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Lessons on risk management from the finance sector for climate change adaptation in Scotland's forestry sector

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Executive summary

This report explores the applicability of risk measurement and management approaches used in the financial sector to climate change adaptation practices for the Scottish forestry sector. The main focus is on productive forestry, with additional consideration of the potential effects of adopting the techniques discussed on wider forestry objectives.

A number of financial risk measurement and management approaches suitable to Scottish forestry are discussed in this report. The approaches taken to measure and monitor risk, and the experiences of the finance sector – particularly during the recent financial crises – provide many lessons for the forestry sector as it seeks to adapt to the challenges of climate change. Whilst many of the approaches outlined in this document are about reducing financial loss to the sector to ensure sector activities are preserved and supported, there are some lessons for wider preparatory approaches, and financial security itself will be an important factor in the resilience of the sector.

Key findings

- The process of risk measurement aims to quantify and measure risk over and above that which is expected i.e. it focuses on unexpected/catastrophic loss rather than expected/average loss. Risk management cannot eliminate risk but aims to take action to reduce the likelihood of risks occurring and to reduce the impact when they do. As for any business or sector, it would be beneficial to all actors within the Sottish forestry sector to identify the level of risk they are prepared to accept (risk appetite) and build reserves and contingency plans to deal with any unexpected loss or business interruption.

- Developing and promoting stakeholder engagement practices that require risk bearers, risk takers, and beneficiaries of forest assets to co-operate in matters of risk measurement and management, could achieve a better understanding and management of risk and promote climate change resilience across the forestry sector.

- Key risks in the finance sector include market and credit risk. These types of risk and some of the techniques to quantify them may have application in the forest sector. Operational risk also impacts on the finance sector but is likely to be of higher importance to the forest sector – particularly as it includes the risk from climate change and natural disturbances. The relative importance of different types of risk will differ between the forest and finance sectors but the

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process of identification and assessment is similar. Promoting the assimilation of appropriate financial risk techniques across the Scottish forestry sector would improve its resilience against adverse financial consequences of climate change.

- The finance sector uses risk measurement to determine how much financial capital is at risk and how much to set aside against losses (capital adequacy). In addition, risk measurement feeds into performance assessment of the risk versus return of different financial products and departments. Systematic measurement and recording of unexpected losses and a more widespread use of decision support systems and risk models across the sector could feed data into a multi-scale forest risk management process. This could provide information on forest assets at risk under different climate change scenarios, and also be used to assess the risk versus return of different practices.

- Once current exposures have been assessed, the forestry sector could adopt financial risk management approaches to proactively reducing these risks. Financial techniques such as portfolio diversification and natural hedging, as well as financial instruments such as derivatives (Futures, Forwards, Options, Weather derivatives, Swaps) and catastrophe bonds would potentially translate well at different geographical and managerial scales into the Scottish forestry sector.

- The 'risk of doing nothing' to adapt to climate change in the Scottish forestry sector is considerable. Whilst adaptation practices may not perform as well as intended, the opportunity cost of not implementing them should be weighed against the cost of continuing current practice ('Business-As-Usual') in the face of future risks.

- Applying natural hedging techniques to forestry could be based on the principle that, in situations of high climate uncertainty, newly-planted stands could include species that will flourish under very different future climatic conditions, alongside species that grow well in the current climate. These financial risk management techniques could therefore encourage the uptake of different species.

- Natural hedging would make forests better adapted to future climates and increase their long-term resilience. However, in the short term natural hedging might be less profitable than other financial approaches, and its implementation might require support, such as forest grants.

- Derivatives and catastrophe bonds mitigate risk in that they reduce impact by providing financial compensation. Overreliance on these financial practices might negatively affect climate change adaptation strategies, by diverting focus from preserving the health of forest ecosystems, timber productivity and other ecosystem goods and services, to purely financial considerations of forest management. However, policy makers may wish to consider adopting appropriate financial approaches including derivatives to help ensure that finance is available to reinvigorate the forestry sector in the wake of a catastrophic event.

- The complexity and size of the Scottish forestry sector mean that implementing novel climate change risk measurement and management practices across the private and public sectors is a challenging endeavour. However, an overarching risk policy umbrella would ensure the continuity and resilience of the sector as a whole.

Content

1 Introduction

Climate related risks must be planned for and managed to ensure that Scotland's forestry sector is well-adapted, and continues to support a resilient natural environment and a robust economy. The finance sector (banking, insurance, investment) arguably leads the way in defining and managing risk and has gone through a number of challenges. Therefore, there is scope and interest in learning and applying lessons on risk management from this sector to other sectors. This report identifies the approaches adopted in the finance sector that are applicable to improving risk measurement and management in the forestry sector.

In order for the risks associated with planting and managing productive forests to be both measured and managed effectively, care must be exercised throughout the entire forestry supply chain, from the selection and breeding of the most suitable tree species for a particular purpose and location, to the implementation of silvicultural management practices appropriate to the objective of a forestry project (e.g. Sing et al., 2017). For forest managers, the design and management planning stage is crucial.

With 43% of forest cover, Sitka spruce is the species most extensively and intensively adopted in Scotland for commercial forestry (Forestry Commission, 2014), as it has been the most profitable species for timber production. The long-term risk of such a strong reliance on a single species is that the sector is vulnerable to adverse changes in climate and to new pest and pathogen outbreaks (Beauchamp et al., 2016). A number of adaptation measures have been identified to increase the resilience of the forestry sector in Scotland, which include planting a wider portfolio of species and provenances that are ecologically adapted to current and projected climates (Forestry Commission Scotland, 2013), and higher species diversity to differentiate risk (Beauchamp, 2016). The combination of high profitability and large coverage of Sitka spruce stands raises the question of whether the expected large timber yields will be sufficient to cover the risks to the sector associated with climate change. Alternatively, should diversification of species, which might provide higher overall resilience, be more actively promoted? The recent catastrophic loss to larch forests in the Dumfries and Galloway forest district caused by a *Phytophthora ramorum* outbreak is an example of the difficulty of both predicting and mitigating risk, and of the serious challenges to forest management in Scotland.

The main risk measurement and management topics discussed in this document are:

- risk concepts and perception, the measurement of risk encompassing both "episodic events" such as extreme natural hazards and the more subtle and long-ranging effects of a changing climate on the forestry sector;
- risk evaluation methods such as 'Value at Risk' and 'risk vs reward' (i.e. how to assess whether the economics and profitability of forest management, both business as usual (BAU) and under adaptation strategies, are sufficient to cover potential loss); and
- delivering optimal risk management through the roles of the forestry sector, the people, and the organisations within it, by applying techniques such as measurement of unexpected risks, identifying exposure concentrations, and using approaches such as 'hedging' and 'portfolio diversification', and financial products such as 'derivatives', to reduce the scale and impact of any losses.

Due to the financial nature of these concepts, the focus of this document is primarily on productive forestry, because the 'costing' and the financial basis of wider forestry objectives are still unclear. Nonetheless, in some cases references are made to the relevance of tools borrowed from the financial sector for risk management for wider forestry objectives.

These topics are analysed and discussed in relation to the challenges and opportunities that climate change is likely to present to both individuals and organisations within the forest sector. The aim is to provide information about available alternative risk measurement and management practices that are appropriate to forestry, and therefore to encourage the development of a resilient, climate-ready forestry sector in Scotland.

This report is developed from Susan Davies' (2015) report on risk management in the finance sector and its implications for climate change adaptation in Scotland, commissioned by Forest Research, which provided an overview of key techniques used in the finance sector to measure and manage risk that might have an application to forestry. The work was funded by ClimateXChange. This report expands on selected approaches identified in Davies (2015) that are seen to have the most potential for the forest sector with examples of how they might be applied in practice.

