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Sabrina Kiszka*, Jessica Hastenteufel**

Climate protection as an opportunity for banks to increase earnings and consumer trust

1. Introductory overview

Climate change is one of the most pressing topics in society and the resulting sustainability risks pose great challenges for the financial sector (BaFin 2018; Waschbusch et al. 2020a, 406). The term 'sustainability' in general includes three dimensions: 'economic sustainability', 'environmental sustainability' and 'social sustainability' (Rauschenberger 2002, 6; Hesse 2008, 5; Hauff 2014, 12–13 and 164; Stoffel 2014, 49; Bauer, Stegmaier 2016, 7–8; Schuster, Hastenteufel 2019, 112; Waschbusch et al. 2020b, 616). These so-called three pillars of sustainability are given equal consideration and are therefore equally important for firms (see Figure 1).

Therefore, sustainability risks are defined as events or conditions in the fields of environment, social affairs, or corporate governance, the occurrence of which can actually or potentially have negative effects on asset, financial and earnings positions as well as on a company´s reputation (BaFin 2020, 13). However, primarily climate and environmental risks are associated with this risk category (Röseler 2019, 22; Waschbusch et al. 2020b, 618). Environmental sustainability risks can be roughly divided into physical and transitory risks. While physical

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risks arise from individual weather phenomena with increasing frequency (e.g. periods of heat and drought, floods or storms) and long-term changes in climatic conditions (e.g. rise in sea level), the transitory risks result from the conversion to a low-carbon economy and the associated changing political frameworks as well as the stigmatization of established technologies (Jaeggi et al. 2016, 451; Roettmer 2016, 244; Bank of England 2018, 7 and 17–20; Röseler 2019, 22; BaFin 2020, 14; Waschbusch et al. 2020b, 618). Thus, the effects of climate change can have both, a direct impact and indirect consequences for the risk universe of financial institutions, as illustrated in Table 1.

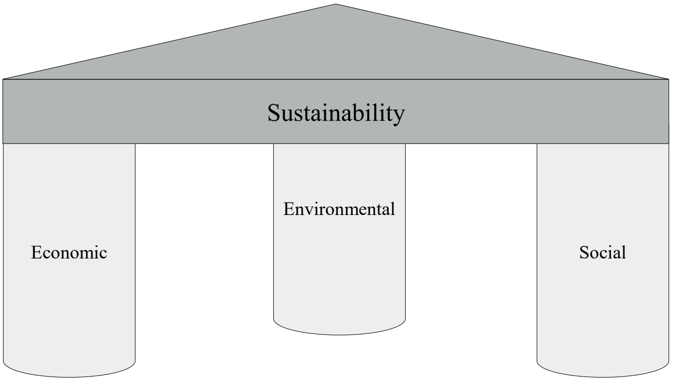

Figure 1. The three pillars of sustainability (Hauff 2014, 164)

Consequently, sustainability risks not only have an impact on credit risk, market risk, operational risk and on the liquidity risk of banks, but also have a significant influence on their reputational risk (Bank of England 2018, 17–19 and 22–25; Carney 2018, 2; Beau 2019, 3; Hannemann et al. 2019, 1230; BaFin 2020, 11–15; Waschbusch et al. 2020b, 619). Reputational risk is defined as the risk that the trust in a company and its credibility are damaged due to a certain internal and external perception (Kiszka 2018, 27–29; Weber, Bopp 2019, B9). In this context, the change in the values of society is a key factor. Therefore, ecological, social, and societal issues are becoming more important when regarding the expectations of bank customers (Bopp 2010, 269; Barthruff 2014, 145; Schuster, Hastenteufel 2019, 119; Weber, Bopp 2019, B9). Firms that do not match these new ethical standards are experiencing an increasing loss of acceptance or are even sanctioned by their customers (Blume 2018; Weber, Bopp 2019, B9).

Table 1

Effects of sustainability risks on the risk universe of banks (Röseler 2019, 23; Waschbusch et al. 2020b, 619)

	credit risk	**market risk**	**operational risk**
physical risk	• reassessment of the debt servicing capacity of borrowers as well as of the collateral provided • rating downgrade	• rating downgrades and asset price losses following catastrophes and due to declines in productivity	• physical damage affects balance sheet; impairment of availability of bank services
transitory risk	• risk shifting • effects on probability of default and losses in the event of default	• sudden extreme price fluctuations for assets; stranded assets • long-term price increases due to environmental and social changes	• reputational damage due to failure to switch to sustainable business practices
risk to financial stability	• affecting entire industries and markets • economy is no longer insurable at reasonable cost	• market-threatening effects due to climate and environmental damage in an entire region	• reputational damage for entire industries or entire markets • collapse of large parts of the financial infrastructure of a country or region
→ the aforementioned risks can be linked to or trigger liquidity risks			

Therefore, based on a study conducted by the authors in Germany this paper examines the expectations bank customers have on how banks deal with the topic of climate protection. As part of this study 1,500 paper questionnaires were given to private individuals. During the distribution of the questionnaires care was taken to ensure that the data are roughly evenly distributed in regard to age and gender. 703 of the received questionnaires were eligible for inclusion in the evaluation.

First it needs to be analysed how customers perceive the importance of banks when it comes to climate protection. Then the perception of climate change by bank customers as well as the willingness of the customers to change their own behaviour to prevent climate change is examined in order to derive the customers' expectations of their banks in general and the advisory services offered in particular. Based on this knowledge some recommendations for the banking industry are made in order to convert the changed value system within society into a long-term opportunity for banks.

2. The key role of banks in combating climate change

While manufacturing companies can contribute to combating climate change through a sustainable design of the supply chain, production or the use of raw materials in their firms, financial institutions have different options to act sustainably. Through their investment and financing activities, they highly influence companies, organizations and entire countries with regard to the implementation of their respective sustainable goals. Due to the potential of this immense cash flow, banks play a key role in creating a sustainable economy (Frese, Colsman 2018, 12). Therefore, the EU action plan for financing sustainable growth and various national guidelines hold financial market players responsible for archiving this goal (Weber, Bopp 2019, B9). Hence, financial institutions must not only behave sustainably and responsibly themselves but must also ensure that sufficient capital is channelled into sustainable investments. To examine whether bank customers are aware of this role of the financial industry, they were asked to what extent different institutions contribute to climate protection (see Figure 2).

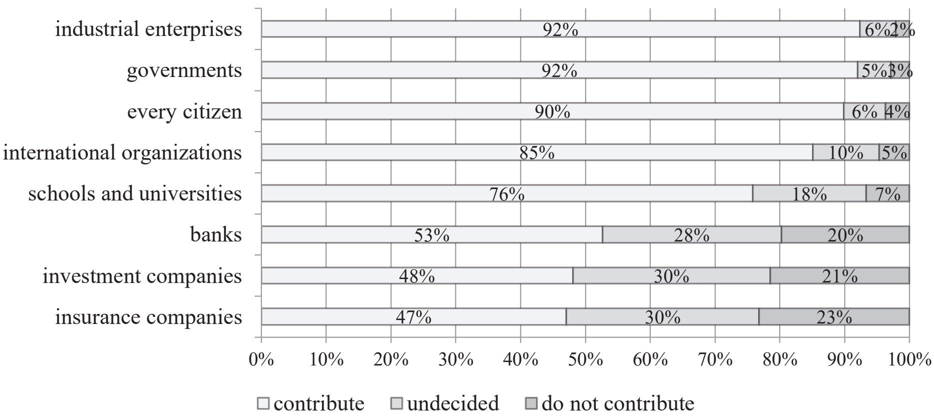

Figure 2. Perceived contribution to climate protection by various institutions

It turns out that industrial enterprises, along with governments, are perceived as the most important institutions in combating climate change. Moreover, the role that every individual citizen can play is also acknowledged. However, the perceived contribution of the financial sector, however, is far behind its actual significance. Only about 50% of bank customers are convinced that the financial sector (banks, investment companies and insurance companies) can contribute to climate protection. This indicates that customers are not aware of the key role played by the financial sector in this context and shows that the influence of financial institutions on the industrial enterprises is obviously not clear to them. This can also be seen in the statement that banks cannot do anything about climate change, which one third of customers agree with. This can be an advantage for banks that have not yet dealt with the topic of climate protection, as customer expectations in this area are rather low at the moment.

Nonetheless, many customers already expect their banks to be and act sustainable. It is important for almost half of the customers surveyed (45.52%) that their bank is committed to climate protection. In this context, it is becoming apparent that although this commitment is particularly important for younger customers, it is also relevant for other age groups. Thus, banks that are already dealing with the topic of climate change should inform their customers about their own activities and their positive effects on the climate. By doing so, it is important not to conduct greenwashing, but to actually integrate the commitment to climate protection into the business model of a bank and to communicate this integration convincingly. Greenwashing is the attempt to achieve a green image through marketing, but without actually implementing appropriate measures in the context of value creation (n.u. 2019, 1499). In this context, there is a certain scepticism of bank customers. 49.64% of those questioned state that banks committed to climate protection only do so to gain a positive reputation. It can be stated that those participants who are convinced that it is merely about hoped-for media effects also believe that banks cannot contribute at all to climate protection.

3. Motivation of bank customers to change their own behaviour

Bank customers rate the influence of each individual (see Figure 2) as being particularly important. Therefore, it will be discussed to what extent customers themselves are willing to adapt their own behaviour and which implications this entails for banks. In order to understand the motivation for possible changes in their behaviour, the participants' personal attitudes towards climate change are discussed first.

There is a broad consensus among bank customers surveyed that climate change and therefore climate protection are important. It turns out that younger customers tend to rate this topic as more important than older generations. Despite the fundamental awareness of the importance of climate change, only 58.18%

of the respondents feel well informed about this topic. The survey results show that customers who describe themselves as well-informed rate climate change as significantly more problematic as customers who feel less informed. Therefore, it can be stated that the better customers are informed, the higher the perceived importance of this topic. There were only a few climate change deniers among the customers surveyed. Only 10.53% of those questioned doubt that the climate is changing at all. For 12.23% of the respondents, there are no doubts about climate change per se, only uncertainties about the influence of humankind on climatic changes. About half of the participants are particularly unsure about the effects of climate change. However, the majority of customers (71.83%) believes that the effects of the changes in climate will affect them in the near future. Only 12.38% of the respondents explicitly denied this statement. Moreover, 68.71% of bank customers are already concerned about being personally affected by these effects in the future.

As 66.43% of customers are aware that they can contribute to climate protection due to their own behaviour, 20.20% were undecided in this context, and only a small number of customers do not believe that their behaviour can contribute to climate protection. Furthermore, the vast majority of customers (75.39%) is willing to adapt their behaviour in favour of climate protection. The figures show that even customers who are not fully aware of the influence of their behaviour on climate protection are willing to make changes. This may be due to the perceived threat from climate change and the high media presence of this topic in the last years before the corona pandemic started. The general motivation of the respondents to reconsider their behaviour and, if necessary, to adjust it, is underlined by the fact that only a small part of bank customers (6.12%) think that climate change cannot be stopped and that behavioural changes will no longer lead to positive results.

Figure 3 provides an overview of individual areas in which each citizen can adapt his or her behaviour, and thus, contribute to climate protection. When asked about the importance of individual fields of action for climate protection, bank customers generally determined the order shown below.

It turns out that the use of renewable energies and alternative means of transport such as public transport and electric or hybrid vehicles are seen as expedient. Customers also consider the reduction in electricity consumption and the increased purchase of regional products to be significant to protect the climate. However, it also shows that the potential of a conscious directing of money flows in sustainable projects is currently not fully understood by customers, since investments in sustainable investment products have been placed lowest in the ranking.

