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Managing dependencies in forest offset projects: toward a more complete evaluation of reversal risk

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Abstract Although forest carbon offsets can play an important role in the implementation of comprehensive climate policy, they also face an inherent risk of reversal. If such risks are positively correlated across projects, it can affect the integrity of larger project portfolios and potentially the entire offsets program. Here, we discuss three types of risks that could affect forest offsets—fat tails, micro-correlation, and tail dependence—and provide examples of how they could present themselves in a forest offset context. Given these potential dependencies, we suggest several new risk management approaches that take into account dependencies in reversal risk across projects and which could help guard the climate integrity of an offsets program. We also argue that data collection be included as an integral part of any offsets program so that disturbance-related dependencies may be identified and managed as early and to the greatest extent possible.

Keywords Carbon offsets · Climate policy · Forestry · Natural disturbance · Risk

1 Forest offset risk and management

Recent years have witnessed rapid growth in voluntary carbon markets and increased discussion of economy-wide limits on greenhouse gas (GHG) emissions. Emerging as a central component of both are carbon offsets, defined broadly as reductions in GHG emissions or increases in carbon storage produced by one entity to compensate for emissions from another. Because the ultimate objective of climate policy is to reduce global

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atmospheric GHG concentrations, it generally makes no difference where reductions occur or who undertakes them. In this way, offsets can expand the pool of available GHG mitigation options. Carbon offsets may also be cheaper to produce than emissions reductions from regulated sources, providing a means to reduce the overall costs of compliance within a broader cap-and-trade climate policy (EPA 2010).

Forest offsets, one subset of potential offset project types, have the potential to contribute significant amounts of relatively low-cost GHG mitigation services (EPA 2005). But they face an inherent risk of impermanence—that the stored or sequestered carbon will be re-released to the atmosphere—a phenomenon known as reversal. In particular, forest offset projects are subject to potential reversals stemming from both anthropogenic causes, such as intentional clearing or land-use change; and natural disturbances, such as wildfires, insect and pathogen outbreaks, ice storms, wind storms, extreme drought, and landslides. This paper focuses specifically on the role of natural disturbances.

Forests are subject to damage from multiple natural disturbances, and climate change is expected to exacerbate the intensity and/or frequency of many of them (Dale et al. 2001). Also at issue are potential large-scale changes in forest management practices in response to carbon market incentives (Galik and Jackson 2009). Against this backdrop of shifting climate, management, and policy, it is important to establish a better understanding of the role that forest offset risk management can play in meeting policy objectives.

The issue of reversal risk and impermanence in forest carbon offsets is well documented in the literature (Ellis 2001; Subak 2003; Kim et al. 2008; Murray and Olander 2008; Mignone et al. 2009), as is the influence of natural disturbance events on forest management (Routledge 1980; Brumelle et al. 1990; Gardiner and Quine 2000). However, with some exceptions (Spring et al. 2005; Seidl et al. 2008; Galik and Jackson 2009), interactions between reversal risk and management for carbon have generally received little attention. Similarly, while there has been some study into the collective impact of individual offset project risk on the achievement of portfolio-level objectives (Laurikka and Springer 2003; Hultman 2006), there has yet to be a systematic examination of the influence of dependencies on forest offset reversal risk and their overall effect on the integrity of offset programs as a whole. In order to assess this overall risk, it is not just the probability of reversal of any one project that needs to be determined but the dependence between them that must be analyzed as well. In this paper, we discuss three types of dependent or correlated risks that could affect forest offsets—fat tails, micro-correlation, and tail dependence—and provide examples of how policy could be designed to help minimize these risks.

Protocols in the voluntary carbon market and proposals before Congress to establish offsets under a federal GHG regulation program recognize the potential risks to environmental integrity posed by offset reversal, and nearly always involve mechanisms to address impermanence of sequestered carbon. The most commonly used approach is to require the establishment of a buffer, whereby a certain amount of credits generated by the project are set aside and held in reserve. If the project undergoes a reversal, the reserve pool is debited to cover the amount of lost carbon. The amount of reserve credits (or "set asides") required can either be a set percentage of the credits earned by the project or can be based on project-specific reversal risk. Another approach that has been used—for example, for forest sequestration projects under the Clean Development Mechanism (CDM) of the Kyoto Protocol—is temporary offset credits. These are carbon credits which have limited shelf-lives and must be replaced after some specified period of time. In the CDM, temporary credits generally trade at a deep discount relative to other more permanent offset credit types (Subak 2003; Chomitz and Lecocq 2004, Murray and Olander 2008). Some authors have suggested that insurance could also be used to manage reversal risk, but such products have been slow to emerge in the voluntary market, although some products are beginning to take shape (Kent and Thoumi 2010).

As the buffer approach is the most widely used, we focus most of our attention in this paper on the use of buffers. One criticism of the buffer approach is that the buffer reserve could be overwhelmed by a catastrophic reversal. The three types of dependencies in reversal risk we discuss in this paper could make the risk of overwhelming a buffer much greater than policymakers and managers would presume if they assume such risks are uncorrelated and independent. To maintain program integrity, it is therefore critical to accurately account for reversal risks at the level of the program as a whole. This has not been done to date. Drawing on common practices in the financial and insurance sectors, we offer several options to take account of this risk in the design of a buffer system for the entire program, and not at the level of a project.