2 General approach to risk management

Uncertainty is intrinsic to financial markets and risk is an inherent part of conducting business in them. Without risk there would be no activity and no return. While to some extent risk management has always been present in banking, it grew significantly as an independent function at the end of the 21st century, following a series of high-profile losses such as that by Barings Bank in 1995, which led to its collapse. Whilst the finance sector has arguably led the way in developing risk management techniques, it does not yet have the perfect system, as the 2007 sub-prime mortgage crisis and ensuing world-wide recession that it caused have shown. Successive crises have provided hard lessons, and led to revision of both external regulatory and internal processes to address risk. Much can therefore be learned from what this sector has experienced so far.

2.1 General Risk Principles

Many definitions exist for both risk and risk management. For the purposes of this report, the definitions provided by the Institute of Risk Management (IRM) will be used, which relate well to the particular kinds of risks faced by the finance sector. Risk is therefore defined as:

> *'the combination of the probability of an event and its consequence. Consequences range from positive to negative' (Hopkin, 2014).*

Adaptation measures can reduce risk by reducing the extent of the consequence (impact) or the probability of the event (e.g. by adopting more drought-resistant tree species in drought-prone areas). In turn, risk management is therefore defined as a:

> *'process which aims to help organisations understand, evaluate and take action on all their risks with a view to increasing the probability of success and reducing the likelihood of failure' (Hopkin, 2014).*

Risk management should be an integral process of any large corporation and should be seen as a positive process that delivers direct benefit, rather than a negative process impeding operations. Implemented correctly, it reduces losses, thereby indirectly increasing profits, and can provide new opportunities. Beauchamp (2018b) highlighted the increasing overlap between climate change adaptation practices in forestry and the broad field of risk management.

It is not the intention of this report to focus on outlining the generic principles of risk management, but rather to focus on those that are common to the finance and forestry sectors. One informative risk-related acronym from the IRM's recommendations is 'PACED' (Hopkin, 2014), which describes the approach to risk management taken within the finance sector. PACED relates to the key criteria for any risk system, advocating that it should be:

- **P**roportionate to the level of risk
- **A**ligned with other activities
- **C**omprehensive, i.e. covering all activities
- **E**mbedded within the organisation
- **D**ynamic, i.e. responsive to the changing risk environment

A risk system proportionate to the level of risk allows risk managers to identify the most appropriate response to a given risk. Once the risk has been described in terms of its consequence and likelihood (e.g. as in Beauchamp's (2018b) Risk Analysis Matrix), or by quantification, an adequate response can be implemented by taking into account how effective that would be. As illustrated by Gardiner and Welten (2013) for the case of wind risk, when risk is low a response might not be required; similarly, when the risk is high, a response other than contingency planning might not be possible, while for intermediate risk a response is worthwhile in that the potential for risk reduction is maximal. For these reasons, a risk system aligned with forest activities can provide the maximum benefits/costs ratios in any forest activity, by informing and complementing best practices. This applies to all activities within the forestry supply chain, as shown by Beauchamp (2018a), as well as to activities within each step of the chain (e.g. nurseries, forest management, timber processing, etc.). To ensure that risk management practices do not impede any of these activities, they are best suited when they are embedded within an organisation and are dynamic and adaptive, so as to be able to keep pace with changing risks.

2.2 Ownership of risk vs ownership of loss

A powerful concept in risk management is the difference between the ownership of risk and the ownership of loss. A common problem in finance is that the traders and the heads of the desks are using the bank's money rather than their own, when managing risky assets or portfolios. In addition, their end-of-year bonuses and those of senior management depend on annual profit. Risk-taking is therefore incentivised as salaries are paid regardless of whether the transactions result in a profit or a loss, and there may be a temptation to take greater risk to achieve a higher profit and a higher bonus. Hence recent moves to reward traders based on risk vs return analyses and not just profit.

This clearly introduces a conflict of interest between those undertaking risky activity and the bank as an organisation bearing any loss. Such dichotomy of interests is equally pertinent to the forest sector. When considering the issues of profitability, coverage, and climate related risks to forests, it is essential to ensure that forest owners/shareholders – who bear the risk – are consulted on these issues as well as forest managers (although in some instances these may be the same). This will ensure that risk bearers understand the risks that their forests are exposed to at present and under an uncertain future climate. They can then determine the level of risk that they are prepared to take (their risk appetite) and use the enhanced understanding to support better decision-making. The process of risk management includes continuously assessing risk and acting on the information to ensure that risks are being reduced. An essential requirement for delivering effective risk management is that senior management supports and empowers risk managers to take action, and accept the concepts of proper risk measurement practices such as those introduced in Section 3.

Within the broader context of land management, stakeholder engagement and interaction are highly topical issues (e.g. Davies *et al.,* 2015). Within this field, the study of power relationships between different stakeholder groups has received increasing attention (Luck *et al.*, 2012; Felipe-Lucia *et al.*, 2015), and resources have been developed to facilitate stakeholders' identification and engagement in land and ecosystem management activities (e.g. Durham *et al.*, 2014). Recently, "stakeholders' visions" approaches have been developed for land use in Europe (Pérez-Soba *et al.,* 2015; Schmidt *et al.,* 2016) and for the forestry sector in the UK (Sing *et al.,* 2017b; Burton, 2017). The user-friendly and intuitive nature of these approaches has found favour across the forestry sector and amongst interested citizen groups. Stakeholder involvement approaches have the potential to ensure that perspectives from all stakeholder groups are included in the evaluation of risk and in the formulation of risk management procedures, but do require that resources are devoted to provide training and set up appropriate practices to promote stakeholder engagement.

2.3 Structure of risk management within the banking sector

Risk is an inherent part of finance. As well as managing their own risks and those of their customers, the finance sector provides products and services that are used by other sectors to mitigate risk. For example, investment managers use market instruments to reduce risk to client portfolios, and insurers provide insurance against loss.

Risk impacts on the activities of all finance sector employees, and not just those specifically employed as risk managers. When referring to the process of risk management within banking, different risk functions sit within the front, middle and back offices:

- The front office is the area of the bank that aims to generate a profit for the bank and those employed in this area include the traders, corporate financiers, asset managers etc. Each employee in this sector will quantify risk as part of their day-to-day activity, which might for example include pricing a trade, making an investment, or providing advice. Risk will be built into the price of any activity, and in turn, activities may be managed to reduce risk as appropriate. Actors within the front office will operate within strict risk limits set by management.
- The middle office is typically where the specific risk management department usually sits. It is a cost centre for the bank rather than a profit centre. The middle office is responsible for determining the overall aggregated risk to the bank from all of its activities. It is also responsible for ensuring that the bank does not unwittingly build up large exposure concentrations across its activities. For example, different traders could without knowing it all build up exposure to one particular counterparty (i.e. one of the parties in a contract or financial transaction), country, sector, index, interest rate etc., which would place the bank at high risk from an adverse movement in a market variable impacting on these. In addition, the middle office is responsible for regulatory compliance on risk, ensuring capital adequacy, and any risk-adjusted profitability measurement for performance measurement and capital allocation purposes.
- The back office is the administrative, processing and record-keeping part of the bank. As such it is not typically seen to be a risk management function, although there are risks inherent in these processes.

Senior management within the bank – together with the credit department – are responsible for defining the risk appetite of the bank, i.e. the amount of acceptable risk and the level of exposure permissible. Risk limits apply at various scales within the bank: from the limits for the bank itself, down to limits for individual traders. In addition, in banking it is important to separate the risk takers from the risk managers who define limits and monitor risks and performance. This concept is explored in more focus in Section 3.