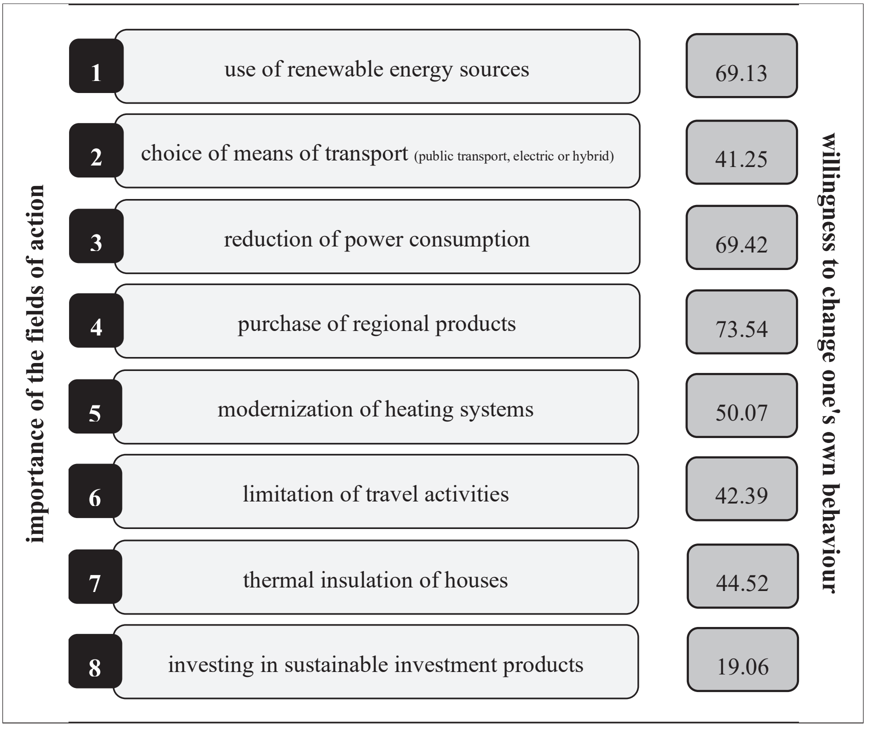

Figure 3. Perceived importance of various fields of action for climate protection and willingness to change own behaviour

The bank customers should also indicate whether they could imagine a change in their behaviour in the different fields of action. The results are illustrated by the values on the right-hand side shown in figure 3. These values indicate the number of participants who would be willing to adapt their own behaviour in favour of climate protection in this specific field of action. The majority of participants are willing to buy more regional products (73.54%), to reduce electricity consumption (69.42%) and to switch to renewable energy resources (69.13%). They are also open to modernizing their homes (50.07%, respectively 44.52%). However, less than half of participants are willing to switch to other means of transport. Limiting travel activities is only an option for 42.39% of those surveyed. This shows that for many people, climate protection is only relevant as long as their own comfort or pleasure is not restricted. Again, investing in sustainable investment products is least popular. Only 19.06% of the respondents are considering investing in sustainable investment products. Therefore, the question arises as to whether bank customers are averse on sustainable investment products per se or whether the findings are based on other motives.

4. Willingness to invest in sustainable investment products

In view of the general interest in the topic of climate change and the willingness to contribute in some form to climate protection by most participants, it is apparent that, due to the lack of understanding of the role of financial institutions in creating a sustainable economy, sustainable investment products do not receive adequate attention by many customers. However, not only the understanding of the complex relationships within the financial system is a problem, but also the respondents' basic understanding of securities in general and the fundamental willingness to invest in them is insufficient. 59.60% of all participants currently do not invest in securities. However, more than a third of these customers (37.71%) would like to invest in securities, but do not feel well enough informed. This reveals a first omission by banks, which in the past few years have apparently not responded to the wishes of their customers and at the same time failed to recognize a large source of income. Even in the current interest rate situation, the banks have not yet succeeded in contacting their customers about these types of investments, and thus, not only failed to optimize the returns of their customers, but also their own earnings potential. The question arises whether this is due to a lack of knowledge of the customer's wishes or because the advisory services offered at the moment are not compatible with the customers' actual needs. However, in this context another study conducted by the authors found that almost half of the customers surveyed do not believe that their bank even knows what they want in financial matters. Therefore, it can be concluded that banks do not seem to ask their customers about current wishes on appropriate occasions, even though this is the basis of any good and holistic advice. In addition, even if the customers' wishes are known, only 42.05% of bank customers feel that the banks cater specifically to those wishes (Hastenteufel, Kiszka 2020b, 540; Hastenteufel, Kiszka 2020c, 25–26).

Customers are just as open about their lack of knowledge on sustainable investments. 73.83% of customers feel not sufficiently informed about sustainable investment options by their banks, which underlines the high need for advisory services and the banks' previous inactivity. Only 14.51% of customers describe their knowledge in this area as good. Therefore, it is not surprising at all that only 6.40% of all customers surveyed have already bought a sustainable investment product. Although for most customers aspects such as security and return on investment are prioritized, 38.98% of those surveyed state that they are considering integrating environmental aspects in their investment decisions in the future. Obviously, the hesitation to invest in sustainable investments is primarily due to the knowledge gap among bank customers, which credit institutions have not been able to adequately close in the past.

5. Need for sustainable financial advice

Almost half of the bank customers surveyed (47.37%) are interested in sustainable financial products and would like their bank to provide them with more advice and assistance on sustainable investments in order to be aware of such companies and projects that take action against climate change. It should be particularly emphasized that for this purpose customers would also accept being actively contacted by their bank. When visiting a bank branch, 64.15% of all customers surveyed would not mind being personally approached to be informed about sustainable investment opportunities. Customers also think it is appropriate to be contacted by email (53.34%), letter (47.08%) and via online banking (44.24%). In this regard, younger and middle-aged customers prefer to be contacted by email and via online banking, while older customers aged 56 and above prefer a letter. Nevertheless, the majority of customers – regardless of age, rejects being contacted by a bank employee via telephone. Thus, banks have a large number of contact options at their disposal in order to actively reach out to their customers to inform them on sustainable investment opportunities, and therefore, to enter into a dialogue with their customers in a conscious, needs-based and customer-oriented manner. By doing so, previously inactive customers can be reached again. However, it is up to the banks to identify and satisfy these customer needs.

Sustainable financial advice, however, offers even more sales potential. In the case of new real estate financing, customers want information on energy-saving opportunities, funding programs for energy efficiency and the use and funding of renewable energies. This is in line with the previous results on the personal willingness to change their behaviour, according to which customers are willing to reduce their electricity consumption and switch to renewable energies. Due to the detected willingness to home modernization measures, the above-mentioned advisory services can also be transferred to existing properties, hereby addressing existing customers.

Customers also request insurance-related advice. More than half of the customers would like to receive more support concerning insurance options for technical systems for energy supply such as solar systems as well as insurance options against the regional consequences of climate change (see Figure 4). Currently, only one third (34.28%) of the customers surveyed feel well informed about personal insurance options against climate risks.

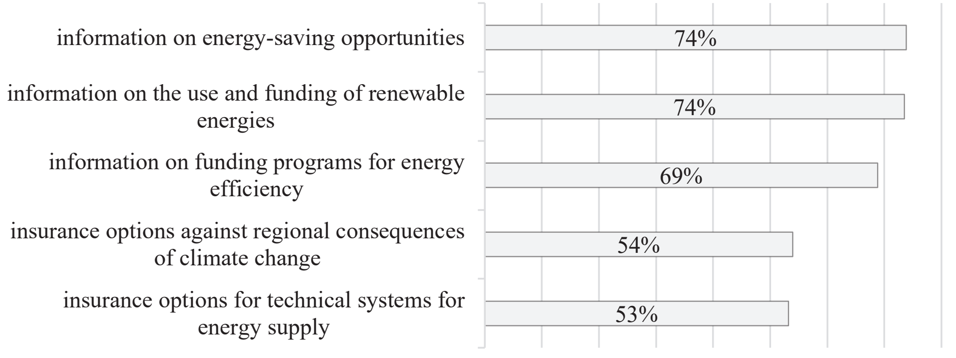

Figure 4. Advisory services requested within real estate financing

Therefore, from a holistic perspective, there is high potential for expanding cooperation with fund companies, development banks and insurance companies. Through sustainable advisory services there is a large, so far (almost) untouched earnings potential for financial institutions, which – especially under the aspect of the decrease in interest income due to the low interest rate environment – focuses on increasing the commission result as well as increasing customer satisfaction and thereby customer loyalty.

6. Climate protection and taking sustainable actions as a competitive advantage for banks – a critical conclusion

Already 64.58% of customers can imagine themselves investing in sustainable investments in the future. 44.95% of all bank customers are firmly convinced that their personal investment decisions can contribute to climate protection. That is why the majority of customers (56.33%) want their bank to actively approach them with regard to the possibilities of sustainable investments. Concerning other customers, however, there are some doubts about the earnestness and effectiveness of sustainable investments that need to be resolved. In this context, 31.29% of bank customers express doubts that sustainable investments can actually contribute to climate protection, instead are only an advertising campaign, and consequently only serve to keep the bank in customers' minds. In this regard, projects such as the EU taxonomy for sustainable activities (European Union 2020) are particularly important in order to prevent investments from being declared as green without contributing to sustainability. Especially younger bank customers up to 25 years of age, on whom the future economic success of a bank will largely depend (Matt, Mocha 2019, 1 and 3), are particularly interested in sustainable investments. There is great potential in this customer group, as more than two thirds of younger bank customers do not yet hold any securities, but the desire to do so is particularly pronounced. Sustainable investments also hold an above-average importance for retirees. It can only be speculated whether they place more trust in those banks that promise their children and grandchildren a more sustainable world. Ultimately, the expansion of sustainability across all age groups fails due to the lack of advisory services by the banks in order to explain securities in general and to erase the existing doubts about sustainable investments caused by the knowledge gap on how sustainable products work and the potential they can unfold. Moreover, banks waste earnings potential due to missed opportunities in offering suitable products to those customers who are already willing to invest sustainably.

Furthermore, the customers' wishes regarding sustainability are not limited to investments. Rather, 64.01% of those surveyed want an all-round advice on the subject of climate change. In order to meet this demand, it is advisable to train some bank advisors to become specialists in sustainable finance, who can then provide comprehensive advisory services to customers either in the branch or digitally. They could also support their colleagues if their specialist knowledge is required. In this context, a close cooperation with the customer advisors of the cooperating investment and insurance companies should be emphasized in order to create the desired all-round advice for the customer. By actively addressing customers concerning sustainable financial advice, banks can not only meet the expectations of their customers, but also address a large number of customers with whom they have no points of contact within the current advisory practice.

Moreover, customers expect climate-friendly behaviour from their banks. The main objective here is to prevent a loss of reputation that can be caused by neglecting sustainable commitments or by pretending to be more sustainable than it is actually the case. Banks should internalize that reputation is an extremely valuable asset that is essential to achieve and maintain customer trust (Imhof 2010, 289). Ultimately, this trust is the basis of any bank's business (Waschbusch et al. 2018, 102). For this reason, great importance should be attached to the sustainable orientation of the behaviour of financial institutions themselves, as it offers the opportunity to regain the trust lost in the financial crisis (Bethge 2018, 4).

For 40.54% of bank customers, a bank that is committed to climate protection appears to be more trustworthy than a bank that is not. 30.87% of the customers questioned were undecided in this regard, so that only 28.59% did not agree with this statement. This relatively low number of customers, among other things, can be attributed to the reservations already mentioned that banks only act sustainably in order to obtain positive media effects.

This remarkable trust bonus is even more apparent when the majority of bank customers (55.76%) stated that they would rather entrust their money to a bank that is not only focused on its own profits, but also deals with general problems such as climate change. In this way, the sense of responsibility that the financial institutions show in terms of climate protection is transferred to the responsible handling of customer assets. This trust effect is particularly distinct among younger bank customers.

The integration of the sustainability aspect, in particular climate protection, into a bank's customer advisory service, which has so far been rated as inadequate (Hastenteufel, Kiszka 2020a, Hastenteufel, Kiszka 2020b, Hastenteufel, Kiszka 2020c), is an unmistakable competitive advantage, as it offers a noticeable added value for customers. Quick action is required here, as most customers have not yet actively informed themselves about the measures their bank is taking to protect the climate. 24.18% of the customers are willing to switch to another bank in the future if their bank does not provide them with sustainable financial products and the much needed information and advice, as well as acting sustainably in general. For younger bank customers this figure is even higher (31.63%).

With the integration of sustainability aspects into banks' advisory services becoming mandatory in the future due to changes in the regulatory framework resulting from the EU action plan for financing sustainable growth (European Commission 2018, 6–7) it is advisable to deal with these sustainability topics as soon as possible. However, the decisive factor for banks to adapt their current advisory concept should not be the regulatory pressure. Taking forward-looking and responsible actions as well as considering climate protection measures within the business model and the advisory service can not only unlock new sources of income and a trust bonus by customers but can also increase customer loyalty and furthermore facilitate new customer acquisition. Therefore, corporate environmental performance can be used as a reputational lever and hereby have a positive impact on financial performance by meeting the demands of relevant stakeholders such as a bank's customers (McWilliams, Siegel 2001, 125; Ortlitzky et al. 2003, 426; Campbell 2007, 962–963; Chernev, Blair 2015, 1421–1422). Thus, the changing value system within society can be transformed into a long-term opportunity for banks.

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Summary

Banks are currently facing numerous challenges. In addition to the ongoing cheap money policy of the European Central Bank, a regulated market environment and a rapidly progressive digitization, financial institutions are increasingly confronted with topics such as sustainability and climate protection. From the latter derive not only risks but also chances for banks. Sustainability risks can impact different risk categories such as market risks, credit risks, operational risks, and liquidity risks. Moreover, reputational risks can occur in this context. This is especially important as bank customers constantly develop a greater awareness of ecological issues, and thus, develop increasing expectations on how companies – like banks – deal with issues like climate protection and sustainability. For this reason, we will start with a theoretical explanation of the key words and then present the results of our customer survey to highlight the current expectations of bank customers in the context of climate protection. Based on this, we formulate recommendations for banks on how to generate a competitive advantage by engaging in climate protection and by taking sustainable actions.

