events. However, the lifetime horizon approach is at odds with the modeling techniques in current use by most practitioners. In addition, the "buy and hold" portfolio management assumption might be excessively conservative in an environment in which credit risk is increasingly liquid. It seems likely, for instance, that even in stressful market situations, banks would have some ability to manage their loss exposures or to raise additional capital.

An intermediate approach to the loss horizon question might be to use a fixed horizon of several years. Since it can take two to three years (or longer) to work through the effects of a credit cycle, a fixed horizon of more than a year might be appropriate from a prudential perspective. However, few models currently incorporate a horizon of more than one year, so the benefits of increased prudential coverage would have to be weighed against the costs of altering the modeling approach most commonly used by banks.

For a variety of reasons, a *fixed one-year horizon* may represent the most workable balance between prudential concerns and practical considerations about modeling practice. As noted above, the multistate setting reflects the possibility of defaults beyond one year through credit downgrades during the year. Further, a one-year horizon may be sufficient for banks and supervisors to begin to respond to emerging credit problems. Finally, this horizon is consistent with market practice, and is the most commonly used approach in the industry. Thus, adopting a one-year horizon

for regulatory capital purposes would be least disruptive to current modeling practice. This consideration—along with the fact that reasonable theoretical arguments can be constructed for different holding period assumptions—suggests that a one-year standard may be the most pragmatic approach.[7]

Target Loss Percentile

Along with the definition of loss and the planning horizon, the target loss percentile is one of the key prudential parameters of an internal-models-based regulatory capital regime. As in the market risk setting, the capital charge could be calculated based on the level of losses at *a specified percentile of the loss distribution*, minus the expected loss.[8] The specified percentile should be chosen so that, in conjunction with other parameters, the capital charge would provide the level of prudential coverage desired by the supervisory authorities.[9]

A number of considerations would apply in determining the appropriate target loss percentile. First, since the purpose of regulatory capital requirements is to ensure that banks hold sufficient capital to withstand significant losses, it seems reasonable to expect that the target loss percentile would be fairly high. For instance, those banks that use credit risk models for internal capital allocation purposes tend to pick target insolvency rates consistent with senior debt ratings in the mid-to-high investment-grade range. Historical data suggest that annual insolvency rates associated with such bonds are less than 1 percent, implying a target percentile above the 99th.[10] This example suggests that one approach to determining a target percentile is to consider the desired public debt rating for large banking institutions.

While safety concerns may suggest setting a very high target percentile, other considerations offset this incentive to some degree. First, the capital guidelines are meant to be minimum regulatory standards, and banks would almost certainly be expected to hold actual capital amounts higher than these minimums.[11] If this is the case, then it would be desirable to establish regulatory minimum capital requirements that are lower than the internal capital amounts that safe and prudent banks choose to hold.[12] This consideration suggests selecting a somewhat lower percentile of the distribution, perhaps one associated with the minimum public debt rating consistent with a bank's operating in a safe and sound manner.

There may also be practical reasons to consider selecting a somewhat lower target percentile. Foremost among these are validation issues. Since we observe losses associated with these high percentiles very infrequently, selecting a very high percentile as the supervisory standard may exacerbate the already difficult task of model validation. One possibility might be to base the regulatory capital requirement on a less extreme value of the PDF—for instance, the 90th percentile—that could be validated more easily and to adjust this figure upward if there is concern about whether the resulting capital charge was stringent enough. While this approach has certain intuitive appeal, establishing a scaling factor that would accurately translate a lower percentile loss estimate into the higher percentile desired for prudential reasons would require making parametric assumptions about the shape of the tail loss distribution. Given the lack of consensus among practitioners and researchers on this issue, as well as possible variation in the loss distribution across different types of credit portfolios, establishing an appropriate scaling factor could be a difficult task. In addition, there are important questions about whether the ability to validate model estimates would be meaningfully improved even using comparatively low percentiles of the loss distribution.[13]

As an alternative to a regulatory framework based on specific modeling restrictions, conceptual *standards could be developed that would require banks subject to an internal-models capital requirement to develop and use a* comprehensive credit risk model.

Model Standards

Portfolio credit risk models would have to meet certain regulatory standards to be judged by supervisors as sufficiently comprehensive to be used for capital calculations. Given the current rapid state of evolution of these models, these standards should not be highly restrictive. That is, they should not require specific mathematical approaches or the use of particular "approved" models, since at present there is little basis for concluding that one specific approach to credit risk modeling is uniformly better than all others in all situations. Such requirements either would impede future modeling advances or would require frequent revision of regulatory standards to encompass innovations and advances in modeling.