There is one final dimension to risk management, which exists external to the private banks, and this is the supervisory authority. In the case of risk management and banking in the UK, this is primarily the Bank of England. The supervisors ensure implementation of global and EU regulatory requirements on regulatory capital, including capital adequacy and liquidity requirements to ensure that banks are able to meet unexpected losses and guard against bank failure and systemic risk. They periodically review and assess the internal procedures and risk models of individual banks, and can demand enhancements and/or request that additional capital is set aside including when markets are volatile.

2.4 Structure of risk management – parallels with the forest sector

Within the forest sector, the risk management activities akin to a bank's front office are typically carried out by tree nursery and forest managers, and forest district staff. Many of their activities have to comply with regulations and directives set out by the Forestry Commission (e.g. performing a formal risk assessment under UK Forestry Standards (UKFS, Forestry Commission, 2017), although nurseries are not required to comply with UKFS). There are parallels between senior FES management and senior bank management, as both are responsible for defining the risk appetite, i.e. the amount of acceptable risk and the level of exposure permissible.

The banks' middle and back office equivalents in the forestry sector are typically merged together. This is the case for both the private and public sectors. Private companies (e.g. land/forest management and timber processing enterprises) will assess the overall risks across the properties under their management, and across the activities carried out within each property. The public forestry sector is also responsible for a supervisory role similar to that of banking supervisory authorities.

However, for risk management specifically, the Forestry Commission does not have the authority to directly demand change within the private forest sector, but rather provides information on best practices on climate change adaptation, leads the way in the implementation of these across its estates, and potentially stimulates the uptake of these practices via grants and subsidies. FCS might set minimum requirements for climate-ready forestry practices, but it would then be up to individual growers to decide if they want to exceed these requirements based on their risk appetite. While each step in Scotland's forestry supply chain will probably take actions to reduce their risk (see Beauchamp 2017a), the long timeframes intrinsic to, and the interdependence between, these steps require that there is collaboration across the sector under an overarching policy umbrella.

Co-ordinating adaptation measures across the entire forestry sector, both within the national forest estate and private forests is not always possible, nor a simple task. Therefore, challenges for policy present themselves when the best risk management decision for an individual or organisation does not translate to heightened resilience of the wider sector, or when similarities in silvicultural practice across the sector combine to create large exposures to individual risks e.g. the current exposure to Sitka spruce. In order to steer individual risk-management decisions to the benefit of the wider sector while ensuring that individual risks are properly mitigated, two complementary avenues could be available to Forestry Commission Scotland, aligned with the criteria set out in the UKFS. One is to disseminate evaluated examples of implementation of risk management practices in public forests. The second is to introduce policy measures to stimulate the uptake of such practices within the private sector, and the development of a culture of risk awareness and management across the forestry sector in general.

2.5 Types of risk in finance

The first stage in risk management is the identification of all the main risks. Some risks will not apply to all sectors, and risks will be of differing levels of impact. Traditionally, risk management in banking has focused on two key types of risk: *market* risk and *credit* risk.

- Market risk – relates to the return 'on' investment. In banking, this primarily relates to the risk that the bank is exposed to from adverse movements in market variables that impact on profit and may lead to a loss. Market variables might include interest rates, exchange rates, and equity prices.
- Credit risk –relates to the risk of default. This occurs when the counterparty to a transaction is unable to meet their financial obligations and defaults. For example, if a borrower is unable to pay the interest on some form of debt.

Towards the end of the 20st century a third type of risk came to be regarded as critically important in banking: *operational* risk. Definitions of operational risk vary widely depending on the sector. The Basel Committee on Banking Supervision (BCBS) defines operational risk for banking purposes as:

> *'the risk of loss resulting from inadequate or failed internal processes, people and systems, or from external events'*

This includes such things as technological failure through the breakdown or inadequacy of IT systems; legal risks such as inadequate contracts or loss of key documentation; fraud; power failure; terrorism; and natural disturbances (e.g. catastrophic hurricanes, earthquakes, etc.), amongst many other things. The Basel definition does not however include reputation risk or business risks from moving into new areas. However, the latter are important risks impacting on banks and other sectors, whether or not they are defined as operational risks. In practice, some of the largest losses experienced by banks have been related to operational risk[1], hence the increased focus.

2.6 Types of risk in finance – parallels with the forest sector

From a forestry perspective, market and credit risks are important risks, but direct exposure to operational risk in the form of natural disturbances is of much higher importance. For forestry, market risk (which relates to the return on investments), includes any risks to yield, timber and carbon prices as well as any other financial exposures such as interest rates from any borrowings or returns on any other investments, which affect the overall profitability of forest projects. Credit risk, which relates to the risk of default, could impact any level of the supply chain, where a company at one stage defaults on payments to another. For instance, if a customer defaulted on payment to a nursery for seedlings; if a sawmill was not able to pay for timber, or if new planting grant scheme payments were not made as the funder ran out of funds, etc. There are a large number of operational risks that could affect forestry, including failure of machinery, computer failure, loss of contracts, legal risks and so forth, as well as natural disturbances which constitute perhaps the major operational risk to forest operations. There are, however, synergies between these risks. For instance, climate change represents an operational risk which could impact on yield, thereby creating market risk, which if significant could ultimately lead to default i.e. credit risk.

With regards to risks deriving from climate change, it is useful to differentiate between direct and indirect risks. Direct climate change risk could be defined as an operational risk to forestry, which would also include the risk from external events such as natural disturbances from wind, drought, fire, and pest and diseases. The occurrence of these biotic and abiotic hazards is expected to increase regionally (e.g. Brown *et al.*, 2016).

Indirect climate change risk affects forest productivity and therefore impacts on market risk. Foresters must plan for both the present and future climate (e.g. species/provenances choices, management practices, machinery, tools, and expertise). However, this is difficult given the uncertainties over the geographical and temporal scales of climate change and its impacts. Returns on forest investments can be of different types:

a) more stable revenues from timber and carbon credits;

b) more cost-effective ways of managing forest ecosystems e.g. for the prevention of floods in urban and peri-urban areas (e.g. the Strathard project[2]);

c) in the form of achieved objectives for climate change mitigation at country level, via carbon storage in forest ecosystems.

National and international markets exist for these flows of capital and income, and climate change has the ability to affect these returns both positively and negatively.

Because of the nature of forestry, the risks caused by climate change to current investments and their returns in Scotland's forestry sector, are associated with past forest management choices. A key tool for risk reduction in the finance sector is diversification to spread risk and reduce exposure to given market variables. This diversification can be done in many ways e.g. spreading exposure across different types of activity, market instrument, countries or sectors etc. A case could be made for promoting a similar approach in the management of Scottish forests. The multiplicity of objectives in modern forest management (e.g. timber, other ecosystem services) suggests that promoting more

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[1] One famous example is the actions of the rogue trader Nick Leeson, which led to losses of almost £1bn and the ruin of Barings Bank in 1995. A failure of internal controls allowed Leeson to undertake trades beyond his remit, and fraudulently hide his losses to preserve his bonus.

[2] www.forestry.gov.uk/fr/strathard

diverse Scottish forests to allow forest managers to e.g. adopt species/provenances or management practices most appropriate for a specific objective at a given location might increase the return on forest investments. Another case that is often made for greater diversity of Scottish forests is the sector’s strong reliance on Sitka spruce, which can potentially put the sector at risk of large losses. These losses could be caused by pests and diseases new to Scotland, extreme climatic events such as prolonged and repeated summer drought, or more subtly to gradual changes in environmental conditions underpinning growth, productivity, and resistance to abiotic and biotic damage. Beauchamp (2018a) ascribes the unsuitability of the classic economic theory of supply and demand in the forestry sector to long forest rotations, slow rate of change in stand composition, and modern approaches aimed at multifunctional forestry. Because they do not happen overnight, the gradual changes in forest productivity and resilience to climate change risk might be underestimated and overlooked throughout the sector. Failure to improve diversification across the sector (e.g. of species, provenances, and management practices appropriate to tree species, location, and objective is likely to maintain the risk of large losses across Scotland’s forestry supply chain.