JEL codes: G21, M14, M31, O16, Q01, Q50

Keywords: *climate protection, climate change, consumer trust, banking*

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An example to illustrate several aspects of optimization theory in Managerial Economics

1. Introduction

Optimization theory plays a significant role in Managerial Economics. Chapter 8 of Peterson and Lewis (1999) provides a lucid exposition of linear programming, followed by Mote and Madhavan (2016), where in chapters 5 and 22, there is a comprehensive and very informed treatment of the same topic and further discussions on integer programming and decision making under uncertainty. Neither of the two books discuss dynamic programming explicitly although simple integer programming problems can be solved easily by dynamic programming. Using dynamic programming for such integer programming leads to the representation of the problem by decision trees which are discussed in chapter 16 of Mote and Madhavan (2016), in the context of decision analysis.

As in chapter 5 of Mote and Madhavan (2016), where a single example is used to discuss almost all aspects of linear programming, it would be good to have a single example that illustrates all aspects of linear, integer and dynamic programming, including such concepts such as value of perfect and imperfect information. That is precisely what we do here.

The purpose of this paper is similar to Shenoy (1998), which is a seminal contribution to decision analysis from a purely pedagogic point of view. If in game theory or in a game tree a player whose turn it is to make a move, does not know the move that was chosen by the former's immediate predecessor, nor can the player whose turn it is to move identify its present position, then such a player is said to be located at an "information set". Exactly the same dilemma is faced by a decision maker whose move is preceded or followed by "chance". In either case, the pay-off of the player or the decision maker we are concerned

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with depends on its move as well as the unknown move of the other player or chance. In Shenoy (1998), the name "information set" is incorporated into decision trees at such nodes where owing to a move by chance, the decision maker is unaware of its exact location. Shenoy (1998) goes on to provide a solution for such a game tree under probabilistic uncertainty (risk) applied to a problem related to drilling of oil. As is well known, the consequences of drilling in a "suspected" oil field are uncertain.

Our example allows for the availability of "additional information" (as for instance a preliminary geological survey to update the existing information regarding the availability of oil) at a price. All of the above and this embedded in a linear programming problem is to the best of our knowledge a novelty for a learner of decision analysis, if not for practitioners as well.

2. The mathematical background

Here we provide the general model in the context of which our discussion takes place.

Given positive integers m, n and M a subset of {1,…, n}, the standard form of the general problem we are concerned with is the following

$$\text{Maximize } \sum_{j=1}^{n} c_j x_j$$

$$\text{s.t. } \sum_{j=1}^{n} a_{ij} x_j \leq b_i,\ i = 1, \ldots, m,$$

$x_j \geq 0$ for $j = 1, \ldots, n$, $x_j \in \mathbb{N} \cup \{0\}$ for $j \in M$, where $\mathbb{N}$ is the set of natural numbers.

If $M = \phi$, then the above is a linear programming (LP) problem, which from the perspective of managerial economics is covered extremely well in both Petersen and Lewis (1999) and Mote and Madhavan (2016). Technical details for such problems are available in Lahiri (2021).

If $M = \mathbb{N}$, then we have an integer programming problem. If in addition we require some variable $x_j \in \{0,1\}$, then we simply add the inequality $x_j \leq 1$ to the above system, unless it is already there.

Sometimes there may be probabilistic uncertainty about certain parameters of the above problem. In such a situation it may be possible to obtain information about the uncertain parameters which leads to an improved value of the objective. The difference in the value of the objective function- after and prior to the availability of information- is called the value of information. This value may depend on whether the information about the uncertain parameters is perfect or imperfect. The important thing to note about information is that it should be available when required.

The example in the next section gives us a peep into the issues discussed above.

3. Numerical example

The following numerical example can be used for instructional purposes to explain the issues mentioned above.

Maximize $x_1 + r(x_3)x_2 - \frac{3}{4}x_3$ where $Pr.\{r(x_3) = \frac{3}{2} \mid x_3 = 1\} = \frac{7}{8}$, $Pr.\{r(x_3) = \frac{1}{2} \mid x_3 = 1\} = \frac{1}{8}$, $Pr.\{r(x_3) = \frac{3}{2} \mid x_3 = 0\} = \frac{1}{8}$, $Pr.\{r(x_3) = \frac{1}{2} \mid x_3 = 0\} = \frac{7}{8}$.

To be precise r(0) and r(1) are two independent random variables.

If in addition we require x_1 and x_2 to be non-negative integers, then we have an integer programming problem and such simple integer programming problems can be solved using decision trees, i.e. dynamic programming.

One can also discuss value of perfect and imperfect information, so that if the person providing information is known to be correct with probability $p(x_3)$, then $r(x_3)$ is the predicted value with probability $p(x_3)$ and the other value with probability $1-p(x_3)$. We could generalize this further by letting $\rho(x_3)$ denote the predicted value of the co-efficient of x_2 for a given value of x_3 and considering $p(r(x_3) = \rho(x_3) \mid \rho(x_3) = \alpha)$ = Probability of the event $[r(x_3) = \rho(x_3)]$ conditional on the event $[\rho(x_3) = \alpha]$ and $1- p(r(x_3) = \rho(x_3) \mid \rho(x_3) = \alpha)$ = Probability of the event $[r(x_3) \in \{\frac{1}{2}, \frac{3}{2}\} \setminus \{\rho(x_3)\}]$ conditional on the event $[\rho(x_3) = \alpha]$, for $\alpha \in \{\frac{1}{2}, \frac{3}{2}\}$. However, that would just be complicating the calculations and is left as an exercise for the interested reader.

In any case we would require to obtain $Pr.[\rho(x_3) = \alpha]$ = Probability of the event $[\rho(x_3) = \alpha]$, which can be done using Baye's rule (please see Appendix for details).

In our case, $Pr.[\rho(x_3) = \alpha] = \frac{\text{Probability of the event}\left[r(x_3) = \alpha\right] - \left(1 - p(x_3)\right)}{2p(x_3) - 1}$.

Hence $Pr.[\rho(0) = \frac{1}{2}] = \frac{\frac{7}{8} - (1 - p(0))}{2p(0) - 1} = \frac{p(0) - \frac{1}{8}}{2p(0) - 1}$, $Pr.[\rho(0) = \frac{3}{2}] = \frac{\frac{1}{8} - (1 - p(0))}{2p(0) - 1} = \frac{p(0) - \frac{7}{8}}{2p(0) - 1}$,

$Pr.[\rho(1) = \frac{1}{2}] = \frac{\frac{1}{8} - (1 - p(1))}{2p(1) - 1} = \frac{p(1) - \frac{7}{8}}{2p(1) - 1}$, $Pr.[\rho(1) = \frac{3}{2}] = \frac{\frac{7}{8} - (1 - p(1))}{2p(1) - 1} = \frac{p(1) - \frac{1}{8}}{2p(1) - 1}$.

In order to determine the value of x_3 it is necessary for the DM to have information about r(0) and r(1) right at the beginning of the decision making process.

4. Solution of the numerical example for an LP and the value of perfect information

In the absence of any information we compare the value of the optimal solutions for $x_3 = 0$ and $x_3 = 1$ using $r(0) = \frac{3}{2}$ with probability $\frac{1}{8}$, $r(0) = \frac{1}{2}$ with probability $\frac{7}{8}$ and $r(1) = \frac{3}{2}$ with probability $\frac{7}{8}$, $r(1) = \frac{1}{2}$ with probability $\frac{1}{8}$ and = $\frac{11}{8}$ and choose the solution which gives the higher optimal value.

Hence we solve

Maximize $x_1 + \frac{3}{2} x_2$
s.t. $2x_1 + x_2 \leq 4$
$x_1 + 2x_2 \leq 4$,
$x_1 \geq 0$, $x_2 \geq 0$,

and

Maximize $x_1 + \frac{1}{2} x_2$
s.t. $2x_1 + x_2 \leq 4$
$x_1 + 2x_2 \leq 4$,
$x_1 \geq 0$, $x_2 \geq 0$.

Without any integer constraints, we know from LP theory that if an optimal solution exists then there must be one at one of the four corner points $\{(0,0), (0,2), (2,0), (\frac{4}{3}, \frac{4}{3})\}$. Since the set of values of the objective function for both problems corresponding to the set of feasible points is bounded above, it is known (a proof is available in Lahiri (2020) that optimal solutions exist for both problems.

The optimal solution for the first LP problem i.e. the one with co-efficient of x_2 being $\frac{3}{2}$ is $(\frac{4}{3}, \frac{4}{3})$ with optimal value being $\frac{10}{3}$.

The set of optimal solution for the first LP problem i.e. the one with co-efficient of x_2 being $\frac{1}{2}$ is the closed interval joining the end points $(\frac{4}{3}, \frac{4}{3})$ and (2,0), with optimal value being 2.

Hence the expected optimal value after choosing $x_3 = 0$ is $\frac{7}{8}\times\frac{1}{2} + \frac{1}{8}\times\frac{3}{2} = \frac{10}{16} = \frac{5}{8}$ and the optimal value after choosing $x_3 = 0$ is $\frac{7}{8}\times\frac{3}{2} + \frac{1}{8}\times\frac{1}{2} - \frac{3}{4} = \frac{22}{16} - \frac{12}{16} = \frac{10}{16} = \frac{5}{8}$.

Hence the DM is indifferent between choosing $x_3 = 0$ and $x_3 = 1$, and having chosen x_3 waits for the realized value of $r(x_3)$ to decide what the optimal values of x_1 and x_2 should be.

The expected optimal value without any information is $\frac{5}{8}$.

If perfect information is available, then there are four possibilities for the pairs of predicted values of r: $(r(0),r(1)) = (\frac{3}{2}, \frac{3}{2})$, $(r(0),r(1)) = (\frac{1}{2}, \frac{1}{2})$, $(r(0),r(1)) = (\frac{3}{2}, \frac{1}{2})$ and $(r(0),r(1)) = (\frac{1}{2}, \frac{3}{2})$.

From the above calculations we know that the optimal value pairs corresponding to (r(0), r(1)) =

(a) $(\frac{3}{2}, \frac{3}{2})$ is $(\frac{10}{3}, \frac{10}{3} - \frac{3}{4})$ with the optimal solution in both situations being $(x_1, x_2) = (\frac{4}{3}, \frac{4}{3})$;

(b) $(\frac{3}{2}, \frac{1}{2})$ is $(\frac{10}{3}, 2 - \frac{3}{4}) = (\frac{10}{3}, \frac{5}{4})$ with the optimal solution for $x_3 = 0$ being $(x_1, x_2) = (\frac{4}{3}, \frac{4}{3})$ and the set of optimal solutions for $x_3 = 1$ being ordered pairs (x_1, x_2) in the closed interval joining the end points $(\frac{4}{3}, \frac{4}{3})$ and (2,0);

(c) $(\frac{1}{2}, \frac{3}{2}) = (2, \frac{10}{3} - \frac{3}{4}) = (2, \frac{91}{12})$ with the set of optimal solutions for $x_3 = 0$ being ordered pairs (x_1,x_2) in the closed interval joining the end points $(\frac{4}{3}, \frac{4}{3})$ and (2,0) and the optimal value for $x_3 = 1$ being $(x_1, x_2) = (\frac{4}{3}, \frac{4}{3})$;

(d) $(\frac{1}{2}, \frac{1}{2})$ is $(2, 2 - \frac{3}{4}) = (2, \frac{5}{4})$ with the set of optimal solution for both $x_3 = 0$ and $x_3 = 1$ being ordered pairs (x_1, x_2) in the closed interval joining the end points $(\frac{4}{3}, \frac{4}{3})$ and (2, 0).

If the predicted value of $r(0) = \frac{3}{2}$, then the optimal choice is $(\frac{4}{3}, \frac{4}{3}, 0)$ with an optimal value of $3\frac{1}{3}$. The probability of such a prediction is $\frac{1}{8}$.

If the prediction is $(r(0),r(1)) = (\frac{1}{2}, \frac{1}{2})$, then the optimal choice is any point in the closed interval with end points $(\frac{4}{3}, \frac{4}{3}, 0)$ and (2, 0, 0) with an optimal value of 2. The probability of such a prediction is $\frac{7}{64}$.

If the prediction is $(r(0),r(1)) = (\frac{1}{2}, \frac{3}{2})$, then the optimal choice is $(\frac{4}{3}, \frac{4}{3}, 1)$ with an optimal value of $2\frac{17}{12}$. The probability of such a prediction is $\frac{49}{64}$.

Hence with perfect information, the optimal expected value of the objective function is $3\frac{1}{3} \times \frac{1}{8} + 2 \times \frac{7}{64} + 2\frac{7}{12} \times \frac{49}{64} = 2\frac{673}{2304}$.

The optimal value of the objective function without any information is $\frac{5}{8}$ and the optimal value of the objective function with perfect information is $2\frac{673}{2304}$.

Hence the value of perfect information is $2\frac{673}{2304} - \frac{5}{8}$ is $2 - \frac{17}{144} = 1\frac{673}{1440} > 0$.