As an alternative to a regulatory framework based on specific modeling restrictions, *conceptual* standards could be

developed that would require banks subject to an internal-models capital requirement to develop and use a *comprehensive credit risk model*. Flexibility could be permitted in how the concepts are incorporated within any given model, subject to a supervisory review and approval process to ensure that the model was sufficiently comprehensive. Supervisors could work with the industry to develop sound-practice guidance, which could be used when assessing banks' models to make certain that models and assumptions fall within an acceptable range. This approach might result in a degree of disparity across banks; however, some disparities may be desirable if they reflect legitimate differences in how individual banks choose to model the risk factors that are most important to their business mix.[14] As long as banking supervisors can verify that a bank's choices are reasonable and that model parameters have a sound empirical basis, conceptual standards could strike a balance between ensuring comparability, on the one hand, and facilitating continued model improvement and innovation, on the other.

The rest of this section considers how modeling standards might address the conceptual elements that characterize comprehensive portfolio credit models as outlined earlier. The discussion covers the key elements of robust credit risk modeling to indicate a potential starting point for regulatory modeling standards. Conceptual standards for comprehensive models would have to cover two major areas: model structure and general data requirements related to parameter estimation and to the way in which portfolio structure is captured within the model.

Standards for Model Structure

Comprehensive credit risk models account for variation in and correlation between losses from individual credits, borrowers, or counterparties. This can be accomplished in a variety of ways, but in general terms it entails accounting for variation due to three key modeling elements: transition probabilities, credit exposures, and asset revaluation. Structural modeling standards would have to address all three areas.

Transition probabilities: In one way or another, comprehensive models incorporate the probability that any given position might have migrated to a different credit quality state at the planning horizon. In a default mode framework, this requires an assessment of the probability of default, while in a multistate framework, the model must capture the probabilities of credits moving from one credit state or risk category to any of the others. At a minimum, standards would require that models used for regulatory capital do this.

However, transitions between credit quality states are correlated to some extent across borrowers. Structural modeling standards would have to address the extent to which models should recognize this fact. A requirement that models incorporate this type of correlation should not pose a significant hurdle for most banks, because few if any models assume that variation in credit quality is independent across borrowers. This is hardly surprising, since a model that made such an assumption would fail to capture one of the most important influences on risk in a credit portfolio. A standard probably would also require that the relevant correlations be based on empirical analysis, although in some cases a more judgmental process might be warranted.

Credit exposures: Uncertainty in credit exposures at the horizon may stem from direct dependence on market prices or rates, such as counterparty credit risk exposures under derivatives contracts. It also may arise for other reasons, as in the case of lines of credit and standby letters of credit that depend on actions of borrowers that are generally beyond a bank's control. Because the size of credit exposures has a first-order effect on measured credit risk—for example, a 20 percent increase in exposure generally leads to a 20 percent increase in the risk estimate—standards for comprehensive models would have to specify an approach to recognizing this uncertainty.

At a minimum, a regulatory standard could require models to recognize that exposures can change, perhaps by making "stress case" assumptions about exposures at the end of the planning horizon. An example of such an approach would be to assume that all credit lines will be completely drawn down, or that derivatives will have exposures equal to some high percentile of their potential future values. In the near term, a realistic and adequate regulatory standard might simply require that models incorporate deterministic changes in exposures according to credit quality states, but a more complete alternative would be to incorporate an element of random variation in exposures.[15]

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For positions that involve derivatives or that otherwise depend to a material extent on market factors, standards likely would require integrated models of market movements and credit exposures. Especially in such cases, banks' credit risk

models should reflect not only the uncertainty in future exposures, but also the potential correlation of exposures across credits. For example, a bank's counterparty exposures from derivatives contracts that are linked to a common market price will certainly be correlated, and this correlation should be captured in exposure estimates. This is an area in which modeling practice is developing rapidly, and fairly rigorous regulatory standards likely would be appropriate.

Asset revaluation: An integral part of any credit risk model is revaluing various credit exposures as they migrate across credit quality states. As noted in the prior section, in multistate models this process of asset valuation consists of revaluing positions according to their credit quality and the general market conditions expected at the end of the planning horizon, generally by using market credit spreads to discount contractual payments.

Standards for comprehensive models should require banks to capture not only the expected change in value as positions migrate across credit quality states, but also the impact of the uncertainty around these changes. Thus, using a market-based but fixed-term structure of credit spreads would be inadequate. Incorporating deterministic changes in credit spreads, perhaps based on the forward spreads implied in the yield curve, is more sophisticated but still does not capture the effects of uncertainty. Thus, modeling standards might require that volatility in market credit spreads and correlations between changes in these spreads be explicitly incorporated into revaluations due to migration across credit quality states.

Default states often are treated separately, with revaluation based on the fraction of the exposure that ultimately will be recovered. Recovery rates vary by facility type, across industries, and across countries. However, they also vary uncertainly with conditions in asset markets, and standards for comprehensive models probably would require banks to incorporate this source of uncertainty.[16] An important question in setting model standards is whether models should be required to capture correlations among recovery rates in addition to variation, and, if so, what sort of standards can reasonably be established to ensure that these correlations are adequately captured.

A comprehensive credit risk model must be based on a rating process that is sound and rigorous and that incorporates all relevant information, both public and proprietary.