3 Risk evaluation methods

As in the definition at the beginning of Section 2.1, risk relates to the combination of a probability and a consequence. Various techniques for measuring this exist. For example, at its most simple, a matrix can be developed listing all of the potential risks facing an entity e.g. organisation/sector, and assigning a probability and consequence to each (e.g. High, Medium, Low). For regulatory and internal purposes, the finance sector has developed a number of ways of quantifying the different types of risk: some of the most important are discussed in this section. Rules for the regulatory capital calculation are set by the Basel Committee on Banking Supervision (BCBS). They determine an amount of capital that must be set aside against losses, to minimise the risk of bankruptcy and systemic risk i.e. the risk to the sector as a whole.

Banks also calculate 'economic capital'. This is the bank's own internal calculation of capital requirements, calculated at different levels (e.g. desk, department, division). It may lead to the bank setting aside further capital than that required by the regulatory authorities. Economic capital can also be used to provide input into other operational activities such as performance assessment (i.e. assessing the performance of individual traders or business lines, etc.) and capital allocation (i.e. determining how much capital to give each business line to carry out their activity). Economic capital may be calculated based on the regulatory approaches, but may also include other types of risks not covered in these assessments and may be based on different levels of confidence and time horizons.

We explore the significance of both regulatory capital and economic capital for the finance and forestry sectors.

3.1 Regulatory capital calculation: the *Value at Risk* approach

From a regulatory perspective, the primary concern is ensuring that banks have sufficient capital in reserve to cover unexpected losses – this is known as capital adequacy. BCBS uses a concept of 'three pillars':

- Minimum capital requirements that banks should hold;
- Supervisory review – by which supervisors regularly review banks' models for assessing risk, and can demand changes or additional capital etc.;
- Disclosure requirements to ensure transparency over the capital adequacy of a bank.

The basic principle of the Basel regulations is that banks should hold in reserve a percentage (currently, 12%) of risk weighted assets (RWA) as relatively liquid assets (liquid assets are those which can be converted to cash relatively quickly). Each bank must calculate its RWAs for market, credit and operational risk.

Determining a value at risk (*VaR*) is the most widely used approach to quantifying risk in finance. *VaR* provides a single number for the level of loss over a specified time period that will not be exceeded for a given level of confidence. It is typically used for market risk and can also be used for credit and operational risk calculations.

The level of confidence used to calculate *VaR* differs for each institution and usually relates to the credit rating of the institution. Confidence levels are typically above 99%. Of the three main approaches to quantifying *VaR* for market risk, the most relevant for forestry climate change adaptation is that of historical simulation, which entails identifying the key variables that affect the current portfolio, and applying the actual daily % movements of these variables over a particular historical time period to the current portfolio over a specified time period.

A criticism of the *VaR* approach is that it does not estimate tail end risk, i.e. how large a loss might be when the confidence level is exceeded. This has given rise to the development of the Expected

Shortfall (or conditional *VaR*) measure, which seeks to quantify the expected loss *given* that *VaR* has been exceeded.

During the recent financial crises it became clear that using the movements of market variables over recent years to assess the *VaR* of the current portfolio has its dangers. The movement of market variables was much more severe than in previous stressed markets, and correlations between variables drastically changed. For example, default rates between different asset classes were more highly correlated than in periods of normal market movements. As a result, the calculation of Stressed *VaR* was introduced, which requires banks to use randomly sampled daily movements in market variables over a period of 250 days when markets were stressed to calculate how the current portfolio would be adversely affected, in addition to normal historical simulation.

In addition to the calculations, supervisors demand that models are back-tested. This involves assessing how well the *VaR* model would have worked if it had been used in the past, i.e. calculating the *VaR* level to verify how often it would have been exceeded over a given time period.

A number of approaches exist to quantify credit and operational risks. Broadly speaking, credit risk is derived by summing 'the probability of default multiplied by the worst-case loss given default' for each exposure. Expected losses are subtracted from each exposure as the risk of these is assumed to be priced into products. *VaR* can be used as part of the process of quantifying the worst-case loss given default if sufficient data are available. Credit and operational risks are typically quantified across a one-year time horizon, whereas market risk is typically assessed for shorter periods e.g. a day.

Given the variety of different types of risk that come under the definition of operational risk, there are often less available information and historical data with which to assess such risks. For this, there may be a need for structured subjective quantification by senior management, or use of third-parties such as consultancies to provide assistance, e.g. by collating information on external operational losses. Operational risks in the finance sector tend to fall into two categories: low frequency high severity, and high frequency low severity (see the Risk Analysis Matrix in Beauchamp, 2018b). The former tend to include the most catastrophic events and require not just risk measurement but often back-up contingency planning (Beauchamp, 2018b).

Market, credit and operational risks are then combined to an overall assessment of risk-weighted assets to the bank. This includes netting off of some exposures e.g. there will be market instruments that make money when a given market goes up and those that make money when the market goes down. Whilst each has its own market risk evaluation, they cannot both occur at the same time and so must be 'netted'. A proportion, currently 12%, of overall risk weighted assets is then set aside against losses. Therefore the regulatory capital requirement can be summarised as:

Regulatory capital = 12% of: (credit risk RWA + market risk RWA + operational RWA)

Similar regulatory capital requirements are also set by the regulators of the insurance markets. The Solvency II regulations set out the rules around how this is done. The insurance sector also uses *VaR* when assessing insurance premiums. For example, insuring against the 1-in-250 year event entails the calculation of the value which will not be exceeded in 250 years (i.e. to a 99.6% confidence level).

3.2 Regulatory capital and *VaR* - parallels with the forest sector

As risk management is primarily focused on dealing with risks above those that are expected, when assessing the risk to the forestry sector *VaR* type analyses are one of the available methods to assess the unexpected. Under climate change, the return intervals (i.e. the probability) of unexpected catastrophic events are expected to change. Consequently, the impacts of these events and the *VaR* to a chosen degree of confidence are also expected to change. One of the requirements for using *VaR* is that the forestry sector is prepared to choose the confidence level for managing risk to forest assets. Climate prediction and decisions support (DS) tools such as Forest Research's Ecological Site Classification and ForestGALES, could potentially be adapted to assessing *VaR* under different climate scenarios. Consequently, actively promoting the uptake of these DS systems, and setting out formal risk assessments requirements for the use of these tools across the private and public forestry sectors, would ensure that high standards of risk evaluation are applied across the entire Scottish forestry sector.

Within the forestry sector, measures of risk are likely to be applicable to estimating the financial consequences of climate change, for example for the potential impact on timber or carbon prices, or credit issues relating to any forest project defaults which might follow on from any losses. Market risks include indirect climate change risk related to forest productivity, while operational risks pertain to forest losses due to natural disturbances, as discussed in Section 2.3.

There are also general lessons to be learned from the lack of preparedness of the financial sector for the credit crises. This has some parallels with climate change adaptation, in that future movements (changes) of climate variables are also likely to have little relation to recent movements - particularly as the future extremes of climate are difficult to predict. The concept of using a stressed *VaR* approach where future climate shifts are not known may have some application. However, the impossibility of predicting the extent of the stress to which forests will be exposed to under future climate will likely require scenario testing. This is partly an issue due to timespans – financial markets generate data at very high frequencies, while most of forestry data are generated on annual or decadal periods (e.g. growth response to climate). Exceptions to these long timespans are those of nursery and timber trade which can be annual or sub-annual.