5. LP and the value of imperfect information

Suppose for $x_3 \in \{0, 1\}$, there is a probability $p(x_3) \in [0,1]$ such that the predicted value of $r(x_3)$ is correct. Recall that $\rho(x_3)$ denotes the predicted value and $r(x_3)$ denotes the realized value for $x_3 \in \{0, 1\}$. Thus, $p(x_3)$ is the probability of the event $\{r(x_3) = \rho(x_3)\}$. In the previous section we were assuming $p(x_3) = 1$ for $x_3 \in \{0,1\}$. In this section, we relax this assumption. Thus, for $x_3 \in \{0,1\}$, $r(x_3) = \rho(x_3)$ with probability $p(x_3)$ and $r(x_3) \in \{\frac{1}{2}, \frac{3}{2}\} \backslash \{\rho(x_3)\}$, with probability $1 - p(x_3)$.

If $\rho(0) = \frac{1}{2}$, then with probability p(0), $r(0) = \frac{1}{2}$ with the optimal value of the corresponding problem being 2 and with probability 1 – p(0), $r(x_3) = \frac{3}{2}$ with the optimal value of the corresponding problem being $3\frac{1}{3}$. Hence if $\rho(0) = \frac{1}{2}$, the expected optimal value of the DM is $2p(0) + 3\frac{1}{3}(1 - p(0)) = 3\frac{1}{3} - 1\frac{1}{3}\ p(0)$.

Similarly if $\rho(0) = \frac{3}{2}$, the expected optimal value of the DM is $3\frac{1}{3}\ p(0) + {} + 2(1 - p(0)) = 2 + 1\frac{1}{3}\ p(0)$.

If $\rho(1) = \frac{1}{2}$, then the expected optimal value of the DM is $2p(1) + 3\frac{1}{3}(1 - p(1)) - \frac{3}{4} = 3\frac{1}{3} - 1\frac{1}{3}\ p(1) - \frac{3}{4} = 2\frac{5}{9} - 1\frac{1}{3}\ p(1)$.

If $\rho(1) = \frac{3}{2}$, the expected optimal value of the DM is $3\frac{1}{3}\ p(1) + 2(1 - p(1)) - \frac{3}{4} = = 2 - \frac{3}{4} + 1\frac{1}{3}\ p(1) = 1\frac{1}{4} + 1\frac{1}{3}\ p(1)$.

As before there are four possibilities for the pairs of predicted values of r: $(\rho(0), \rho(1)) = (\frac{3}{2}, \frac{3}{2})$, $(\rho(0), \rho(1)) = (\frac{1}{2}, \frac{1}{2})$, $(\rho(0), \rho(1)) = (\frac{3}{2}, \frac{1}{2})$ and $(\rho(0), \rho(1)) = (\frac{1}{2}, \frac{3}{2})$.

If $(\rho(0), \rho(1)) = (\frac{3}{2}, \frac{3}{2})$, then the DM will choose $x_3 = 0$ or 1, depending upon whether $2 + 1\frac{1}{3}\ p(0)$ is greater than or equal to $1\frac{1}{4} + 1\frac{1}{3}\ p(1)$ or the other way around. Hence the DM's expected optimal value is $\max\{2 + 1\frac{1}{3}\ p(0), 1\frac{1}{4} + 1\frac{1}{3}\ p(1)\}$. The probability of the prediction being $(\rho(0),\rho(1)) = (\frac{3}{2}, \frac{3}{2})$ is $\left(\frac{p(0)-\frac{7}{8}}{2p(0)-1}\right)\left(\frac{p(1)-\frac{1}{8}}{2p(1)-1}\right)$.

If $(\rho(0), \rho(1)) = (\frac{1}{2}, \frac{1}{2})$ the DM's expected optimal value is $\max\{3\frac{1}{3} - 1\frac{1}{3}\ p(0), 2\frac{5}{9} - 1\frac{1}{3}\ p(1)\}$. The probability of the prediction being $(\rho(0), \rho(1)) = (\frac{1}{2}, \frac{1}{2})$ is $\left(\frac{p(0)-\frac{1}{8}}{2p(0)-1}\right)\left(\frac{p(1)-\frac{7}{8}}{2p(1)-1}\right)$.

If $(\rho(0), \rho(1)) = (\frac{3}{2}, \frac{1}{2})$ the DM's expected optimal value is $\max\{2 + 1\frac{1}{3}\ p(0), 2\frac{5}{9} - 1\frac{1}{3}\ p(1)\}$. The probability of the prediction being $(\rho(0), \rho(1)) = (\frac{3}{2}, \frac{1}{2})$ is $\left(\frac{p(0)-\frac{7}{8}}{2p(0)-1}\right)\left(\frac{p(1)-\frac{7}{8}}{2p(1)-1}\right)$.

If $(\rho(0), \rho(1)) = (\frac{1}{2}, \frac{3}{2})$ the DM's expected optimal value is $\max\{3\frac{1}{3} - 1\frac{1}{3}\ p(0), 1\frac{1}{4} + 1\frac{1}{3}\ p(1)\}$. The probability of the prediction being $(\rho(0), \rho(1)) = (\frac{1}{2}, \frac{3}{2})$ is $\left(\frac{p(0)-\frac{1}{8}}{2p(0)-1}\right)\left(\frac{p(1)-\frac{1}{8}}{2p(1)-1}\right)$.

Hence with imperfect information, the optimal expected value of the objective function is $[\left(\frac{p(0)-\frac{7}{8}}{2p(0)-1}\right)\left(\frac{p(1)-\frac{1}{8}}{2p(1)-1}\right)][\max\{2 + 1\frac{1}{3}\ p(0), 1\frac{1}{4} + 1\frac{1}{3}\ p(1)\}] + [\left(\frac{p(0)-\frac{1}{8}}{2p(0)-1}\right)\left(\frac{p(1)-\frac{7}{8}}{2p(1)-1}\right)]$ $[\max\{3\frac{1}{3} - 1\frac{1}{3}\ p(0), 2\frac{5}{9} - 1\frac{1}{3}\ p(1)\}] + [\left(\frac{p(0)-\frac{7}{8}}{2p(0)-1}\right)\left(\frac{p(1)-\frac{7}{8}}{2p(1)-1}\right)][\max\{2 + 1\frac{1}{3}\ p(0), 2\frac{5}{9} - 1\frac{1}{3}\ p(1)\}] + \left[\left(\frac{p(0)-\frac{1}{8}}{2p(0)-1}\right)\left(\frac{p(1)-\frac{1}{8}}{2p(1)-1}\right)\right]\left[\max\left\{3\frac{1}{3} - 1\frac{1}{3}p(0), 1\frac{1}{4} + 1\frac{1}{3}p(1)\right\}\right]$.

Without any information the optimal expected value of the objective function is $\frac{5}{8}$.

The value of imperfect information is the difference between the optimal expected value of the objective function with imperfect information and $\frac{5}{8}$.

If it is positive, then the value of imperfect information is the maximum the DM is willing to pay for obtaining imperfect information.

If p(0) = p(1) = 1, then the above sum reduces to $\frac{7}{64}[3\frac{1}{3} + 2] + \frac{1}{64} \times 3\frac{1}{3} + \frac{49}{64} \times 2\frac{7}{12} = \frac{7}{64} \times 5\frac{1}{3} + \frac{1}{64} \times 3\frac{1}{3} + \frac{49}{64} \times 2\frac{7}{12} = 2\frac{673}{2304}$.

If p(0) and p(1) are sufficiently close to 1, then the value of imperfect information is likely to be positive.

6. The integer programming version of the above problem

The integer programming version of the above problem is the following

Maximize $x_1 + r(x_3)x_2 - \frac{3}{4}x_3$
s.t. $2x_1 + x_2 \leq 4$
$x_1 + 2x_2 \leq 4$
$x_3 \leq 1$,
$x_1 \geq 0$, $x_2 \geq 0$, $x_3 \geq 0$,
where $Pr.\{r(x_3) = \frac{3}{2} \mid x_3 = 1\} = \frac{7}{8}$, $Pr.\{r(x_3) = \frac{1}{2} \mid x_3 = 1\} = \frac{1}{8}$,
$Pr.\{r(x_3) = \frac{3}{2} \mid x_3 = 0\} = \frac{1}{8}$, $Pr.\{r(x_3) = \frac{1}{2} \mid x_3 = 0\} = \frac{7}{8}$.

Once again, r(0) and r(1) are two independent random variables.

The analysis differs from the above only in the computational strategies of the following two integer linear programming problems:

Maximize $x_1 + \frac{3}{2}x_2$
s.t. $2x_1 + x_2 \leq 4$
$x_1 + 2x_2 \leq 4$
$x_1, x_2 \in \mathbb{N} \cup \{0\}$,

and

Maximize $x_1 + \frac{1}{2}x_2$
s.t. $2x_1 + x_2 \leq 4$
$x_1 + 2x_2 \leq 4$
$x_1, x_2 \in \mathbb{N} \cup \{0\}$.

In this situation it is easy to observe that for both problems the set of feasible solutions is {(0, 0), (0, 1), (0, 2), (1, 0), (1, 1), (2, 0)}.

The optimal solution for the first problem is at (0, 2) with the optimal value being 3 and the optimal solution for the second problem is at (2, 0) with the optimal value being 2. However, the interesting point to note is that solving the original problem using a decision tree can be quite instructive about several aspects of managerial decision analysis.

At the root of the tree, which is a node, the DM chooses an action/move i.e. an edge of the tree, from the two edges $x_3 = 0$, $x_3 = 1$. A note where the DM, has a move, called a decision node, is usually denoted by a square.

At the next pair of nodes, regardless of what the choice at the root of the tree, it is the turn for chance to make a move. A note where chance has a move, called a chance node, is usually denoted by a circle.

If $x_3 = 0$, then chance chooses the edge $[r(0) = \frac{1}{2}]$ with probability $\frac{7}{8}$ and $[r(0) = \frac{3}{2}]$ with probability $\frac{1}{8}$. Let the resulting nodes be denoted $IP^1(0)$ and $IP^2(0)$. These are decision nodes with the states variables $(b_1, b_2) = (4, 4)$ and value $V_2 = 0$ inscribed within it. From this node the DM, is required to choose one of three possible edges corresponding to the three values of x_2: $x_2 = 0$, $x_2 = 1$, $x_2 = 2$.

If $x_3 = 1$, then chance chooses the edge $[r(1) = \frac{1}{2}]$ with probability $\frac{1}{8}$ and $[r(1) = \frac{3}{2}]$ with probability $\frac{7}{8}$. Let the resulting nodes be denoted $IP^1(1)$ and $IP^2(0)$. These are decision nodes with the state variables $(b_1, b_2) = (4, 4)$ and value $V_2 = -\frac{3}{4}$ inscribed within it. From this node the DM, is required to choose one of three possible edges corresponding to the three values of x_2: $x_2 = 0$, $x_2 = 1$, $x_2 = 2$.

If $x_3 = 0$, then for the chosen values of r(0) and x_2 we arrive at a decision node with the state variable $(b_1, b_2) = (4 - x_2, 4 - 2x_2)$ and value $V_1 = r(0)x_2$ inscribed within it.

If $x_3 = 1$, then for the chosen values of r(1) and x_2 we arrive at a decision node with the state variable $(b_1, b_2) = (4 - x_2, 4 - 2x_2)$ and value $V_1 = -\frac{3}{4} + r(1)$ x_2 inscribed within it.

At the decision node with $(b_1, b_2) = (4 - x_2, 4 - 2x_2)$ and value $V_1 = r(0)x_2$ inscribed within it, the possible values of x_1 are all non-negative integers less than or equal to $\min\{\frac{4-x_2}{2}, 4 - 2x_2\}$, with an edge corresponding to each such non-negative integer. At the end of such an edge is a terminal node of the tree with $V_0 = V_1$ + the value of x_1 along the chosen edge = $r(0)x_2$ + the value of x_1 along the chosen edge.

At the decision node with $(b_1, b_2) = (4 - x_2, 4 - 2x_2)$ and value $V_1 = -\frac{3}{4} + r(1)x_2$ inscribed within it, the possible values of x_1 are all non-negative integers less than or equal to $\min\{\frac{4-x_2}{2}, 4 - 2x_2\}$, with an edge corresponding to each such non-negative integer. At the end of such an edge is a terminal node of the tree with $V_0 = V_1$ + the value of x_1 along the chosen edge = $-\frac{3}{4} + r(1)x_2$ + the value of x_1 along the chosen edge.

Since the optimization problem is a maximization problem with the co-efficient of x_1 being positive at all decision nodes at the last stage of the decision tree the chosen value of x_1 will be $\min\{\frac{4-x_2}{2}, 4-2x_2\}$.