Other aspects of correlation: As noted above, cross-credit correlations are important within each of the three dimensions of transition probabilities, exposures, and revaluation. However, there can also be important correlations across these dimensions. For example, the same factors that cause a borrower to transition to an inferior credit quality state might also cause an increase in the draw on a line of credit and a simultaneous decline in the value of collateral assets. In that case, all three dimensions of credit uncertainty are correlated.

Capturing these types of correlations is an area in which credit risk models have made limited progress. To date, most credit risk models assume that most of these correlations are zero. Model developers sometimes assert that such assumptions are appropriate because the correlations either are relatively unimportant or are impractical to model. Further exploration of such assertions would be necessary to ensure that these assumptions are reasonable. Standards for comprehensive models could require banks to either estimate and incorporate the relevant correlations or demonstrate convincingly that they are not material. This would likely present a significant hurdle, given the current state of model development.

Thus far, this section has outlined a qualitative standard requiring a model to capture correlations both within and across each of the three dimensions of transition probabilities, exposures, and revaluation. As noted earlier, nearly all models assume that these correlations are driven by one or more risk factors that represent various influences on the credit quality of the borrower. The assumptions about the statistical process driving these risk factors determine the overall mathematical structure of the model and the ultimate shape of the PDF. As such, a comprehensive models standard would need to address the underlying distribution of these risk factors.

Although it might be desirable to develop a specific standard for the distribution of the risk factors, differences in model structure again make it difficult to establish minimum requirements that would be broadly applicable. Given the importance of these embedded assumptions, the development of such standards may be one of the most important hurdles that banks and supervisors will need to clear before an IM approach for credit risk could be implemented. At a minimum, as an alternative, supervisors would need to address the calibration and statistical process driving these risk factors in sound-practice guidance.

Standards for Data and Estimation

Data requirements may pose some of the most significant implementation hurdles for an IM capital adequacy regime.[17]

Two major categories of data are required for models-based capital calculations. First, the credit portfolio must be characterized in some consistent way, appropriate to the model being used. That is, the portfolio structure must be captured. Second, any model relies on certain parameter estimates, typically computed from empirical observations, corresponding to the conceptual dimensions described above. These parameter estimates tailor the more general conceptual model of credit risk to the specific operating environment of a bank. This section discusses some general issues related to data, for both portfolio structure and parameter estimation, and the types of regulatory standards that might be appropriate for this aspect of credit risk modeling.

Portfolio structure: In a comprehensive credit risk model, the two most important aspects related to portfolio structure are that the portfolio be appropriately segregated by credit quality and that all material exposures be accounted for. The nearly universal approach within the industry for characterizing credit quality is to assign each exposure a numerical rating along a continuum of risk grades that divides the exposures into various categories according to credit risk. A number of different approaches are used in practice, based on some combination of external agency ratings, market and financial statement data, and other information. In marked contrast to market risk models, banks use internal analysis and private, proprietary information on relevant borrower and counterparty characteristics to determine how exposures are included in credit risk models. Sound practices in the area of internal credit risk rating have been evolving rapidly. Whatever approach a bank uses, the overall quality of the credit risk modeling effort depends heavily on the quality of the rating process. Thus, a comprehensive credit risk model must be based on a rating process that is sound and rigorous and that incorporates all relevant information, both public and proprietary. Standards in this area are the subject of ongoing efforts by regulatory and industry groups.

Aside from being based on a rigorous credit rating system, a comprehensive credit risk model must capture all material credit exposures and incorporate them appropriately in the calculations. This process would start with identifying which positions within a bank's portfolio were subject to the credit risk capital charges. The current regulatory capital structure separates positions into those subject to market risk capital standards and those subject to credit risk standards, primarily on the basis of whether a position is held inside or outside of a bank's trading account. Thus, a clear delineation between the banking and trading books would be necessary to prevent "regulatory arbitrage" intended to minimize regulatory capital requirements by inappropriately shifting positions across books. Of course, such incentives exist even in the absence of an IM approach to credit risk, and supervisors have developed guidance to govern the treatment of various types of positions. To the extent that the incentives to engage in such regulatory arbitrage are heightened under an IM regime, supervisors could refine this guidance to ensure that it limits the opportunity for banks to shift positions solely to benefit from reduced capital requirements.

Once the positions subject to the credit risk capital requirements have been identified, regulatory standards would require institutions to demonstrate that their information systems consolidate credit exposure data globally, with any omissions immaterial to the overall credit risk profile of the institution. For completeness, the structural data would have to capture the flow of new credits into each rating category, the elimination of any retiring credits, and the migration of existing credits into other rating categories. That is, initial ratings should be updated periodically to reflect the current financial condition of borrowers or counterparties. In addition, the model should aggregate all material exposures for each borrower, so that a consolidated exposure estimate is produced.

Banks would be expected to explain and justify estimation methods to bank supervisors and to provide sufficient support—such as literature citations, technical documents, and access to developers—to make possible a rigorous assessment of the parameter estimation methodology.