2 The nature of reversal risk

Although the reversal risk associated with individual offset projects has been recognized in policy and in the literature, the overall riskiness of a portfolio of projects remains largely uninvestigated. The likelihood of reversal could be correlated across project types, across project locations, or among the different threats to the permanence of the carbon storage. If offsets are part of a system to regulate carbon emissions, program administrators will need to understand the reversal risk associated with the sum total of all the projects, which will be affected by dependencies. There are multiple types of dependence that could arise in evaluating a portfolio of forestry offset projects beyond simple linear correlations. Here, our focus is on three types of dependence: fat tails arising from spatial correlation, micro-correlations, and tail dependence. If neglected, these could compromise the integrity of a broader climate policy.

2.1 Fat tails and spatial correlation

Natural disturbances in forests are random events that can be characterized using size-frequency distributions. The distribution of the magnitude of many natural disturbances have been found to be fat-tailed. With fat-tailed risks, a large proportion of the total forest area affected by a disturbance process can be attributed to a small percentage of the total number of events. Several studies, spanning a wide range of forest types in the United States, have concluded that wildfire regimes are fat-tailed (Strauss et al. 1989; Malamud et al. 2005; Holmes et al. 2008). A similar pattern has been found for Mountain Pine Beetle epidemics in British Columbia, Canada where the size-frequency distribution describing the clusters of trees killed has a fat tail (Gamarra and He 2008).

The concept of a distribution with a fat tail is illustrated in Fig. 1. This figure shows data on the acreage of wildfires in the state of Florida between 1981 and 2006. The curved line shows the number of fires occurring in various size classes exceeding 500 acres—and thus is the tail of the overall size-frequency distribution. (A total of 131,359 fires of 500 acres or less were omitted in this figure.) The final size class (10,000 acres and above) accounts for less than 1% of all the wildfires in Florida during this time period, but accounts for nearly two-thirds of the entire area burned. This is indicative of fat tails.

Fat-tailed size-frequency distributions are characterized by an extremely high variance, meaning that a large event can occur simply as a result of the normal functioning of the

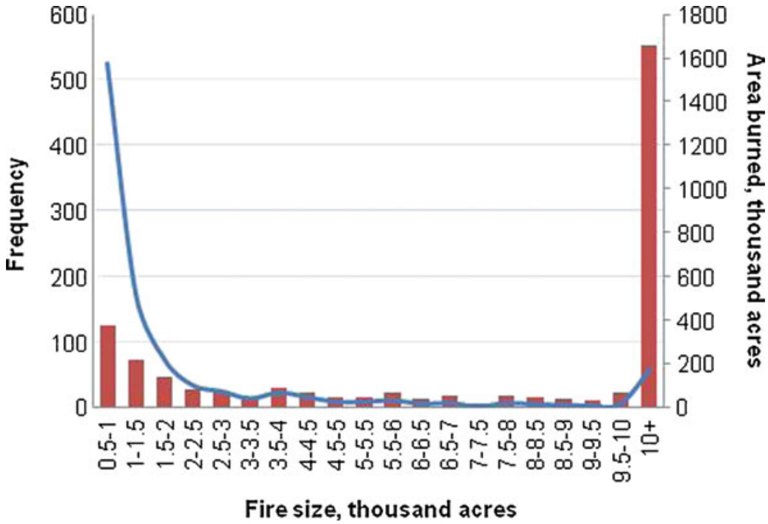

Fig. 1 A fat-tailed distribution as depicted by the smoothed frequencies (*curved line*) and area burned (*solid bars*) associated with discrete wildfire size classes (*horizontal axis*) in Florida for the years 1981–2006

disturbance process. Recall the Yellowstone fires of 1988—the largest fires recorded in the history of Yellowstone National Park. They burned nearly 800,000 acres. Subsequent research showed that the 1988 fires were not abnormal, but were similar to fires occurring in that region during the 1700s (Romme and Despain 1989).

The notion of fat-tailed disturbances is intimately connected to spatial correlation in reversal risk. Take the case of wildfires again. The very fact that some fires can burn enormously large areas makes the risk of fire on parcels located near each other correlated. When one parcel burns, it is more likely a nearby parcel will also burn. On the other hand, it is this fact that fire can spread to neighboring parcels, due to similar vegetation types or climatic conditions, for example, that introduces the spatial correlation in the first place and makes fat-tailed disturbances possible.

2.2 Micro-correlations

Micro-correlations refer to correlations between variables that are so small, they are likely to be overlooked. Aggregations of variables with a small correlation, however, become themselves strongly correlated (Kousky and Cooke 2009).[1] In an offsets program with thousands of individual projects, even a tiny positive correlation in reversal risk between projects will result in correlation across portfolios of projects. Increasing the number of projects aggregated in each portfolio will result in higher correlation of risk across the portfolios. Rather than serving to diversify risk, aggregating projects into distinct portfolios actually serves to amplify these micro-correlations.