Thus if $x_3 = 0$, then for the value of r(0) chosen by chance the chosen value of x_2 must be a maximizer of $r(0)x_2 + \min\{\frac{4-x_2}{2}, 4-2x_2\}$ which is $\max\{\frac{1}{2}x_2 + \min\{\frac{4-x_2}{2}, 4-2x_2\} | x_2 \in \{0, 1, 2\}\}$ with probability $\frac{7}{8}$ and $\max\{\frac{3}{2}x_2 + \min\{\frac{4-x_2}{2}, 4-2x_2\} | x_2 \in \{0, 1, 2\}\}$ with probability $\frac{1}{8}$.

Thus, the optimal expected value resulting from choosing $x_3 = 0$ is $\frac{7}{8} \times [\max\{\frac{1}{2}x_2 + \min\{\frac{4-x_2}{2}, 4-2x_2\} | x_2 \in \{0, 1, 2\}\}] + \frac{1}{8} \times [\max\{\frac{3}{2}x_2 + \min\{\frac{4-x_2}{2}, 4-2x_2\} | x_2 \in \{0,1,2\}\}]$. Let us call this $EV(x_3 = 0)$.

Similarly if $x_3 = 1$, then for the value of r(1) chosen by chance the chosen value of x_2 must be a maximizer of $-\frac{3}{4} + r(1)x_2 + \min\{\frac{4-x_2}{2}, 4-2x_2\}$ which is $\max\{-\frac{3}{4} + \frac{1}{2}x_2 + \min\{\frac{4-x_2}{2}, 4-2x_2\} | x_2 \in \{0,1,2\}\}$ with probability $\frac{1}{8}$ and $\max\{-\frac{3}{4} + \frac{3}{2}x_2 + \min\{\frac{4-x_2}{2}, 4-2x_2\} | x_2 \in \{0,1,2\}\}$ with probability $\frac{7}{8}$.

Thus, the optimal expected value resulting from choosing $x_3 = 1$ is $\frac{7}{8} \times [\max\{-\frac{3}{4} + \frac{1}{2}x_2 + \min\{\frac{4-x_2}{2}, 4-2x_2\} | x_2 \in \{0, 1, 2\}\}] + \frac{1}{8} \times [\max\{\frac{1}{2}x_2 + \min\{\frac{4-x_2}{2}, 4-2x_2\} | x_2 \in \{0, 1, 2\}\}]$. Let us call this $EV(x_3 = 1)$.

An optimal solution for x_3 is equal to 0 if and only if $EV(x_3 = 0) \geq EV(x_3 = 1)$. Otherwise, the optimal value of x_3 is equal to 1.

In our problem $EV(x_3 = 0) = \frac{7}{8} \times 2 + \frac{1}{8} \times 4 = \frac{18}{8} = 2\frac{1}{4}$ and $EV(x_3 = 1) = \frac{7}{8} \times 3 + \frac{1}{8} \times 2 - \frac{3}{4} = \frac{17}{8} = 2\frac{1}{8}$.

Thus $EV(x_3 = 0) > EV(x_3 = 1)$ and hence the optimal choice is $x_3 = 0$.

Contrast this result with the one we obtained for LP without any information.

The result for the cases with perfect and imperfect information for an IP are obtained in an analogous manner for that of an LP.

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Appendix

r and ρ are two random variables defined on a set A consisting of two elements a generic element of which is denoted by α.

Probability [r = α] and Probability [r = α| ρ = β] = p(r = α| ρ = β) known for all α, β ∈ A. We need to find Probability [ρ = α] for all α ∈ A.

p(r = α|ρ = α) × Pr.[ρ = α] = Probability of the event [r = α & ρ = α)].

p(r = α|ρ ∈ A\{ α}) × Pr.[ρ ∈ A \{α}] = Probability of the event [r = α & A\{α}].

Adding the two equations we get p(r = α|ρ = α) × Pr.[ρ = α] + p(r = α|ρ ∈ A\{ α}) (1 − Pr.[ρ = α]) = Probability of the event [r = α].

Thus, Pr.[ρ = α] =

$$\frac{\text{Probability of the event}\left[r=\alpha\right]-p\left(r=\alpha\,|\,\rho\in A\setminus\{\alpha\}\right)}{p\left(r=\alpha\,|\,\rho=\alpha\right)-p\left(r=\alpha\,|\,\rho\in A\setminus\{\alpha\}\right)}=$$

$$=\frac{p\left(r=\alpha\,|\,\rho\in A\setminus\{\alpha\}\right)-\text{Probability of the event}\left[r=\alpha\right]}{p\left(r=\alpha\,|\,\rho\in A\setminus\{\alpha\}\right)-p\left(r=\alpha\,|\,\rho=\alpha\right)}$$

Note: If Probability of the event [r = α] > p(r = α|ρ = α), then if 1 > Pr.[ρ = α] > 0, Pr.[ρ = α] × Probability of the event [r = α] > Pr.[ρ = α] × × p(r = α|ρ = α).

Since Probability of the event $[r = \alpha] = Pr.[\rho = \alpha] \times$ Probability of the event $[r = \alpha] + (1 - Pr.[\rho = \alpha]) \times$ Probability of the event $[r = \alpha]$, it must be the case that $(1 - Pr.[\rho = \alpha]) \times$ Probability of the event $[r = \alpha] < p(r = \alpha | \rho \in A \backslash \{\alpha\}) \times (1 - Pr.[\rho = \alpha])$, and hence Probability of the event $[r = \alpha] < p(r = \alpha | \rho \in A \backslash \{\alpha\})$.

The converse is also true, as can be checked from the calculations above.

Summary

We provide a single example that illustrates all aspects of linear, integer and dynamic programming, including such concepts such as value of perfect and imperfect information. Such problems, though extremely plausible and realistic are hardly ever discussed in managerial economics.

JEL codes: A22, A23, C61, D01, M21

Keywords: *managerial economics, optimization, linear programming, decision making under risk, value of information*

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Calculating capital requirements for operational risk

1. Continuum of measurement approaches for operational risk

The Capital Requirements Regulation (CRR) aims to standardise bank regulation within the EU. It therefore regulates the amount and requirements of the regulatory capital base of institutions, financial holding companies and mixed financial holding companies. The regulation has direct legal effect in the EU states, so that any conflicting national regulations are superseded by the regulation (Andrae 2014, 9; European Council 2020). According to art. 92 (3)(e) CRR, institutions must back their operational risks with own funds. From a regulatory point of view, the operational risk of an institution is understood as the risk of loss resulting from the inadequateness or failure of internal processes, people, and systems or from the occurrence of external events. This definition also includes the legal risks of an institution (art. 4 (1) no. 52 CRR). The need for own funds results from the knowledge that institutions bear considerable operational risks, especially against the background of growing IT dependency and the increasing complexity of their activities (Federal Ministry of Finance 2007, 116).

The CRR provides a tiered concept for calculating the capital required to cover operational risks. According to Part 3 Title III CRR, an institution may use either the Basic Indicator Approach, the (Alternative) Standardised Approach or a so-called Advanced Measurement Approach to determine the capital requirements for operational risk (see Figure 1).

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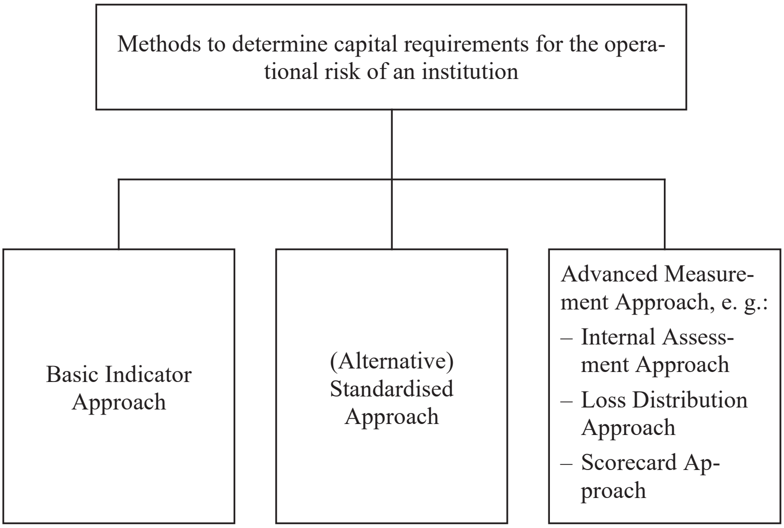

Figure 1. Methods to determine capital requirements for the operational risk of an institution

The various measurement methods of Part 3 Title III CRR are characterized by a different level of risk sensitivity and implementation effort respectively requirements for risk management (see Figure 2). In doing so, they specify the basic order in which these methods should be used by the institutions (Basel Committee on Banking Supervision 2006, 144). If certain qualitative and quantitative minimum standards are met, however, a more risk-sensitive measurement approach can be used right from the start (Basel Committee on Banking Supervision 2001a, 4). The use of an Advanced Measurement Approach instead of the Basic Indicator Approach or (Alternative) Standardised Approach is expected by internationally active institutions as well as by institutions with a significant risk from operational risks (e.g. banks specializing in the processing of transactions) (Basel Committee on Banking Supervision 2006, 144). The various measurement methods are therefore designed in such a way that institutions are rewarded for improving their risk management, because the more advanced the measurement method used, the lower the minimum capital requirements are likely to be (Basel Committee on Banking Supervision 2001a, 14; Buzziol, Steffi 2004, 16–17; Deutsche Bundesbank 2004, 86; Schulte-Mattler, Hermann 2007, 58; Conlon et al. 2020, 34).

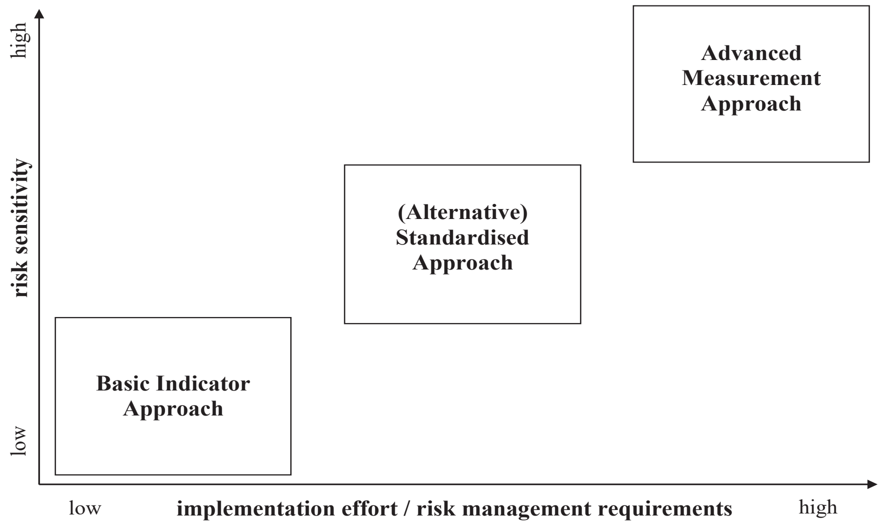

Figure 2. Risk sensitivity and implementation effort respectively risk management requirements of the methods to determine the capital requirements for the operational risk of an institution

In order to facilitate the development of a more risk-sensitive measurement approach, the institutions are given the opportunity – at least temporarily – to move only partially along the intended spectrum of measurement methods, i.e. initially only using a more risk-sensitive measurement method for individual areas of their business activities (so-called 'partial use') if certain minimum requirements are met (Basel Committee on Banking Supervision 2006, 144 and 156). This way an institution can use the Advanced Measurement Approach with either the Basic Indicator Approach or the Standardized Approach. A combination of different approaches, however, always requires permission from the competent supervisory authority (art. 314 (1) CRR). A prerequisite for such a permit is the that the selected combination of approaches captures all operational risks of the institution. In addition, the methodology used by an institution to cover different activities, geographical locations, legal structures or other significant divisions is to be found satisfactory by competent supervisory authorities (art. 314 (2)(a) CRR). Moreover, the criteria set out in art. 320 CRR for the application of the Standardised Approach and the requirements in accordance with art. 321 and 322 CRR for the application of the Advanced Measurement Approaches must be met for those activities covered by the Standardised Approach or the Advanced Measurement Approaches (art. 314 (2)(b) CRR, see Table 3). Additional conditions for a transitional approval of the combination of an Advanced Measurement

Approach with either the Basic Indicator Approach or with the Standardised Approach are that on the date of implementation of an Advanced Measurement Approach a significant part of the institution's operational risks are captured by that approach and that the institution takes a commitment to apply the Advanced Measurement Approach across a substantial part of its operations according to a time schedule approved by the competent supervisory authority (art. 314 (3) CRR). The purpose of these requirements is for institutions to introduce an Advanced Measurement Approach, which goes hand in hand with an improvement in internal management of operational risk, in as large an area of their business activities as possible. It should therefore be ensured that almost all business operations are covered by an Advanced Measurement Approach and, for reasons of practicality, at most an insignificant part of business activity is covered by a simpler measurement method in the long term (Federal Ministry of Finance 2007, 134). However, only in exceptional cases – e.g. the recent acquisition of new business to which the Standardised Approach may only be applied after a transitional period – a permit for the use of the combination of the Basic Indicator Approach and the Standardised Approach may be requested (art. 314 (4)(1) CRR). Here too, the institution must commit itself to applying the Standardised Approach within a time schedule submitted and approved by the competent supervisory authority (art. 314 (4)(2) CRR). This is ultimately intended to establish a consistent method for determining the capital requirements for the operational risk of an institution and thus avoid capital arbitrage (Federal Ministry of Finance 2007, 124).