Parameter estimates: Parameter estimation gives rise to some of the most significant data issues in constructing a comprehensive credit risk model. Estimation techniques often are unique to a particular model, so again the standards must be conceptual rather than specific. However, banks would be expected to explain and justify estimation methods to bank supervisors and to provide sufficient support—such as literature citations, technical documents, and access to developers—to make possible a rigorous assessment of the parameter estimation methodology.

Data sources vary by type of parameter. Data on transition probabilities may come from a bank's own credit migration experience. In contrast, parameters that reflect state values and their variations generally are based on market credit

spread data, estimated from historically realized values on asset sales for certain types of assets, or based on recovery rates for assets in default. Whatever the specific data used to calibrate the parameters, regulatory standards likely would reflect three general principles. First, the data should be drawn from a historical period that reflects a wide range of potential variation in factors related to credit quality, thereby providing adequate *historical coverage*. Second, the data should be *applicable to the specific business mix* of the bank. Third, the data should reflect consistent *definitions of default* or of relevant credit-state transitions.

With regard to historical coverage, a comprehensive approach would require that the data, in combination with the model structure, be sufficient to reflect credit cycle effects. To achieve that, regulatory standards likely would require a historical window that encompasses a period sufficiently long to capture defaults and downgrades that were at various times both high and low by historical standards. Specific requirements may vary depending on the asset type, geographic region, or product market in question, since different products and markets experience cycles at different times and with different frequencies, but an adequate window would almost always span many years.

The supervisory validation process can be viewed as comprising the following two elements. The first is the development of sound-practice guidance for the structure and implementation of credit risk management models. . . . The second element . . . is the use of quantitative testing to detect systematic biases in model results.

With regard to bank-specific applicability, regulators probably would expect a bank to be able to demonstrate that the data used to estimate model parameters are appropriate for the current composition of its portfolio. For example, data from U.S. corporations might not be appropriate for use in models that cover exposures to European or Latin American borrowers. Similarly, transition probabilities or state-valuation estimates based on national level data might be inappropriate for institutions with loan portfolios that contain highly specific regional or industrial concentrations.

At least in the near term, banks and supervisors are likely to face a trade-off between the dual requirements of data applicability and coverage of the historical window. Using a bank's own internal data generally solves the applicability problem, as long as any significant historical changes in the bank's business profile are addressed and provided the bank has experienced a sufficient number of defaults and losses to produce reasonably accurate parameter estimates. However, at present it appears that few banks can construct an adequate data history based on internal data. Alternatively, banks could use vendor-provided or public data—for example, data from publicly traded bonds—or pooled data from a group of peer institutions to estimate parameters. Since historical data of this type are more readily available, issues related to sample period and coverage of the credit cycle can be addressed more easily, but demonstrating that the results are applicable to a specific bank's business mix becomes more difficult.

Finally, parameter estimates should be based on common definitions of default or, in a multistate framework, common definitions of credit-state transitions. Inconsistency in the data used could lead to highly erroneous estimates. It may be particularly important to ensure that the data used for default probabilities and associated losses-given-default reflect consistent definitions. For example, if default probabilities calculated from publicly traded bond data were combined with loss-given-default figures from internal bank data on nonaccrual loans, the resulting estimates of risk could be seriously understated, owing to the less severe credit events defined as "default" in the internal data. This type of definitional issue also may be especially problematic when data are drawn from multiple bankruptcy regimes, as is generally the case for international data.

Validation

The third component of an IM capital regime concerns supervisory model validation, that is, the process of ensuring that the model is implemented in a rigorous way.[18] As in the discussion of the structure of an IM capital regime for credit risk, it is useful to begin this discussion by recalling the validation approaches applied in the market risk setting. The market risk validation approach relies on a combination of qualitative standards and statistical testing. The qualitative standards address the internal controls and procedures surrounding the design and operation of the models used for regulatory capital purposes, focusing on issues such as the need for an independent risk management function, regular risk reporting to senior management, and periodic independent audits of the model. In addition to the qualitative standards, supervisory validation also

involves statistical testing of the output of the market risk measurement models, or so-called back-testing. Back-testing is a way of assessing the accuracy of a model's estimate of the target percentile of the loss distribution—the 99th percentile in the case of the market risk capital charge—through a comparison of the actual gains and losses on the trading portfolio with the risk estimates supplied by the model.

Against this background, the supervisory validation process can be viewed as comprising the following two elements. The first is the development of sound-practice guidance for the structure and implementation of credit risk management models. This guidance would consist of a largely qualitative description of the current state of the practice in credit risk measurement, covering both technical aspects of model design and estimation and qualitative standards for the risk management environment. The technical aspects of model design would cover the elements of a comprehensive credit risk model, as indicated above, while the qualitative standards would focus on the policies and procedures used by the bank in its risk management activities. A key element among these policies and procedures would be a "use test" to ensure that any model used for regulatory capital purposes is in fact an integral part of the bank's risk management structure.