Modelling risk from natural disturbances requires adequate data on losses and impacts for modelling and scenario testing[3]. For operational risks, 'low frequency/high (and medium) severity' risks to the forestry sector are represented by the catastrophic losses due e.g. to destructive storms, fire, drought and pest and diseases. Conversely, the 'high frequency/low severity' risks are typical, "budgeted" relatively small annual losses. While there is considerable uncertainty over the risk of catastrophic damage, annual losses for the forestry sector are likely to increase over time under repeated stress to Scottish forests, and could reach the 'high frequency/medium severity' status. Promoting the development of an extensive and modern infrastructure for data collection of climatic variables, forest dynamics and response to climate change across Scottish forest estates could greatly increase the preparedness of the forestry sector in the face of climate change related challenges. Operationally, a much desired consequence of such investments in a state-of-the-art climate-ready forestry sector would be that appropriate adaptation actions that can mitigate climate change risks could be more confidently adopted across the private and public sectors.

Identifying and measuring each type of risk to the Scottish forest sector is the first step in implementing a risk management system. At its simplest, quantification could be done within a Risk Analysis Matrix framework (see Beauchamp, 2018b) which assesses probability and consequence of risk according to relative criteria e.g. high, medium, low. Where data is available, risk can be quantified by assigning a value to the probability and consequence of each type of risk and summing these up as with the credit/operational risk approaches in finance. Where sufficient data is available, progressing to *VaR* type approaches would provide the best means of measurement.

The type and the timing of damage are also relevant for risk perception of forest owners and managers. Recent experience of an extreme event such as storm damage and flooding has the

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[3] One example is that of monitoring forest loss due to fire. Forest fire statistics were collected for the Public Forest Estate between 1969 and 2003-4, but were then discontinued. In recent years a new system for monitoring forest fires has been developed based on the UK Incident Reporting System (IRS), which has included wildfire reporting since 2009 including standardised data under a UK Vegetation Fire Standard (Gazzard, 2009). Whilst the system only records incidences of fire responded to by the Fire and Rescue Services, this should include most of the larger, more damaging fires. The publicly available annual report series focus primarily on the impacts on non-forest sites such as structural property. However, the Forestry Commission in England and Scotland has developed a new methodology to produce better information from these data on forest fires, by cross-referencing the fire location coordinates from IRS with the National Forest Inventory and Land Cover Map 2007, to determine which of the fires were likely to have affected woodland.

highest impact on attitudes to risk and on the course of action most likely to be considered in adaptation responses (Blennow and Sallnas, 2002). However, it should be noted that these attitudes are not necessarily related to the actual return periods of the hazard, or the likelihood of the hazard occurring again within the rotation length of the forest crop. Therefore, understanding impact and having information available for the formulation and testing of better risk-impact models are essential. It should be noted that at present forest management plans (private sector plans submitted to the FC for grants) are required to complete a historic-based risk assessment, rather than use decision support tools and/or projected climate change information. While the use of climate projections in risk modelling (e.g. the upcoming UKCP18) will surely help forest managers and researchers model future forest dynamics, given the dynamic nature of climate change and the sporadic occurrence of hazards resulting in high risks, a case could be made for the use of weather and climate data from other countries whose current weather the UK is likely to experience in future decades (i.e. 'climate analogues').

As described by Beauchamp (2018b), contingency planning for unexpected losses as a climate change adaptation measure for the forestry sector in Scotland is an essential operational risk management tool. Contingency plans exist for wind damage (Forestry Commission Scotland, 2016) and, in view of the projected changes in climate, additional plans for drought and fire risk might be advantageous at a national or regional level, as well as at a local level by forest managers. By increasing response rate and reducing recovery time, contingency plans are critical for a well prepared forestry sector to cope with medium and high severity operational risk.

The way in which credit risk is calculated in finance and used to determine the amount of capital set aside against losses, has some parallels with the way that carbon buffers are estimated for forest carbon projects. Until recently, under the Woodland Carbon Code (https://www.forestry.gov.uk/carboncode), each project had to be assessed at the outset for the potential percentage loss from a range of risks including natural disturbances, and these percentages were summed together and used to determine the size of the buffer. After each carbon verification, that percentage was set aside into this buffer as a reserve against future losses. The assessment of loss was therefore similar in nature to credit RWA, as each project developer was required to consider likelihood and impact for each risk. Davies *et al.* (2017) applied this approach to the risks posed to woodland from pest and diseases. However, except for carbon project buffers, setting aside a proportion of forest assets against losses might be inappropriate for broader forest risk management. If future policy involved pooling together areas of forest set aside to act as a buffer against future losses, any forest stand set aside into this buffer would need to be resilient to climate change. Forest managers need adequate finance to cover management and replanting costs to reduce the impact of any operational risks that occur. This could be done by taking out insurance against such losses or setting aside contingency funds for this purpose. Assessment of operational risk is needed to determine the level of any contingency funds, and would also be undertaken by insurers pricing any insurance product.

Finally, the BCBS approach does not cover reputation risk, which in finance corresponds to losses arising from damage to the banks reputation. This is a major concern for banks, but often difficult to measure as a wide range of activity can cause it. The same is true for the forest sector. While confidence in the sector as a whole is important, it is difficult to determine a generic probability for reputation risk. A possible way to estimate the impact on the sector's reputation might be to look at the impacts of certain losses. Approaches exist that have assessed reputation risk by looking at the fall in share prices of companies, or a fall in investment following a particular event. The impact of reputation risk on investment in the forestry sector following a pest and disease outbreak, for example, could be evaluated by looking at trends in share prices of forestry sector companies following the arrival of e.g. Ash Dieback. It should be noted that some pests and diseases can reach Scottish forests naturally or through trade of plant material, in which case they would not be linked to 'bad practice' and thus might not result in reputation damage. However, reputational risk might arise if institutional response to these events were lacking.

The impact on investment and share prices in other countries could be looked at where UK experience is limited. For example, confidence in forestry as an investment and land-use in the Aquitaine region of France was reduced following extensive damage from two extreme storms within ten years (Gardiner et al. 2013). Similarly, the impact on forestry sector investment in Spain and Portugal following widespread forest fires could provide important insight on the future reputation risk for Scottish forests due to fire losses exacerbated by climate change.

3.3 Economic capital

The practices outlined in the previous section exemplify those required by regulators to ensure that banks and insurance companies hold sufficient capital to prevent systemic risk in the finance sector caused by the failure of a financial institution. A second type of capital routinely calculated in banks is 'economic capital', described in this section.

The basic premise is that, whilst banks typically aim to ensure that the expected losses that are an integral part of business are factored into the price of the products and services of the bank, economic capital should cover the unexpected losses that might arise. Banks develop their own proprietary models for assessing market, credit and operational risk losses. These models may be based on the regulatory approaches such as BCBS, but may also include other types of risks not covered in these assessments – such as reputation and business risk – and may be based on different levels of confidence and time horizons.

An important concept within banking is that of risk versus reward. This has led to the development of Risk Adjusted Performance Measurement (RAPM) - an approach that seeks to evaluate return against the risk that was undertaken and which can be applied at different levels, e.g. to individual trader performance or a business line. The notion behind this approach is NOT to prevent risk being taken, but to ensure that the reward (return) being received for the risk is sufficient to cover the risk.

As an example, imagine two different types of investments, regularly undertaken by different business lines, both requiring the same amount of capital for each investment. One type is 10 times as risky as the other, yet achieves a return 15 times as great on those investments that are successful. Therefore, the first type of investment is achieving a greater risk *vs* return and should be preferable. This example simply presents the basic concept of RAPM, as in reality additional factors are taken into account. While RAPM can be used to compare the relative performance of different types of activity or departments, it does not replace the need to diversify.