The progression from a simple measurement method to a more risk-sensitive measurement method usually represents a 'one-way street'. According to art. 313 (1) and (2) CRR, an institution that uses a Standardised Approach or an Advanced Measurement Approach to determine capital requirements for operational risk may only revert to a less sophisticated approach if that institution can prove to the competent supervisory authority, 'that the use of a less sophisticated approach is not proposed in order to reduce the operational risk related own funds requirements of the institution, is necessary on the basis of nature and complexity of the institution and would not have a material adverse impact on the solvency of the institution or its ability to manage operational risk effectively' (art. 313 (3)(a) CRR). Approval from the competent supervisory authority to return to a less sophisticated method must be applied for in advance by the institution (art. 313 (3)(b) CRR).

2. Basic Indicator Approach

The Basic Indicator Approach is the simplest method for determining the own funds that an institution must hold for its operational risks. According to the rules of this measurement procedure, the calculation of the capital requirement for operational risks of an institution is based on a single risk indicator, which serves as an approximation for the full scope of operational risks of this institution. This risk indicator is the so-called ‘relevant indicator’. In accordance with art. 315 (1)(1) CRR, the capital requirements for operational risks of an institution using the Basic Indicator Approach are equal to 15% of the three-year average of the relevant indicator. The three-year average of the relevant indicator is calculated based on the last three twelve-monthly observations at the end of the financial year (art. 315 (1)(2) sentence 1 CRR). If no audited figures are available, the calculation may also be based on internal estimates of these annual values (art. 315 (1)(2) sentence 2 CRR). The purpose of using a three-year average is to reduce variation in the capital requirements for operational risk (Federal Ministry of Finance 2007, 118). When determining the three-year average of the relevant indicator, however, only annual values with a positive value are taken into account (art. 315 (4)(1) CRR). The three-year average of the relevant indicator is therefore always calculated ‘as the sum of positive figures divided by the number of positive figures’ (art. 315 (4) sentence 2 CRR). Therefore, if a negative relevant indicator occurs in one of the last three years, the determination of the capital requirements for operational risk is based only on the two-year average of the years with a positive relevant indicator. For institutions whose relevant indicator is equal to zero or negative in all three years considered, this results in an own funds requirement for operational risk equal to zero. However, this case is unlikely to be of any significance in practice. The rule that only annual values with a positive value are to be considered in the calculation is intended to ensure that even in case of a negative earnings situation of the institution the operational risks inherent in the business of this specific institution are still backed with own funds (Federal Ministry of Finance 2007, 118). Pattern 1 summarizes the above remarks in a formula.

$$CR_{OR} = 0{,}15 \cdot \left[\frac{1}{n} \cdot \sum_{i=1}^{n} rI_i \right]$$

CR_{OR} = capital requirements for operational risk
i = financial year i
n = number of financial years i with a positive relevant indicator (a maximum of three years)

Pattern 1. Conception of the Basic Indicator Approach

The relevant indicator is defined in art. 316 CRR. Accordingly, the relevant indicator is to be calculated based on the items listed in Pattern 2, considering the structure of the profit and loss accounts of institutions according to art. 27 of the directive on consolidated financial statements (art. 316 (1)(1) CRR). The directive on consolidated financial statements aims to harmonise the accounting standards of credit institutions within the EU (Rogler 2020, 204–205).

relevant indicator = interest receivable and similar income

–	interest payable and similar charges
+	income from shares and other variable/fixed-yield securities
+	commissions/fees receivable
–	commissions/fees payable
+/–	net profit or net loss on financial operations
+	other operating income

Pattern 2. Calculation of the relevant indicator according to art. 316 CRR

The list in Pattern 2 makes it clear that the calculation of the relevant indicator does not include any deductions in the form of provisions, risk provision amounts and operating expenses (art. 316 (1)(2)(a) sentence 1 CRR). In addition, expenses for outsourced services that are provided by third parties may only reduce the relevant indicator if the expenditure is incurred by a company that is also subject to the CRR or equivalent regulations (art. 316 (1)(2)(a) sentence 3 CRR). This also applies if they are included in the operating expenses. Furthermore, the following items must not be included in the calculation of the relevant indicator (art. 316 (1)(2)(b) CRR):

1) realised profits/losses from the sale of non-trading book items,
2) income from extraordinary or irregular items,
3) income derived from insurance.

The removal of extraordinary or irregular income and realised profits/losses from the sale of non-trading book items from the calculation of the relevant indicator can be justified by the fact that in this way larger variations in the relevant indicator can be avoided. The disregard of income derived from insurance in the calculation of the relevant indicator can be explained by the separate supervision of companies conducting insurance business. Since commissions received from insurance brokerage is not included in income derived from insurance, it is part of the relevant indicator (Federal Ministry of Finance 2007, 119).

If revaluations of trading items are part of the profit and loss statement of an institution, they may be included in the calculation of the relevant indicator (art. 316 (1)(2)(c) sentence 1 CRR). If an institution applies art. 36 (2) of the directive on consolidated financial statements and accounts for transferable securities which are not held as financial fixed assets at the higher market value at the balance sheet date, there is an obligation to include revaluations booked in the profit and loss account in the calculation of the relevant indicator (art. 316 (1)(2)(c) sentence 2 CRR).

If an institution does not prepare its annual financial statements according to the specifications of the directive on consolidated financial statements or its implementation in national law, but according to other accounting standards (e.g. according to IFRS), the calculation of the relevant indicator must be based on data that best reflect the definition set out in art. 316 CRR (art. 316 (2) CRR).

The Basic Indicator Approach represents the entry-level method for calculating the capital requirements for an institution's operational risk. Therefore, the CRR does not provide any special requirements for the use of this measurement method (Buzziol 2004, 17; Köhne 2005, 282). Nonetheless, those institutions that decide to use the Basic Indicator Approach are asked to follow the guidelines set out by the Basel Committee on Banking Supervision in the paper 'Principles for the Sound Management of Operational Risk' (Lenzmann 2008, 290; Basel Committee on Banking Supervision 2011; Kiszka 2018, 44–49). In 2021, the Basel Committee on Banking Supervision published a revised version of these principles (Waschbusch, Kiszka 2020b, Basel Committee on Banking Supervision 2021). Ultimately, however, the application of the Basic Indicator Approach is in no way equal to a 'real risk measurement' (Schulte-Mattler 2007, 59). Although the relevant indicator is a variable that can largely be derived from the institutions' profit and loss account, a connection to the actual operational risk profile of an institution cannot be established with the aid of the relevant indicator. In this context, the Federal Ministry of Finance of Germany speaks of an indirect measure of the scope of business activities and thus also of the operational risks of an institution (Federal Ministry of Finance 2007, 118). A simple connection between the earnings and the operational risk profile of an institution is assumed (Auer 2008, 45). In particular, however, the regulatory 'punishment' of additional income by the Basic Indicator Approach is diametrically opposed to the business policy goals of an institution (Schulte-Mattler 2007, 59). After all, the fixing of the multiplication factor at 15% is only a blanket estimate by the banking supervisory authority. In this respect, the Basic Indicator Approach does not identify weaknesses of operational nature in an institution and consequently cannot make any significant contribution to the management of operational risk. Institutions are not given any incentive to improve their operational risk profile or risk management, since ultimately only a reduction in the income generated enables a reduction in capital requirements (Buchmüller 2001, 12). Finally, when using the Basic Indicator Approach operational risks that have materialized result in a reduction of capital requirement due to the decline in earnings that those risks have caused (Capobianco 2014, 4; Enrique 2015, 8), rather than increasing the capital requirements because of a higher risk profile.

3. Standardised Approach

If an institution intends to use the Standardised Approach to calculate the capital requirements for operational risk instead of the Basic Indicator Approach, it has to qualify for the use of the Standardised Approach by meeting the requirements of art. 320 CRR (art. 312 (1)(1) sentence 1 CRR; see Table 3). The institution must notify the competent authorities prior to using the Standardised Approach (art. 312 (1)(1) sentence 2 CRR). If an institution decides to use the Standardised Approach, it must first assign its business activities to the eight regulatory business lines listed in art. 317 (4) CRR (art. 317 (1) CRR), which are shown in Table 1. The relevant indicator to be determined in accordance with the requirements of art. 316 (1) CRR is then allocated proportionally to these eight regulatory business lines (art. 317 (2) sentence 2 CRR). The last three financial year values are also decisive for the calculation of the relevant indicator in the Standardised Approach (art. 317 (2) sentence 1 in conjunction with (4)(1) sentence 1 CRR). If no audited figures are available, business estimates of these annual values can also be used for the calculation (art. 317 (4)(1) sentence 2 CRR).

Table 1

Mapping of business activities into the regulatory business lines of the Standardised Approach

Regulatory business line	List of activities
Corporate Finance	– underwriting of financial instruments or placing of financial instruments on a firm commitment basis – services related to underwriting – investment advice – advice to undertakings on capital structure, industrial strategy and related matters and advice and services relating to the mergers and the purchase of undertakings – investment research and financial analysis and other forms of general recommendation relating to transactions in financial instruments

Table 1 cont.

Trading and Sales	– dealing on own account – money broking – reception and transmission of orders in relation to one or more financial instruments – execution of orders on behalf of clients – placing of financial instruments without a firm commitment basis – operation of Multilateral Trading Facilities Corresponding transactions with retail customers are assigned to Retail Brokerage.
Payment and Settlement	– money transmission services – issuing and administering means of payment
Agency Services	– safekeeping and administration of financial instruments for the account of clients, including custodianship and related services such as cash/collateral management
Commercial Banking	– acceptance of deposits and other repayable funds – lending – financial leasing – guarantees and commitments Corresponding transactions with retail customers are assigned to Retail Banking.
Retail Banking[1]	– acceptance of deposits and other repayable funds – lending – financial leasing – guarantees and commitments
Asset Management	– portfolio management – managing of UCITS – other forms of asset management
Retail Brokerage[1]	– reception and transmission of orders in relation to one or more financial instruments – execution of orders on behalf of clients – placing of financial instruments without a firm commitment basis

[1] These are transactions with retail customers. Business with retail customers includes business with natural persons or small and medium-sized companies, which are to be classified as retail exposure in analogous application of the criteria of art. 123 CRR.

In addition to the mapping of an institution's business activities into the separate regulatory business lines, the CRR determines a beta factor in the form of a fixed percentage for each of the eight regulatory business lines listed (art. 317 (2) sentence 2 CRR in conjunction with table 2 in art. 317 (4) CRR). These beta factors represent the relationship between the industry-wide operating losses in a specific regulatory business line and the industry-wide relevant indicators for this regulatory business line (Basel Committee on Banking Supervision 2001b, 7; Basel Committee on Banking Supervision 2006, 147). A beta factor of e.g. 12% in the 'Asset Management' business line means that the operational losses that have occurred in this business line amount to 12% of the relevant indicator generated in the 'Asset Management' business line across the industry. Table 2 provides a summary of the regulatory business lines, relevant indicators and beta factors defined in the Standardised Approach. The allocation of the relevant indicator from an institution's own business lines and activities to the separate regulatory business lines must be made in accordance with the requirements of art. 318 CRR. In this regard, art. 318 (1) CRR calls for the development of specific policies and criteria for mapping the relevant indicators for current business lines and activities into the standardised framework shown in Table 1. These policies and criteria are to be documented, reviewed and adjusted regarding new or changed business activities and risks.

Table 2

Regulatory business lines, risk indicators and beta factors in the Standardised Approach

Regulatory Business Line	Risk Indicator	Beta factor
Corporate Finance	relevant indicator $_1$	β_1 = 18%
Trading and Sales	relevant indicator $_2$	β_2 = 18%
Payment and Settlement	relevant indicator $_3$	β_3 = 18%
Agency Services	relevant indicator $_4$	β_4 = 15%
Commercial Banking	relevant indicator $_5$	β_5 = 15%
Retail Banking	relevant indicator $_6$	β_6 = 12%
Asset Management	relevant indicator $_7$	β_7 = 12%
Retail Brokerage	relevant indicator $_8$	β_8 = 12%

Art. 318 (2) CRR also includes the following requirements for the development of policies and criteria for the mapping of business activities into the regulatory business lines in the Standardised Approach:

1. Every business activity can be assigned to exactly one regulatory business line. In this context it must be considered that the regulatory business lines do not necessarily have to correspond to the internal business lines or business

areas originating from the internal organisation of the institution (Federal Ministry of Finance 2007, 122). In case of need, a corresponding reconciliation is therefore necessary.