The second element of the supervisory validation process is the use of quantitative testing to detect systematic biases in model results. Unlike in the market risk setting, formal back-testing of credit risk model results is not feasible because of the length of a typical credit cycle and the resultant limited number of independent observations of actual outcomes.[19] As a result, model validation in the credit risk setting will likely have to draw on a combination of tests, at least until more internal data become available and more robust statistical methodologies are developed. These tests could consist of both work that banks have done internally as part of model design and upkeep (for example, sensitivity tests of key parameters) and supervisory tests intended to identify systematic differences across banks in model outputs (for example, "test portfolio" exercises). Finally, public disclosures about model design, estimation, and output are another way to bring scrutiny to the models used by banks for capital purposes. All of these elements together are intended to provide both supervisors and the banks themselves assurance that any model used for regulatory capital purposes is theoretically sound and properly implemented.

Sound-Practice Guidance

The purpose of sound-practice guidance would be to describe in more detail the various elements that supervisors would consider when evaluating internal models used for regulatory minimum capital calculations. In some cases, guidance would describe standards that any model should meet to be considered accurate. In other cases, guidance would serve to reflect the range of practice found at banks with more advanced approaches to modeling. Guidance on sound practices would be dynamic and change over time to reflect the then-current state of the practice in credit risk modeling, providing both supervisors and banks with a benchmark against which to assess a particular model's structure and implementation. In particular, since credit models will almost inevitably incorporate a certain degree of management judgment—for instance, simplifying assumptions about correlations or other parameters, the use of less-than-perfect data to calibrate model parameters, or assumptions about the distribution of aggregate losses—the guidance could provide a way of assessing these assumptions against the range of current practice.

The experience gained by both banks and supervisors in implementing the revised Basel Accord has the potential to provide important insight into the development of qualitative standards and for validation more generally.

Within the supervisory process, there is growing emphasis on qualitative reviews of banks' methods for measuring, managing, and controlling their risk exposure and the implications for capital adequacy.[20] A key part of any sound-practice guidance would be qualitative standards for the risk management environment. Supervisors have developed significant experience using qualitative sound practice standards to assess banks' risk management processes in the context of market risk. Finally, the upcoming revisions to the Basel Accord will likely incorporate a greater reliance on banks' internal risk rating systems in assessing regulatory minimum capital requirements. The experience gained by both banks and supervisors in implementing the revised Basel Accord has the potential to provide important insight into the development of qualitative standards and for validation more generally.

Building on the precedent of the market risk amendment to the Basel Accord, banks' use of portfolio credit models for regulatory capital purposes would be contingent upon their meeting a series of qualitative standards aimed at ensuring that

the models used are sound and implemented with integrity. Qualitative standards aimed at aligning banks' risk management techniques with supervisory safety and soundness objectives could include:

- compliance with a documented set of internal policies, controls, and procedures concerning the operation of the credit risk measurement system
- an independent risk control unit responsible for the design and implementation of the bank's credit risk model
- a regular independent review of the credit risk model as part of the bank's own internal auditing process, either by internal or by external auditors.

Finally, the qualitative guidelines should incorporate a "use test" to ensure that any model used for regulatory capital is closely integrated with the ongoing credit risk management process of the bank. In particular, the model's output should be an integral part of the process of planning, monitoring, and controlling the bank's credit risk profile. For instance, the model might be used in conjunction with internal credit exposure limits, capital and portfolio allocation decisions, or pricing. All of these uses suggest that a bank would have significant incentives to invest sufficient resources in model development and maintenance to ensure that the model is producing reliable risk estimates. Just as in the IM approach for market risk, where a use test is one of the key elements of the qualitative guidelines, such tests could help to provide discipline in the credit risk setting.

Quantitative Testing

Aside from ensuring that a model meets sound-practice standards, supervisory validation could include empirical testing of the model's inputs and results. Given the shortcomings of formal back-testing of model results, quantitative testing in the credit risk setting is likely to rest on independent review of model parameters such as expected default probabilities, loss given default, and exposure estimates; sensitivity analysis of key parameter estimates; stress testing of model results; and test portfolio exercises intended to identify possible systematic biases in model outcomes across banks.[21]

These elements provide a possible roadmap for quantitative testing for model validation, but considerable work would be required to implement these ideas in an effective way. With the exception of the test portfolio exercises, this quantitative testing would most likely build on the work done by the banks themselves as part of their internal-model development and maintenance procedures. That is, the first step in a supervisory review of a bank's credit risk model should be the review of the bank's own work papers documenting the tests done by the model builders and by the bank's internal or external auditors to calibrate and test the model.

To support this process, supervisors could develop sound-practice guidance on the types of tests that banks would be expected to perform as part of developing and maintaining their credit risk models. For instance, testing could include sensitivity analysis—that is, analysis of the sensitivity of the model results to changes in parameters and key assumptions. Sensitivity analysis allows management to probe the vulnerabilities in a model that arise from its structure, use of a particular type of statistical technique, or limitations in terms of historical observations. This analysis might include demonstrating the impact on the model's output and resulting capital charge from changes in recovery rates, correlations, and credit spreads. In all cases, banks would likely be expected to maintain adequate documentation to permit a rigorous review of model development and testing.