The most commonly used measure for Risk *vs* Reward is Risk Adjusted Return on Capital (RAROC), which is given by the formula:

$$RAROC = \frac{Revenue - Cost - Expected\ Loss}{Economic\ Capital}$$

This calculation can be done ex-ante (i.e. before the event) to predict RAROC, i.e.:

$$Ex - ante\ RAROC = \frac{Forecast\ Revenue - Forecast\ Cost - Expected\ Loss}{Economic\ Capital}$$

Alternatively, performing an ex-post (e.g. based on analysis of past performance) calculation allows the determination of actual RAROC using actual realised revenues, costs and losses i.e.:

$$Ex - post\ RAROC = \frac{Profit}{Economic\ Capital}$$

Ex-ante RAROC can be used for capital allocation purposes, to apply the forecast risk-adjusted return to determine how much capital to allocate to each business line or product/service. The bank will also consider other factors in determining capital allocation such as the need to diversify: RAROC is simply an additional tool to support such decision-making. Ex-ante should be favoured over ex-post RAROC, as the cyclical nature of markets mean that expected losses are averages and vary annually around the mean. For this, the longer term expectation should be used rather than the previous year's performance, due to the possibility of unusually bad (or good) performance the previous year. However, ex-post RAROC is more appropriate for performance assessment to determine how much profit each business line (or trader/asset manager, etc.) achieved, compared to how much risk they exposed the bank to.

It is worth noting that the total economic capital for the bank is likely to be less than the sum of the capital for each business line, due to diversification and the netting of exposures. For example, a bank may have many different positions in the same market instrument, some of which will lose money if the value of the instrument falls, and some if it rises (as in natural hedges, discussed in the next section). These two situations clearly cannot arise simultaneously and so the outcomes can be considered together. Additional approaches are therefore used to allocate the actual economic capital to each business line when performing the above calculations. Risk Reward ratios could also be calculated for different time horizons and to different confidence levels.

3.4 Risk *vs* Reward - parallels with the forest sector

The RAROC concept lends itself well to being adapted and used as a tool to assess the risk *vs* reward of different adaptation practices, or in geographical areas more or less prone to e.g. drought if building a portfolio of forested areas.

Following on the potential risks to over-relying on Sitka spruce, RAROC could e.g. be used to calculate the risk *vs* reward of Sitka spruce versus other species under different climate change scenarios by looking at the forecast returns from Sitka spruce over a *VaR* calculation of the worst-case loss of Sitka spruce (i.e. replacing economic capital in the RAROC formulas above), bearing in mind that expected high frequency/low severity losses are already factored into average yield tables for carbon and timber.

More generally, ex-ante RAROC could be used to inform management choices (e.g. species/provenances, thinning regimes, infrastructure decisions etc.) to assess alternatives and build up portfolios of species/areas/management practices, while ex-post RAROC could be done e.g. at 5-year intervals, to monitor the effectiveness of the management practices implemented in the previous period, for instance by monitoring growth and tree health and climate change indicators (e.g. ClimateXChange, 2016).

Experimenting with RAROC applications in diversification approaches appear to be suitable for FES and other large forest landowners in Scotland that can bear the risk of small losses. Experimenting with contrasting scenarios of different adaptation practices in areas which are currently, or are expected to be prone to environmental risk under climate change projections, would generate valuable information on the resilience of Scottish forests. Similarly, applying Risk Reward ratios to these contrasting scenarios has the potential to provide further insight into the suitability of, and attitudes to, adaptation options such as species/provenances selection and management practices to specific areas at local and regional levels. This approach would complement well analyses of rates of return and net present values, and dynamic forest planning approaches that can account for the likelihood of future climatic changes such as the action/expiration charts approach (Petr et al., 2015). Similarly, *VaR* and RAROC practices would help in assessing adaptation options within the robust methods approach for climate change adaptation suggested by Dittrich *et al.* (2016) in situations of high uncertainty. Therefore, the adoption of these risk measurement techniques alongside scientific assessments such as scenario modelling might provide the Scottish forestry sector with robust, quantifiable tools that would aid in the characterisation and selection of climate change adaptation practices.

4 Delivering optimal risk management

The banking and finance sector is equipped with a number of different tools to manage risk. These are typically in the form of statistical models applied to different scenarios. In finance, as in many other sectors including forestry and climate change, it is now common practice to test models outwith their typical application range and for extreme scenarios, in order to assess the robustness of the models while obtaining insight on variable correlation and model behaviour (e.g. Wade *et al.* (2015) for extreme climate change scenarios for natural hazards, or Locatelli *et al.* (2017) for the wind risk model ForestGALES). In this section, the most common approaches are briefly introduced, and their potential application in Scotland's forestry sector is then discussed.

4.1 Natural Hedges

Hedging is a common tool to reduce risk in finance. The process of hedging in a financial context can be defined as:

> '*Making an investment to reduce the risk of adverse price movements in an asset'* (*Investopedia*)

Perhaps one of the most conceptually simple hedging practices to understand is that of 'Natural Hedges'. The strategy on which these are based is to guard against a particular risk by purchasing instruments that move in opposite directions in the case of an extreme event. For example, investing in sunscreen and umbrella companies would be hedging against extreme weather. While the investments are made in the hope that both investments show positive return, in the event of a significantly hot or wet year, any losses in one instrument are likely to be offset by the gain in the other. Although there is no complete assurance that the alternatives in such a hedge will perfectly cancel each other out, and could still result in a net loss, natural hedges do provide some assurance against extreme movement.

4.2 Portfolio Risk

A key element of risk measurement is identifying large areas of exposure to one variable e.g. a specific country, product type, market movement, currency etc. Scenario testing can be used to identify where such exposures occur by simulating what would happen under different scenarios e.g. simulating what would happen to bank exposure if a given index for a given country were to move significantly e.g. the UK FTSE or US Dow Jones. The purpose of 'portfolio risk' management is to maximise returns on a number of investments while reducing the overall risk through diversification. Adding further investments to a portfolio requires that attention is given to how the investments and their associated risks interact with each other. The portfolio 'owner' will have a certain appetite for risk and will be seeking a minimum level of return given the risk that is undertaken. Typically: the higher the risk, the higher the return – but also, the higher the potential loss.

4.3 Derivatives

Whilst the basic concept of a derivative is relatively easy to understand, their usage and the strategies to which they are employed can be extremely complex. The name derivative comes from its value having been 'derived' from another. A derivative is primarily a contract/agreement between parties, and when this contract has value, it can itself be traded. The main types of derivative are futures, forwards, options and swaps.

4.3.1 Futures and Forwards

Futures and Forwards represent a fixed agreement to purchase an asset at a specified price in the future. As such, they represent the financial markets' view of how markets might develop. The main difference between Futures and Forwards is that Futures are traded over an exchange, and are available in standardised form, while Forwards are arranged 'Over-The-Counter', i.e. directly between counterparties to the contract, rather than via an exchange. For example, a producer wishing to guarantee the price at which they can sell a crop, could arrange a Forwards contract for a fee, thereby fixing the price at which their product can be sold at harvest. The producer would effectively lose out if there was a shortage of that crop and the price was higher than the forward contract price, but they would benefit if the price fell. The benefit to the producer is that these instruments reduce risk and allow the producer to plan based on known income.

4.3.2 Options

Whereas a Future or Forward is a *fixed agreement* to purchase an asset at a given price in the *future*, as the name suggests an Option is an *option* to buy or sell an asset at a given price (the 'strike price') in the future. The key point is that Option contract holders are not bound to adhere to the prices included in their contracts, but can exercise the option if they so wish. Following from the previous example of a crop producer, if they had arranged an Option to sell their crop at a fixed price in the future, and at that date the price had risen higher than the strike price, they would not exercise the Option, gaining full benefit from the market movements. Whilst options can be used for risk management, they are also often used for speculative purposes[4].