2. Supporting activities that cannot be directly assigned to a regulatory business line are to be assigned to the regulatory business line that they support. If an activity supports several business activities that can be assigned to different regulatory business lines, an objective criterion must be used for the assignment of this supporting activity.
3. Business activities which cannot be assigned to any regulatory business line, including the activities that support them, are to be fully assigned to a regulatory business line with the highest beta factor.
4. When allocating the relevant indicator to regulatory business lines, internal pricing methods can be used. However, this must be factually justified. In addition, costs generated that arise within one regulatory business line but are imputable to a different regulatory business line may be assigned to the regulatory business line to which they pertain.
5. The criteria for mapping business activities into the regulatory business lines must be consistent with the criteria used in the credit and market risk area.
6. The responsibility for the policies and criteria for the mapping of business activities and the relevant indicator into the separate regulatory business lines lies with the senior management under the control of the management body of the institution.
7. The mapping process must be subject to an independent review by internal or external auditors. This is to be understood as a person who is not identical to the person who conducted the mapping process and who is not dependent on the instructions of the latter (Federal Ministry of Finance 2007, 133).

The procedure for determining the capital requirements for the operational risk of an institution that uses the Standardised Approach is regulated in art. 317 (2) CRR. According to this, the capital requirements for the operational risk of an institution correspond to 'the average over three years of the sum of the annual own funds requirements across all regulatory business lines' (art. 317 (2) sentence 1 CRR). The annual own funds requirement of each regulatory business line results from the weighting of the relevant indicator mapped to the respective regulatory business line with the beta factor assigned to this specific regulatory business line (art. 317 (2) sentence 2 CRR). If there is a negative own funds requirement in a regulatory business line in a given financial year, which results from a negative value of the relevant indicator assigned to this regulatory business line, this negative own funds requirement can be offset against the positive own funds requirements in other regulatory business lines of this financial year without limitation (art. 317 (3) sentence 1 CRR). However, if the sum of the capital requirements of all regulatory business lines within a given financial year is negative, the relevant indicator for this year will be considered as zero within the numerator (art. 317 (3) sentence 2 CRR). In contrast to the calculation of the capital requirements for an institution's operational risk using the Basic Indicator Approach, the value of the denominator of the three-year average does not decrease in such a case; rather it is still "3" (Federal Ministry of Finance 2007, 121). The following Pattern 3 summarizes the above statements in a formula.

$$CR_{OR} = \frac{1}{3} \cdot \sum_{i=1}^{n} \left(\max \left\{ 0; \sum_{j=1}^{k} rI_j \cdot \beta_j \right\} \right)_i$$

CR_{OR} = capital requirements for operational risk
i = financial year i (i = 1, 2, 3)
n = number of financial years i with a positive relevant indicator (n = 3)
j = regulatory business line j (j = 1, …, 8)
k = number of regulatory business lines j (k = 8)
rI_j = relevant indicator of the regulatory business line j
β_j = beta factor of the regulatory business line j
$rI_j \cdot \beta_j$ = capital requirement of the regulatory business line j

Pattern 3. Conception of the Standardised Approach

Art. 319 CRR gives institutions the option of using the so-called Alternative Standardized Approach instead of the Standardized Approach. In the Alternative Standardized Approach, an institution is allowed to replace the relevant indicator for the calculation of the capital requirements in the regulatory business lines 'Retail banking' and 'Commercial banking' with an alternative indicator, which corresponds to 0.035 times the nominal amount of loans and advances (art. 319 (1)(a) CRR). The loans and advances in Retail Banking and Commercial Banking consist of the total drawn amounts in the respective credit portfolios in accordance with art. 319 (1)(b) sentence 1 CRR. In Commercial banking the securities held in the non-trading book must also be added in accordance with art. 319 (1) (b) sentence 2 CRR. Otherwise, the calculation of the own funds requirements for the operational risk of an institution corresponds to the procedure in the Standardised Approach. In particular, the same beta factors as in the Standardised Approach apply to these two regulatory business lines. Pattern 4 demonstrates the calculation of the capital requirement for the operational risks of an institution using the Alternative Standardised Approach.

The use of the Alternative Standardised Approach for calculating the capital requirements for the operational risk of an institution, however, is only permitted if the following conditions are cumulatively met (art. 319 (2) CRR):

– At least 90% of the institution's income is derived from the two regulatory business lines 'Retail Banking' and 'Commercial Banking'.
– A significant proportion of the retail or commercial banking activities consists of loans associated with a high probability of default.
– The Alternative Standardised Approach provides an appropriate basis for calculating the capital requirements for operational risk.

The application of the Alternative Standardised Approach is also subject to prior approval by the competent supervisory authorities (art. 312 (1)(2) CRR).

$$CR_{OR} = \frac{1}{3} \cdot \sum_{i=1}^{n} \left(\max\left\{ 0; \sum_{j=1}^{k} (rI_j \cdot \beta_j) + m \cdot nala_{RB} \cdot \beta_{RB} + m \cdot nala_{CB} \cdot \beta_{CB} \right\} \right)_i$$

CR_{OR} = capital requirements for operational risk
i = financial year i (i = 1, 2, 3)
n = number of financial years i with a positive relevant indicator (n = 3)
j = regulatory business line j (j = 1, …, 6); this does not include the two regulatory business lines 'Retail Banking' and 'Commercial Banking'
k = number of regulatory business lines j (k = 6)
rI_j = relevant indicator of the regulatory business line j
β_j = beta factor of the regulatory business line j
$rI_j \cdot \beta_j$ = capital requirement of the regulatory business line j
m = factor of 0.035
$nala_{RB}$ = nominal amount of loans and advances of the regulatory business line 'Retail Banking'
$nala_{CB}$ = nominal amount of loans and advances of the regulatory business line 'Commercial Banking'
β_{RB} = beta factor of the regulatory business line 'Retail Banking'
β_{CB} = beta factor of the regulatory business line 'Commercial Banking'

Pattern 4. Conception of the Alternative Standardised Approach

In general, the assignment of business activities and the relevant indicator of an institution to the separate regulatory business lines in the Standardised Approach represents a step forward compared to the procedure of the Basic Indicator Approach. If it is possible to delimit the regulatory business lines of an institution in a useful way and to determine the beta factors in such a way that they estimate the specific operational risks of the individual regulatory business line with sufficient accuracy in relation to the relevant indicator assigned, the Standardised Approach possesses a higher risk sensitivity compared to the Basic Indicator Approach. It is obvious that the consideration of the focus of activity within an institution leads in principle to a more realistic mapping of the operational risks than the use of a single indicator that represents the entire operational risks of an institution. In practice, however, the precise delimitation of the eight regulatory business lines is seen as a major problem. The mapping of the different business activities of an institution into the individual regulatory business lines usually causes a high level of implementation effort. In addition, the beta factors specified by the banking supervisory authorities do not exhibit any statistically significant relationships between the operational risks and the relevant indicator of the individual regulatory business lines. Thus, the Basel Committee on Banking Supervision found inconsistencies in the assessment of the risk potential of the individual regulatory business lines in the past (Federal Financial Supervisory Authority 2009, 15; Basel Committee on Banking Supervision 2014, 7). Therefore, the Standardised Approach is unlikely to be suitable for adequately mapping the operational risks inherent in the individual regulatory business lines of an institution. The Standardized Approach, just like the Basic Indicator Approach, does not allow a precise measurement of the operational risk profile of an institution (Schulte-Mattler 2007, 59). Ultimately, this is due to the fact that the calculation of the capital requirements for the operational risk of an institution in both measurement methods is not based on any institution-specific loss data (Schulte-Mattler 2007, 59). The above conclusion that neither the Basic Indicator Approach nor the Standardised Approach are linked to the actual operational risk profile of an institution applies equally to the Alternative Standardised Approach.

4. Advanced Measurement Approaches

According to art. 312 (2)(1) CRR, an institution may use an Advanced Measurement Approach instead of the Basic Indicator Approach or the (Alternative) Standardised Approach to determine the capital requirements for operational risk. However, the use of an Advanced Measurement Approach requires prior approval by the competent supervisory authority. Apart from this, the CRR grants the institutions a high degree of flexibility in developing Advanced Measurement Approaches for calculating the capital requirement for operational risks. Institutions can use measurement approaches that are based on their own systems for measuring operational risk, as long as they meet all the qualitative and quantitative requirements of art. 321 and 322 CRR as well as the general risk management standards of art. 74 and 85 CRD (art. 312 (2)(1) CRR). Table 3 summarizes these minimum requirements.

Table 3

Minimum requirements for the use of the (Alternative) Standardised Approach or Advanced Measurement Approaches

<table>
<tr><th>(Alternative) Standardised Approach</th><th>Advanced Measurement Approach</th></tr>
<tr><td colspan="2">establishment of a well-documented system for identifying, assessing, managing and controlling of operational risk with clearly assigned responsibilities</td></tr>
<tr><td colspan="2">regular independent reviews of the risk management system for operational risks by internal or external auditors</td></tr>
<tr><td colspan="2">integration of the system for assessing operational risks in the risk management processes of the institution</td></tr>
<tr><td colspan="2">establishment of a management reporting system and methods to take appropriate corrective action</td></tr>
<tr><td>collection of the relevant data for operational risk, including material loss data</td><td>independent central risk management function</td></tr>
<tr><td rowspan="2">consideration of the results of the system for assessing operational risks as an integral part of the processes for monitoring and controlling the operational risk profile of the institution</td><td>solid and effective validation processes</td></tr>
<tr><td>transparent and accessible data flows and processes related to the risk measurement system</td></tr>
<tr><td></td><td>methods that capture both expected and unexpected losses from operational risks, severe events on the edge of distribution, key risk drivers and correlations</td></tr>
<tr><td></td><td>calculation of the capital requirements for operational risk based on internal loss data, external data, scenario analyses as well as bank-specific business environment and internal control factors, including expert judgments</td></tr>
<tr><td></td><td>ensuring the internal coherence of the risk measurement system and avoidance of multiple counting of qualitative assessments or risk reduction techniques that are recognized in other parts of the CRR</td></tr>
<tr><td></td><td>at least five-year observation period for internal loss data (three years if the method is approved for the first time)</td></tr>
<tr><td></td><td>documentation of the framework for risk measurement, internal review and audit by the competent supervisory authority</td></tr>
</table>

According to art. 312 (2)(2) CRR, significant changes and extensions to an Advanced Measurement Approach that has already been approved require renewed approval from the competent supervisory authority. In addition, the competent supervisory authority must be notified of any change made to an Advanced Measurement Approach (art. 312 (3) CRR).

In addition to these minimum requirements for the usage of an Advanced Measurement Approach, further requirements for the use of internal and external data, scenario analyses and factors that affect the business environment and the internal control systems of the institution are included in art. 322 CRR. For example, an institution must be able to map its historical internal loss data into the business lines of the Standardised Approach according to art. 317 CRR and, in addition, into the event types according to art. 324 CRR (art. 322 (3)(b) CRR) – as shown in Table 4.

Table 4

Event categories for mapping historical internal loss data

Event-type Category	**Losses due to:**
Internal fraud	– acts of a type intended to defraud – misappropriate property – circumvent regulations, the law or company policy This does not apply to losses due to diversity or discrimination events if at least one internal party is involved.
External fraud	– acts of a type intended to defraud, – misappropriate property – circumvent the law These losses must each be caused by a third party.
Employment Practices and Workplace Safety	– acts inconsistent with employment, health or safety laws or agreements – payment of personal injury claims – diversity or discrimination events
Clients, Products & Business Practices	– an unintentional or negligent failure to meet a professional obligation to specific clients (including fiduciary and suitability requirements) – the nature or design of a product
Damage to Physical Assets	– loss or damage to physical assets from natural disaster or other events
Business disruption and system failures	– disruption of business – system failures
Execution, Delivery & Process Management	– failed transaction processing or process management – relations with trade counterparties and vendors.

In contrast to the regulations of the Basic Indicator Approach and the (Alternative) Standardised Approach, institutions that decide to use an Advanced Measurement Approach are permitted to recognise the risk mitigating effect of insurance and other risk transfer mechanisms when calculating their own funds requirements for operational risk (art. 323 (1) CRR). By taking insurance and other risk transfer mechanisms into account, however, the capital requirements for operational risk may be reduced by a maximum of 20% compared to its amount before the recognition of risk mitigation techniques (art. 323 (5) CRR). This limitation of the recognition of the risk-reducing effect of insurance and other risk transfer mechanisms is justified by the fact that an adequate capital requirement for operational risk is to be guaranteed (Federal Ministry of Finance 2007, 131).