This list is not intended to be exhaustive, because these tests would by neccessity be somewhat model-specific. However, there are likely to be a general range of parameters and assumptions that banks could be expected to examine. Where the analysis indicates that particular parameters and assumptions have a significant impact on the model results, the sensitivity analysis should yield a thorough understanding of the impact of changes.

While stress testing is far from a perfect validation tool, it can provide important information about the impact of unlikely but potentially damaging events that could result in very large losses in a bank's credit portfolio.

Another important benchmark against which supervisors can assess the reasonableness of a bank's modeled capital requirement is stress testing. Stress testing is an important element of the modeling and risk management process that can help ensure that potentially large portfolio losses are not hidden by overly optimistic or simplistic assumptions. While stress testing is far from a perfect validation tool, it can provide important information about the impact of unlikely but potentially damaging events that could result in very large losses in a bank's credit portfolio.

The key, of course, is identifying a meaningful range of stress scenarios and accurately assessing their likely impact on the

credit portfolio.[22] These stress scenarios could involve actual historical events; simulated increases or decreases in the model's transition probabilities, volatilities, or correlations; or a widespread deterioration in credit quality. As challenging as identifying meaningful stress scenarios might be, the lack of historical data and the inability to back-test model results make stress testing an important and independent indicator supervisors can use for gauging the reliability of the modeling process and the appropriateness of the resulting capital charge. As such, it is an important tool in the arsenal for the evaluation of credit risk models.

Beyond the testing done by the bank, supervisors may want additional verification that the model output is reasonable. However, the absence of back-testing requires that supervisors rely on other tools to help them evaluate the output of a bank's credit risk measurement model and to serve as a foundation for dialogue and discussion with the bank. Possible tools include supervisory stress tests, the use of test portfolios, and supervisory use of vendor-provided models.

Public Disclosure of Model Specifications

Another approach to model validation, somewhat different from the supervisory processes described above but possibly complementary to them, would be to require all banks using internal models for regulatory capital purposes to disclose publicly full documentation of the model's mathematical structure, key assumptions, and parameter estimates.[23] The purpose of such disclosure would be to expose the bank's model to the discipline of public scrutiny. This scrutiny could aid the supervisory validation process by providing independent assessments of a bank's model by market practitioners and interested academics. In addition, it could improve modeling practices for the industry as a whole by ensuring that the latest modeling innovations were quickly disseminated to all practitioners.

While the benefits of such disclosure could be substantial, they would depend on the ability of supervisors and banking institutions to establish a workable disclosure framework. In principle, this could be accomplished through regulatory disclosure requirements, though these could be difficult to define in view of the wide variety of models and the continuing rapid evolution in industry practice. Alternatively, disclosures could be assessed through the supervisory review process to ensure that key elements of model structure and design were being accurately portrayed. The benefits of public disclosure would also have to be weighed against their potential costs, including the possibility that mandatory disclosure would undercut banks' incentives to develop new and innovative modeling practices, since they would have to share the benefits of any innovations with their competitors.

Summary and Conclusions

In this article, we have attempted to lay out the issues that would have to be addressed in creating a regulatory minimum capital requirement based on the output of banks' internal credit risk models. Using the current market risk capital requirements as a guide, we identified three basic components of an IM credit risk capital charge: prudential standards defining the risk measure to be used in the requirement, modeling standards describing the essential components of a comprehensive credit risk model, and validation standards governing the techniques used by banks and by supervisors to ensure that the models are conceptually sound and reasonably accurate. An important consideration in specifying standards in these three areas would be to balance the desire for flexibility and innovation in modeling practice, on the one hand, with the need to ensure that the capital charge is conceptually sound, empirically accurate, and reasonably comparable across banks, on the other.

This article is not intended to be a policy proposal. Instead, our goal is to stimulate discussion among financial institutions, supervisors, and other interested parties about the many practical and conceptual issues that would be involved in structuring a workable IM regulatory capital regime for credit risk. The Basel Committee is in the process of revising regulatory capital standards, and a key factor in considering any IM regulatory capital regime will be the experience of both supervisors and financial institutions with these new, more risk-sensitive standards. For these reasons, the discussion above should be interpreted as an initial step in trying to establish some general principles that could guide the ultimate formation of an IM approach to regulatory capital rather than any kind of definitive statement of what such an approach would look like.

As our discussion suggests, the challenges in developing an IM framework would be significant, both for banks and for supervisors. These challenges involve the further technical development of the credit risk models used by financial institutions, the accumulation of improved data sources for model calibration, and the refinement of procedures used by banks and supervisors to validate the accuracy of the models' risk estimates. In addition, a variety of detailed implementation issues would have to be worked out (see the appendix for a discussion of these points). Our hope is that this article will represent a constructive step in identifying the most important of these many issues and in helping to determine the feasibility of an IM approach for credit risk.