4.3.3 Weather Derivatives

Insurance companies, as well as banks, are increasingly offering 'parametric insurance', such as weather derivatives to manage weather risks, without restricting these to catastrophic events. Weather derivatives are designed to provide support against the risks of a volatile climate. Products can cover drought, heavy rain, extreme heat, wind, snow, etc. and are used by a wide variety of sectors, including agriculture.

These products are usually tailored to the client and 'parametrised' to an appropriate index such as amounts of rainfall. A typical product offers a specific pay-out when the index meets certain conditions, e.g. when the amount of rainfall is higher or lower than the average by a certain percentage, or when the rainfall is higher or lower than a specified amount for a specified number of days. With weather derivatives, if these conditions are met the pay-out is made regardless of whether or not any damage or loss has occurred.

4.3.4 Swaps

A swap is a derivative where two counterparties exchange the cash flows of each other's financial instrument. The notional amount is not exchanged, while it is simply used as an amount to reference the cash flows against. Swaps can be used for hedging or speculative purposes and are widely used in the finance sector. Reinsurance companies take on the risk of insurance companies for a fee, when the latter want to reduce their exposure. A reinsurer that has built up a particularly large exposure to a

[4] For example, when markets are extremely volatile, traders can 'trade volatility' to make money. A trader could decide to buy an Option to *sell* at a certain strike price in 6 months, while also buying an Option to *buy* at the same strike price in 6 months. Although the trader would have to pay a fee for each Option, provided the price moved in either direction more than the cost of the fees, the trader would ultimately make a profit. Essentially, the trader is not concerned with which direction the price moves. If the price rises above the strike price they exercise the Option to buy at the strike price; if it falls below it, they exercise the Option to sell at the strike price.

given location or sector, by assuming the risk from a number of insurers, may wish to reduce their exposure, and in some circumstances could do this using a swap[5].

4.4 Catastrophe Bonds

Another tool used by insurance companies and traded by the finance sector is catastrophe bonds (or 'Cat Bonds'). They are a way for insurance companies to transfer to investors in the securities markets the risks that catastrophes expose them to. Essentially, bonds are issued that investors purchase in fixed amounts (the principal value of the bond) and which pay a fixed, relatively high interest rate (known as the coupon) on the principal amount. At the end of a specified time period, the principal is paid back to the investor. However, in return for the high interest rate, if a catastrophe occurs that requires a large pay-out, the coupon and – depending on the size of the loss – all or part of the principal, are used to pay for the losses. Such tools can be used for catastrophes including hurricanes or large storms, floods, fire, etc.

4.5 Financial approaches to reducing risk - Parallels with the forest sector

The approaches outlined in this section have clear applications to climate change policy.

Natural hedging has the potential to be used in forest planning. Where climatic changes are difficult to predict, newly-planted stands could include species that will flourish if climate is projected to change in one way, and species that will flourish if it changes in another way, alongside species that will do well in the current climate. Forest Research's Ecological Site Classification (ESC) decision support system can inform such decision-making, as it predicts the suitability of species at particular locations with different climate scenarios. For example, in an area where future rainfall patterns are uncertain, species presently closer to the edge of their tolerance but that would flourish in either drier or wetter conditions could be planted alongside one another. Whether rainfall increased or decreased, the increased yield from the species that flourished from the change could partially offset the reduced yield from those that became stressed. The degree to which this is viable obviously depends on available climate data, knowledge of local climate scenarios, and on the preparedness of the sector to use novel species and provenances with the required characteristics suitable for specific locations. A key point here is that the decision to try this approach depends on realising that the 'risk of doing nothing' is considerable. Thus the 'cost' of the species that will fail/do less well, is to be weighed not against present BAU conditions, but against a realistic assessment of the future risk and cost of carrying on with BAU practices. As shown by Beauchamp (2018a), climate change is expected to have multiple impacts on Scotland's forestry supply chain, and the resilience of the sector will depend on its ability to adapt. Given that the risk of not taking adaptation action is considerable, for large forest land owners natural hedges represent a potentially risk-neutral way of experimenting with other species, provenances, and management practices, with the expectation that in most cases all or most of the different implemented alternatives will deliver some benefits (e.g. timber, pulp/chip wood, carbon storage, recreation, natural flood management, etc.).

Futures, Forwards, and Options can be used in uncertain times to guard against falling prices for timber as outlined above. For example, such derivatives would be especially useful in the event of a catastrophic windstorm causing widespread damage. In the past such storms have resulted in a glut of timber on the market and falling prices. If climate volatility increases as widely anticipated, such

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[5] An example provided by a UK reinsurance company describes a situation whereby they entered into a swap with a Japanese reinsurer. The reinsurer had built up a large aggregated risk exposure to timber in a particular area in the US, meaning that if this area was hit by a catastrophe such as a hurricane, they would face large losses. The Japanese reinsurer had similarly built up a large exposure to an area in Japan. The two companies entered into a swap to 'exchange' some of the risk from each portfolio. Under this agreement, if the US area was hit by a hurricane, the Japanese reinsurer would have to pay the first reinsurer a portion of the losses, and vice-versa if the Japanese area was hit. Each company therefore hedged their exposure using a swap.

techniques could be very useful in preserving revenues in the timber sector. Futures markets already exist for the timber industry: lumber futures are already actively traded on various markets in the US including the NASDAQ and CME exchanges[6, 7].

Weather derivatives (a type of parametric insurance) clearly have a role to play in climate change adaptation and can be used to reduce losses, provided that appropriate environmental indices of events influencing forest health and productivity (e.g. amount of rainfall over a fixed period of time in a given location) are agreed upon between the policy and insurance sectors. Weather derivatives are also particularly attractive to insurers as the pay-out is fixed (i.e. there should not be any unexpectedly large pay-out). If suitable parameters could be developed, weather derivatives could be used as a type of insurance for the forestry sector. They are already widely used in agricultural applications.

While swaps are a relatively complex instrument, it is not unfeasible that some sort of swap could be employed to reduce exposure to forest losses in the same way that (re)insurers do. Large forest owners could swap exposure with others within regions with a sufficiently different climate (e.g. areas prone to drought, and others with projected increased precipitation), within the UK or elsewhere in Europe (e.g. Portugal, where foresters are reported to be positively disposed towards climate change adaptation practices (Blennow *et al.*, 2012)). Extensive adoption of these techniques might expose large forest areas to climate change risks in locations where information on these risks is likely be less well known than for the Scottish territory, which might increase the indirect exposure to risk for Scottish forests. Consequently, management of risks across political boundaries would be beneficial.

Finally, catastrophe bonds are currently a tool used primarily by insurance companies, but could potentially be used by the forestry sector as a risk management tool. There would need to be some cross-sector coordination for this to be viable at organisational and policy levels, i.e. investigating the potential and regulations requirements for such a product with the finance sector. However, for a catastrophe bond to exist which would pay out in the event of a large windstorm, fire, or pest and disease event in the UK, sufficient data would be required to predict the likelihood and impact. This might prove difficult for pest and diseases, which would require further information such as how to identify when the pest and disease was first present, and at what point an infestation could be declared to be over. For other climate change threats, such as drought, fire, and wind, the promotion of infrastructure and networks to collect and analyse climate data would be a beneficial investment for the future of Scottish forests.