For an institution to be allowed to consider the risk-reducing effect of insurance contracts, all of the following requirements must be met (art. 323 (2) and (3) CRR):

- The insurance provider is authorised to provide insurance or re-insurance.
- The insurance provider has an appropriate credit rating. This is considered to be given if the insurance provider is assigned at least credit quality step 3 under the rules of the Standardised Approach for measuring credit risks.
- The insurance policy has an initial term of no less than one year.
- If the insurance policy includes a notice period for cancellation of the contract, it is at least 90 days.
- The insurance policy does not contain any exclusion clauses or limitations on insurance coverage in the event of supervisory actions, nor those which preclude the institution's receiver or liquidator from recovering the damages suffered or expenses incurred by the institution in case of a failed institution. This does not apply to events that occurred after the initiation of receivership or liquidation proceedings in respect of the institution. However, the insurance policy may exclude any fines, penalties or punitive damages resulting from actions by the competent authorities.
- The insurance coverage is calculated in a transparent and consistent manner with the likelihood and impact of loss used in the overall determination of operational risk capital.
- The insurance is provided by a third party entity. In the case of insurance through captives and affiliates, the insured risk must be transferred to an independent third party. This regulation is intended to ensure that the conclusion of an insurance policy leads to an additional coverage for risks (Federal Ministry of Finance 2007, 133).
- The framework for recognising insurance is well reasoned and documented.

In addition, art. 323 (4)(a) and (b) CRR determines that when taking into account the risk-reducing effect of insurance suitable discounts must be made for insurance policies with residual term or cancellation term being less than one year. For example, in the case of insurance policies with a residual term of less than one year, the institution applies appropriate haircuts in order to take into account the decreasing residual term of the insurance policy, up to a 100% haircut for insurance policies with a residual term of 90 days or less (art. 323 (3) (a) sentence 2 CRR). Appropriate discounts or haircuts must also be applied if there are payment uncertainties or mismatches in coverage of insurance policies (art. 323 (4)(c) CRR).

Only the Advanced Measurement Approaches, including the Internal Measurement Approach as well as various types of Loss Distribution and Scorecard Approaches can provide an individual and risk-adequate measurement of operational risk, as there is a tangible connection between the operational risk profile and the resulting capital requirements. Thus, suitable control measures can be introduced. This advantage of the Advanced Measurement Approaches is offset by the high requirements that must be met when using these approaches and that go hand in hand with considerable investments in management tools and specialist staff.

It should be noted, however, that even the Advanced Measurement Approaches do not necessarily ensure reflecting the actual risk situation, as quality defects, e.g. due to an inadequate database or the selection of unsuitable indicators or scenarios, can negatively affect the significance of the models. Furthermore, there is a certain scope for manipulation when designing the models. For this reason, when the Advanced Measurement Approaches were introduced, it was criticized that institutions can design the models just the way they want to. This is problematic due to the different objectives that are being pursued. The internal models are usually based on efforts to optimize shareholder value, whereas regulatory measurement approaches try to guarantee the solvency of the banking sector. Attempts are made to limit this scope for manipulation through the approval and monitoring of the models by the competent supervisory authorities. On top of that, the flexibility in choice of method leads to a lack of comparability of the different Advanced Measurement Approaches. Ultimately, the Basel Committee on Banking Supervision found that when using Advanced Measurement Approaches, there are large differences in the capital requirements of institutions, which, however, are difficult to justify due to similar risk profiles of these institutions (Kiszka 2018, 91–94 as well as the references given there).

5. Outlook on the changes resulting because of the Basel III finalisation

Based on the experience in the implementation of the previous measurement approaches for operational risk gained in recent years and because many of the aforementioned weaknesses of the measurement approaches have become apparent, the adequacy of the previous capital framework was reviewed by the Basel Committee on Banking Supervision (Basel Committee on Banking Supervision 2014, 5; KPMG 2014, 2; Kiszka 2018, 95). As a result of this review, the final Basel III reform package was published on December 7, 2017 (Basel Committee on Banking Supervision 2017; Feridun, Özün 2020, 8), which is currently being transposed into European and national law. According to the notion of the Basel Committee on Banking Supervision, the new requirements must be implemented by January 1, 2023 at the latest. The implementation was originally planned by January 1, 2022. However, this implementation date was postponed by one year due to the burdens on the institutions because of the corona pandemic (Waschbusch, Kiszka 2020a).

Since institutions that use an Advanced Measurement Approach to determine capital requirements for operational risk have not been able to establish a consistent market standard and this ultimately resulting in a wide range of calculated capital requirements, institutions are no longer allowed to use an Advanced Measurement Approach in the future (the statements in this chapter largely refer to Deutsche Bundesbank 2018, 88–89 in conjunction with Basel Committee on Banking Supervision 2017, 128–130). Instead, the new Standardised Measurement Approach was developed, which will replace the Basic Indicator Approach and the previous Standardised Approach. This new Standardised Measurement Approach is designed similarly to the Basic Indicator Approach in that it also considers the three-year average of a single risk indicator. However, since the previous risk indicator proved to be unsuitable in the Great Financial Crisis of 2007/2008, the calculation of the capital requirement for operational risk will be based on the so-called business indicator (BI), the composition of which is shown in Table 5.

The business indicator consists of an interest, leases and dividend component (ILDC), a service component (SC) and a financial component (FC). All components are considered with a positive sign, so that a negative component does not reduce the business indicator. The three-year average is calculated for all sub-items underlined in Table 5.

Table 5

Calculation of the business indicator in the new Standardised Measurement Approach

Business Indicator	**= Interest, Leases and Dividend Component (ILDC) + Service Component (SC) + Financial Component (FC)**
ILDC	Min [Absolute Value (Interest Income – Interest Expense); 2.25% · Interest Earning Assets] + Dividend Income
SC	Max [Other Operating Income; Other Operating Expense] + Max [Fee Income; Fee Expense]
FC	Absolute Value (Net Profit/Loss Trading Book) + Absolute Value (Net Profit/Loss Banking Book)

Due to the importance of the institution's size for the operational risk profile, marginal coefficients are introduced (Feridun, Özün 2020, 15). For this purpose, the institution's business indicator – as shown in Table 6 – is assigned to three buckets.

Table 6

Buckets for determining the business indicator component in the new Standardised Measurement Approach

Bucket	**Business Indicator range (in €bn)**	**Business Indicator marginal coefficients**
1	≤ 1	12%
2	1 < BI ≤ 30	15%
3	> 30	18%

The so-called business indicator component is calculated by multiplying the business indicator by the marginal coefficients. The respective marginal coefficients relate to that portion of the business indicator that is assigned to the corresponding bucket, which is intended to counteract a sudden increase in capital requirements when the bucket limits are exceeded (Kiszka 2018, 101). For an institution a business indicator in the amount of 35 €bn, results in a business indicator component of:

$$1 \text{ €bn} \cdot 12\% + 29 \text{ €bn} \cdot 15\% + 5 \text{ €bn} \cdot 18\% = 5{,}37 \text{ €bn}.$$

To increase the risk sensitivity of the new Standardised Measurement Approach, a loss component was introduced, which represents the loss potential of an institution, which is derived from its past loss experience. The loss component is equal to 15 times the average annual operational losses incurred over the previous 10 years. The loss component is then considered in the capital requirements using the so-called internal loss multiplier, which is calculated as follows:

$$\text{internal loss multiplier} = \text{Ln}\left\{\exp(1) - 1 + \left(\frac{\text{loss component}}{\text{business indicator component}}\right)^{0,8}\right\}$$

Ultimately, the capital requirements for operational risk in the new Standardised Measurement Approach are determined by the product of the business indicator component and the internal loss multiplier. The latter thus scales the business indicator component up or down (Kiszka 2018, 118). As a result, this means that the capital requirements for operational risk increase if the losses incurred by an institution are above average in a long-term comparison. However, by using a logarithmic function, the internal loss multiplier rises less and less as the loss component increases. If, on the other hand, comparatively few operational losses have occurred, the capital requirement can be reduced by half, so that the integration of the loss component creates an incentive for effective risk management. The above explanations are combined in a formula in Pattern 5.

$$CR_{OR} = BIC \cdot ILM$$

CROR = capital requirements for operational risk
BIC = business indicator component
ILM = internal loss multiplier

Pattern 5. Conception of the Standardised Measurement Approach

For institutions with a business indicator that does not exceed 1 bn, the loss component does not apply, so that for small institutions the capital requirements for operational risk will correspond to the business indicator component (= 12% of the business indicator). This regulation is intended to relieve smaller institutions but was criticized during the consultation phase. Smaller institutions would be discriminated against, despite a possibly existing database on historical losses, and unequal competitive conditions would be created. In this context, in the consultation phase an option to integrate the loss multiplier for small institutions was proposed, which, however, was not included in the final Basel paper (Capobianco 2016, 8).

In principle, however, the loss component is not mandatory and can therefore be disregarded at national discretion (Feridun, Özün 2020, 15), which would, however, severely limit risk sensitivity. The Deutsche Börse Group comes to the conclusion that, after 20 years of exchange and the development of a new measurement method, the new Standardised Measurement Approach is an appropriate method for calculating the capital requirement for the operational risk of an institution (Thompson, Hillen 2016, 5), even though some of the aforementioned criticism of the previous approaches is still partially valid.

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Summary

Operational risks have become increasingly important for banks, especially against the background of growing IT dependency and the increasing complexity of their activities. Further-more, the corona pandemic contributed to the increased risk potential. Therefore, banks have to back these risks with own funds. There are currently three measurement approaches for determining the capital requirements for operational risk. In recent years, and especially during the Great Financial Crisis of 2007/2008, however, some of the weaknesses inherent in these approaches have become apparent. Thus, the Basel Committee on Banking Supervision revised the current capital framework. Therefore, this article examines the various measurement approaches, addresses inherent weaknesses and moreover, presents the future measurement approach developed by the supervisory authorities.

JEL codes: G21, G22, G28, G32, M16, M21, C02

Keywords: *banking, banking supervision, operational risk, measurement approaches*

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All illustrations, figures, and tables are placed within the text at the appropriate points, rather than at the end.

Title page should include a footnote, giving the author(s) affiliation(s) (including postal and e-mail addresses of all authors).

Figures must be prepared in a form suitable for direct reproduction. Digital artwork at least 300 dpi resolution is accepted. Photographs, on glossy paper (9 by 13 cm or larger), should display sharp contrast. Figures, tables and photographs should be numbered according to their reference in text.

Illustrations should be edited in CorelDraw (*.CDR), DrawPerfect (*.WPG) or in any other vector graphics form e.g. HPGL, Encapsulated PostScript (*.EPS), Computer Graphics Metafile *.CGM) or bitmaps (*.TIF, *.PCX).

Mathematical equations within the text should be written in separate lines, numbered consecutively (numbers within round brackets) on the right-hand side. Greek characters must be written out clearly.

Summary and 3–5 keywords should be submitted in separate file containing the name of the author, title of the paper with the heading “Summary”.

Authors using Word are requested to employ, as far as possible, text form of mathematical symbols leaving graphic form for the equations longer than single line.

Reference style

In general, the authors should use the Harvard style of referencing. References to literature within the text should be given in the form: the name of the author(s) and the year of publication (in parentheses), e.g. "Smith (1990) underlines…", "As shown in Smith (1990)…". In case of more than two authors of the cited publication the "et al." shortcut should be used.

Lists of references should be written in alphabetical-chronological order, numbered and follow the rules:

- JOURNAL ARTICLE

Muller, V. (1994) 'Trapped in the body: Transsexualism, the law, sexual identity', *The Australian Feminist Law Journal*, vol. 3, August, pp. 103–107.

- BOOKS

Book with one author

Adair, J. (1988) Effective time management: How to save time and spend it wisely, London: Pan Books.

Book with two authors

McCarthy, P. and Hatcher, C. (1996) Speaking persuasively: Making the most of your presentations, Sydney: Allen and Unwin.

Book with three or more authors

Fisher, R., Ury, W. and Patton, B. (1991) Getting to yes: Negotiating an agreement without giving in, 2nd edition, London: Century Business.

Book – second or later edition

Barnes, R. (1995) Successful study for degrees, 2nd edition, London: Routledge.

Book by same author in the same year

Napier, A. (1993a) Fatal storm, Sydney: Allen and Unwin.
Napier, A. (1993b) Survival at sea, Sydney: Allen and Unwin.

Book with an editor

Danaher, P. (ed.) (1998) Beyond the ferris wheel, Rockhampton: CQU Press.

A chapter in a book

Byrne, J. (1995) 'Disabilities in tertiary education', in Rowan, L. and McNamee, J. (ed.) Voices of a Margin, Rockhampton: CQU Press.

- WORLD WIDE WEB PAGE

Young, C. (2001) English Heritage position statement on the Valletta Convention, [Online], Available: http://www.archaeol.freeuk.com/EHPostionStatement.htm [24 Aug 2001].

- CONFERENCE PAPERS

Hart, G., Albrecht, M., Bull, R. and Marshall, L. (1992) 'Peer consultation: A professional development opportunity for nurses employed in rural settings', Infront Outback – Conference Proceedings, Australian Rural Health Conference, Toowoomba, pp. 143–148.

- NEWSPAPER ARTICLES

Cumming, F. (1999) 'Tax-free savings push', Sunday Mail, 4 April, p. 1.

All the items cited in the main text, and no other items, must be placed in the list of references.

Authors should include 2–3 JEL codes with manuscript during submission. For more details on the JEL classification system CLICK HERE.

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