Appendix: Practical Implementation Issues

A number of issues not discussed in this article would have to be addressed before an internal-models-based (IM) approach to regulatory capital for credit risk could be implemented. These issues include:

- *Loan loss reserves and expected loss*: A capital charge based on unexpected losses raises important issues concerning the role and definition of loan loss reserves. Recall that unexpected losses equal losses at the target percentile minus expected losses. Therefore, if loan loss reserves fall short of expected losses, the total resources available to absorb losses—reserves plus capital—will not be sufficient to provide protection at the desired soundness standard. Unfortunately, there is no necessary correspondence between the accounting definition of loan loss reserves and the concept of expected losses from a credit risk measurement model. Thus, over the longer run, basing a regulatory capital charge on unexpected losses may require a rethinking of the treatment of loan loss reserves.
- *Eligible institutions*: The set of institutions subject to an IM capital requirement will most likely be defined by the minimum standards that are developed. Initially, only a small set of banks would likely have models that were sufficiently well-developed; many banks currently employ default mode models and few, if any, fully capture the correlation between risk drivers such as the potential correlation between defaults and recovery rates. Over time, however, the set of institutions with comprehensive credit risk models is likely to grow as modeling expertise disseminates through the industry, as data sources become more readily available, and as the competitive incentives for institutions to manage their credit risk exposures in a more active way intensify.
- *Scope of application*: An important issue is whether an IM capital requirement could be designed to cover all of a bank's credit exposures, or only those in selected portfolios (for instance, large commercial loans). The models discussed in this article are applied primarily to commercial lending portfolios, while other portfolios—such as retail lending—are either covered by models whose structures are very different or, occasionally, not covered at all. In this situation, it might make sense to allow banks to apply an IM capital requirement only to those portfolios covered by comprehensive credit risk models of the type described here and to use a non-models-based regulatory capital requirement for other portfolios. However, "cherry picking," or selective adoption, is a clear concern if banks are allowed to use internal models to determine capital charges for some, but not all, of their exposures. That is, a bank may have an incentive to model only those portions of its portfolio in which capital charges are reduced.
- *Scaling factor*: The IM capital requirement for market risk incorporates a multiplicative scaling factor that is intended to translate value-at-risk estimates into an appropriate minimum capital requirement, reflecting considerations both about the accuracy of a bank's value-at-risk model and about prudent capital coverage. There could be a similar role for a scaling factor in an IM credit risk capital regime. For instance, given shortcomings in data availability, uncertainty surrounding the calibration of credit risk model parameters (so-called model uncertainty) is a significant concern in using these models for regulatory capital purposes. More generally, supervisors and banks lack long-term experience with credit risk models, a fact that creates uncertainty about how the models will perform over future credit cycles and during times of financial market distress. These concerns could be addressed—albeit roughly—by scaling up the raw loss figures reported by the banks. In this instance, a scaling factor might be incorporated when an IM approach is initially implemented, and then revisited as both supervisors and banks gain experience with the IM regime.
- *Frequency of capital calculations*: Prudential standards would have to specify how frequently banks would be required to run their credit risk models and report the results to supervisors. Unlike value-at-risk models, which are run on a daily basis to assess the market risk in banks' trading activities, credit risk models are run less frequently. Monthly runs of the model—where a "run" of the model means a new estimate of the PDF of future losses incorporating changes in portfolio composition, credit ratings, market prices, and parameter updates, where warranted—seem a reasonable minimum standard in the near term, though over the longer run, banks would probably be expected to develop the capability to generate fresh model estimates on an even more frequent basis (perhaps weekly or biweekly).

  Given frequent model results, capital could be based on the average of monthly or weekly estimates during the quarter. Using an average should mitigate banks' incentives to window dress, as might be the case if the capital charge were based on model outputs as of a single point in time, such as quarter-end. In addition, averaging should smooth short-run volatility in the model

estimates and ensure that the capital requirement is not overly sensitive to short-term anomalies in credit markets.

- *Parameter updates*: A bank using an internal model for credit risk capital would also be required to update the model's inputs and parameters with some minimum frequency. There are obvious trade-offs between accuracy of risk assessment and reporting burden: more frequent updating gives regulators and banks more confidence in the model results, but may impose a greater burden on the banks. Different updating schedules may be reasonable for different types of parameters and different data sources. For instance, many models use market-based credit spreads to revalue credit exposures. These spreads should be updated frequently, probably more frequently than the full model is reestimated, to account for the potentially significant variation of spreads over relatively short periods. In contrast, state-value estimates based on recovery rates or on market prices from asset sales could be updated less frequently, as could transition probabilities and correlations, although additional work would be desirable to confirm the optimal timing. Portfolio structure data should be updated at least as often as the material is run.

Endnotes

1. This section draws heavily on a recent Federal Reserve study of the structure and implementation of credit risk models at large U.S. banking institution (Board of Governors of the Federal Reserve System 1998b). For interested readers, this paper contains an in-depth discussion of credit risk modeling issues.

2. A discussion of internal risk rating systems is beyond the scope of this article. However, since sound-practice standards and guidelines for internal rating systems are under active consideration as part of the Basel Committee's efforts to revise capital standards, regulators' expectations regarding such rating systems will become known as part of that process. For further discussion regarding internal rating system standards, see Board of Governors of the Federal Reserve System (1998a). In addition, for information on the range of internal rating practices among international banks, see Treacy and Carey (1998) and Basel Committee on Banking Supervision (2000).