It is evident that in addition to straightforward insurance a variety of tools, some of which have been outlined here, could be used to reduce financial losses caused by climate change. However, with the exception of natural hedging, these approaches reduce the severity of the impact (and consequently, risk) primarily by providing financial compensation. This might introduce "moral hazard" (the lack of incentive to guard against risk where one is protected from its consequences, e.g. by insurance) to practical considerations around the management of forest assets in the face of climate change. In fact, whereby a focus on extensive adoption of financial practices might reduce the financial consequence of any negative climate change impacts, it would divert focus from preventing the loss of forest ecosystems, timber productivity and other ecosystem services. If financial tools were to be adopted, it would be important that adequate policies were produced to insure that when these tools were applied as ways of reducing the impact of any losses, they should complement rather than replace activity to prevent loss in the first instance. Conversely, a further advantage of natural hedging is that it might allow forests to adapt to future climates, increasing their long-term resilience. However, because at least in the short term natural hedging might be less profitable that the other approaches, its implementation might require support such as *ad-hoc* grants. These considerations aside, it should be

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[6] See: www.nasdaq.com/markets/lumber.aspx for NASDAQ lumber market
www.cmegroup.com/trading/agricultural/#lumber for CME lumber market

[7] One of the authors knows of a forest asset manager in the UK who had persistently tried to persuade a large client to enter into timber futures trading. However, the client resisted the advice, as they did not feel comfortable with the concept of trading futures.

noted that safeguarding the financial security of forest industries in the event of volatile climates remains an important consideration, and adoption of appropriate financial approaches as described in this section would help ensure finance was available following a catastrophic event in order to reinvigorate the forestry sector.

The diversification technique is already used within the wider forestry sector. Several large forest fund managers, including TIMOs (Timber Investment Management Organisations) that were contacted during the preparation of this report stated that they did not believe natural disturbance from storms and fire were risks worth insuring against, as they preferred instead to diversify their investments by location, species and age. For large forest owners/investors, this strategy could be cheaper than taking out insurance for all of the projects i.e. effectively they could self-insure. One important consideration about self-insuring is that if the economic returns and the mitigation benefits of a portfolio are going to be characterised by high uncertainty – as expected with climate change – the reliability of self-insuring through diversification will be dependent on the resilience of the stands that compose the portfolio. This suggests that species/provenance diversification *by itself* might not be sufficient to spread the risk. Silvicultural management techniques such as intensity and timings of thinnings and rotation length need to be correctly implemented to ensure the resilience of a portfolio approach. In addition to this, while the resilience of forest stands might be increased by adopting these self-insuring practices, the resilience of the sector would still be affected unless other stages of the forestry supply chain were equipped to cope with changes in e.g. species composition following a portfolio approach to stand management by large companies. Adequate policy instruments could ensure that the sector as a whole is prepared to manage changes on the ground that would increase the resilience of Scotland's forest assets.

Whether or not the approaches outlined above could be used more directly to e.g. select the most suitable species/management practices within a portfolio would depend on the availability of data for the appropriate environmental and climatic variables that affect the performance of a e.g. species under certain silvicultural practices, and appropriate data on the full economic value of the different options to determine diversification benefits. Such a rigorous financial as well as environmental data-driven approach should also take into account the human side of forestry operations. It is well established that human sentiments, such as business confidence and risk perception, have an impact on market variables, thus making them less predictable and more volatile than the physical variables employed in forestry models and climate forecasting.

Human sentiment is known to also affect land management practices. As shown in a cross-country European study that focussed on Sweden, Germany, and Portugal, foresters with experience of events attributable to climate change were more likely to believe in the reality of climate change, and to follow their beliefs by undertaking adaptation measures in their forests – akin to "seeing is believing is adapting" (Blennow *et al.,* 2012). In a previous study on Swedish forest owners' attitudes to climate change adaptation, Blennow and Persson (2009) showed that experiences of the effects of climate change did not need to be direct for foresters to adopt adaptation measures, emphasising the role of national institutions in disseminating climate change information and statistics to the forestry sector. Applying the theory of Persson (2004) on the dynamics of trust, Blennow *et al.* (2014) argue that transparency in the communication of scientific findings (including uncertainties) of climate change to the forestry sector is the most effective way of promoting the uptake of adaptation of climate-ready silvicultural practices by foresters. It could therefore be argued that if climate change effects and responses were to gradually become more focal topics in the nation's collective psyche – e.g. through media and campaigns coverage – the public and private sectors would become more cohesive in their understanding of climate change effects and acceptance of adaptation responses.

5 Conclusions

Risk is an essential part of undertaking any activity, and as such it is inherent in any business or sector. Risk management cannot remove risk entirely. Instead, risk management has a number of objectives that hold true for both finance and forestry. These are:

- establishing the acceptable level of risk (i.e. the risk appetite);
- raising a culture and awareness of risk whereby all stakeholders, including risk bearers, risk takers (and more widely, forest users) co-operate towards the identification, measurement, and management of risk that apply to modern forest management objectives, and do not reward excessive risk taking;
- promoting intensive and comprehensive collection and analysis of data on risk variables to measure and monitor risks;
- exploring management options to reduce risks using all available instruments, such as those discussed below, to increase resilience of the sector in order to be better prepared to coping with unexpected losses or business interruptions.

Risk management techniques used in the financial sector, such as natural hedges, portfolio diversification, derivatives (Futures and Forwards, Options, weather derivatives, and swaps) and catastrophe bonds, all have the potential to be applied in the forestry sector. When translating these to the forestry sector, it is essential to differentiate between purely financial instruments, and approaches that have an effect 'on the ground'. The solely financial nature of derivatives and bonds means that they can help reduce the economic impact of forest losses, but cannot bring any additional benefits to the resilience of forests. Derivatives and bonds can however help maintain the financial vigour of the forestry sector against large unexpected losses, providing a safety net in case of catastrophic damage. Adoption of these financial tools would require collaboration between policy, forest science, the insurance sector, and financial markets. On the other hand, 'on the ground' risk management techniques such as natural hedges and portfolio diversification can reduce risk by informing forest planning and physically affecting forest resilience to ensure that Scottish forest assets are – to an extent – 'self-insured'. Developing policy instruments that promote the application of natural hedges and forest portfolios to risk management in the Scottish forestry sector would likely result in stands with more diverse species compositions, therefore putting into practice the FCS' tenet of the 'right tree in the right place'. Consequently, the various steps of the forestry supply chain described in Beauchamp (2018a) would be affected by these policies. It is likely that risk management forestry policies would benefit from adopting purely financial methods (derivatives and bonds) and more natural approaches (natural hedges and portfolios). Adoption of these policies would contribute towards the creation of a more solid risk measurement and management approach which would ensure that forestry in Scotland maintains its role of timber supplier while expanding the functionality of forests, and continuing to contribute to the Scottish Government's commitments to climate change mitigation. Transparency and openness are essential to preserve the reputation of the forestry sector, and strong risk management will help retain confidence in the sector.

Whilst the Scottish Government has a duty to protect Scottish forests and promote sustainable management, it does not have a similar regulatory supervisory authority that exists in the finance sector for the Basel Committee on Banking Supervision, the European Union, and the Bank of England. That is, they can impose regulations on banks and insurance companies, whilst the Scottish Government cannot enforce regulations in terms of coordinating climate change adaptation actions. However, the ability to raise awareness of risks, estimate the potential impacts and scenarios, and provide justification for actions to reduce risk and take opportunities will have a strong indirect impact on the sector. It is of the utmost importance to realise that the risk of not taking action in the face of the uncertainties associated with the impacts of climate change is too large. If risk measurement and management policies were to be designed that incorporate financial instruments, and these policies were to be implemented across public sector forests (National Forest Estate), these areas could be used to demonstrate climate change adaptation options that would likely reduce risks while maintaining economic benefits and other key ecosystem services. Consequently, the wider forest sector would ultimately benefit, as the resilience of Scottish forests would be increased, and the uptake of these policies by the private sector would be incentivised.

The financial sector can draw on many years of daily data on market variables to build complex models. It is important that investments are made for the forestry sector to continually improve its own data, including more accurate measuring and monitoring natural disturbances, spatial and temporal patterns of pest and diseases, and forest health and productivity, as a prerequisite for the development of more sophisticated models to estimate the risk of climate change to forests.

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