3. The LGD, sometimes also referred to as the loss in event of default, is equal to 1 minus the recovery rate on the defaulted loan.

4. See, for example, Gordy (2000a).

5. See Basel Committee on Banking Supervision (1996) and Hendricks and Hirtle (1997) for a full description and discussion of the market risk capital requirements.

6. It is interesting to note that under a lifetime horizon, there is no distinction between the multistate and default-mode loss definitions since credits will either default or mature over their lifetimes; intermediate upgrades and downgrades short of default have no impact on the value of credits at the horizon.

7. One concern that arises in specifying a given planning horizon for regulatory capital purposes is that this choice may impede supervisors from urging banks to use different planning horizons for internal purposes if market best practice evolves over time. In the market risk setting, this concern is addressed through a simple scaling approach, where capital requirements based on a ten-day standard may be calculated with scaled risk estimates based on the one-day horizon that is typical for most value-at-risk models. However, the nature of the processes underlying credit risk is sufficiently different that this approach may not be acceptable. For credit risk, it may be more appropriate for supervisors to address such issues through the review of banks' internal capital allocation methodologies (see Board of Governors of the Federal Reserve System [1999]). Another alternative would be to allow each bank to use a bank-specific planning horizon—or even a bank-specific loss definition/planning horizon/target loss percentile combination—but this approach would introduce very significant problems in establishing a consistent minimum regulatory capital requirement across banks.

8. Subtracting the expected loss from the specified loss percentile reflects the concept that capital is used primarily to cover unexpected losses. Regulatory standards would have to ensure that expected losses were covered in other ways, such as through loan loss reserves or through credit spreads on the pricing of credit extensions. See the appendix for a more detailed discussion.

9. As an alternative to value at risk, some have suggested that using the "expected tail loss"—that is, the expected loss given that the loss is greater than the target percentile—as a measure of risk. See, for instance, Gordy (2000b).

10. For instance, the historical insolvency rate on AA-rated bonds is about 0.03 percent, implying that a target percentile of 99.97 would be required to provide that degree of coverage. A 99.97th target percentile would mean that unexpected losses would exceed capital only 0.03 percent of the time.

11. See Estrella (1995) and Basel Committee on Banking Supervision (1999b) for a discussion of the role of minimum capital requirements in regulation and supervision.

12. Establishing higher regulatory capital requirements than banks themselves would select on safety and soundness grounds would imply that supervisors were having an inappropriate impact on banks' business decisions. Under the current capital standard, this phenomenon sometimes encourages banks to securitize assets when regulatory capital requirements exceed what the market demands.

13. For instance, even using a 90th percentile figure, we would expect to see losses exceeding this level only once every ten years. Further, validation procedures that examine the entire tail of the distribution—rather than a single point at a given percentile—may prove more powerful in identifying models that fail to capture extreme loss behavior. In that event, the ability to validate models would depend much less on the particular percentile chosen to form the basis of the capital requirement.

14. A study by the Institute of International Finance, Inc., and the International Swaps and Derivatives Association (2000) highlights not only some of the differences that can result from banks' different

modeling choices, but also differences that arise from the calibration and implementation of models that are otherwise similar.

15. Asarnow and Marker (1995) present an empirical study of the relationship between the use of lines of credit in the event of default and borrower credit quality.

16. Frye (2000) highlights the challenges and potential importance of incorporating recovery rate uncertainty.

17. See Basel Committee on Banking Supervision (1999a) for a full discussion of these hurdles.

18. This section focuses on validation of portfolio credit models. Critical validation issues also arise with regard to the mappings of individual credits into a given institution's internal credit grades. As indicated above, both banks and supervisors have been devoting significant attention to this process in recent years, and considerable progress has been made in addressing some of the key issues. See, for instance, Basel Committee on Banking Supervision (2000) and Board of Governors of the Federal Reserve System (1998a).

19. Lopez and Saidenberg (2000) discuss some of the challenges and limitations of back-testing credit risk models.

20. See Board of Governors of the Federal Reserve System (1999) for a discussion of banks' internal capital allocation procedures and Basel Committee on Banking Supervision (1999b) for a discussion of internal capital as "pillar two" of the proposed revisions to the Basel Accord.

21. In a test portfolio exercise, supervisors construct one or more standard portfolios, which may be composed of actual or hypothetical credit positions, and each bank is asked to produce risk estimates for these portfolios using its internal model. The resulting figures are then compared across institutions to generate a sense of the range of model outcomes and potentially to identify "outliers" whose risk estimates fall outside the typical range.

22. Berkowitz (2000) discusses the challenges of establishing a comprehensive approach to stress testing.

23. Basel Committee on Banking Supervision (1999b) and Estrella (1995), among others, outline the importance of disclosure and market discipline as components of banking regulation and supervision.

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