What could cause such a tiny correlation between projects? One possibility is that all the offset projects are correlated with a third variable. For instance, if the probabilities of carbon loss due to fire and pine beetles are both positively correlated with temperature, then

[1] This is seen by calculating the correlation, ρ, between two portfolios of N projects with σ giving the covariance between individual projects: $\rho\left(\sum_{i=1\ldots N} X_i, \sum_{i=N+1\ldots 2N} X_i\right) = \frac{N^2\rho\sigma^2}{N\sigma^2+N(N-1)\rho\sigma^2} = \frac{N\rho}{1+(N-1)\rho}$. This goes to 1 as $N \to \infty$.

they will have a tiny correlation with each other. As temperature increases, both types of forest loss will become more common. Or, as another example, if the probability of fire is correlated with U.S. Forest Service fire suppression policies, then forestry projects in even widely dispersed locations will be correlated if they are similarly affected by that policy. When multiple entities create portfolios in which the individual offset projects have even tiny correlations, then the risks to those portfolios will themselves be highly correlated. This means that when one entity is experiencing reversal in their portfolio, it is more likely others will be as well, making the entire program riskier.

2.3 Tail dependence

Tail dependence refers to the tendency for the dependence between variables to concentrate in the extreme values. With tail-dependent disturbance risks, small disturbances are more or less independent but catastrophic disturbances tend to be correlated. Reversal risk for forest carbon offset projects could be tail-dependent if, for example, small fires and minimal outbreaks of pine beetle are largely independent from each other, but catastrophic levels of each tend to be correlated.

Tail dependence can occur for two reasons. First, there could be a causal link between two variables, such that when one takes on an extreme value, it pushes the other variable to do so as well. This is akin to the observation that disturbances can be cascading (Dale et al. 2001). For example, extreme drought can weaken trees and lessen their ability to produce resin, which is necessary to protect themselves from pine beetles. Thus, extreme drought and extreme beetle infestations may be tail dependent.

Second, tail dependence could arise when a third, normally dormant variable, pushes both variables into extremes when activated. Looking again at drought, water stress can lead to both increased fire risk and risk of insect infestations. When drought conditions prevail, therefore, it could lead to extremes of both fire and infestation, introducing tail dependence between these threats.

While tail dependence has not yet been investigated with regard to threats to forest offset projects, damages from hurricanes provide an intuitive example. Flood damage and wind damage are often independent; a rising river does not necessarily mean strong winds and a storm with high winds may not have enough rain to cause flood damage. A severe hurricane, however, causes both. This suggests that wind and water insurance payments may be tail dependent in a hurricane-prone state such as Florida. Tail dependence can be seen in two variables by ranking them. Here we show flood claims in Florida between 2000 and 2006 from the federal National Flood Insurance Program and wind claims from the Florida state insurer Citizens Property Insurance Corporation. Claims for each program by county and month were ranked from largest to smallest, with the largest claim normalized to 1. These ranks are plotted against each other in Fig. 2 to see whether the largest ranked wind claims tend to occur at the same time as the largest ranked water claims. Figure 2 shows little to no correlation between wind and water claims at low levels of either claim, but the abundance of points in the upper right quadrant is an indication of tail dependence between these variables.

3 Lessons for policy

Most policies that have attempted to address reversal risk in carbon offsets projects implicitly assume that such risks are thin-tailed and independent. The generic buffer

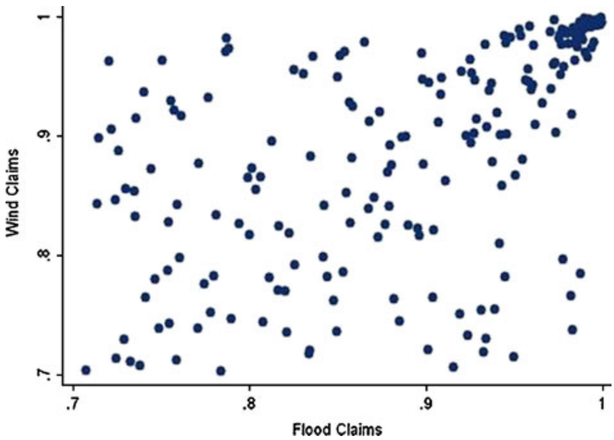

Fig. 2 Plotted ranks of wind claims from Citizens Property Insurance Corporation and flood claims from the National Flood Insurance Program by county and month for the years 2000–2006 in constant 2007 dollars

approach, for example, works well in this case, as the central limit theorem ensures that the probability that a reversal exceeds the common buffer will become negligibly small as projects are added to the portfolio. In the presence of any or all of the dependencies discussed here, however, there is a greater probability that multiple projects could experience reversal simultaneously, potentially overwhelming the buffer.

For risks of disturbance with fat tails, impacts will come primarily from a relatively few number of events, such as catastrophic fires, which could tax the buffer system. If risks among projects have small positive correlations (micro-correlations), normal risk-management techniques, such as geographic diversification through the aggregation of individual projects, may not adequately address the problem. The problem with traditional buffers could be exacerbated further if the risks are tail-dependent, which could result in high losses from two separate impacts, such as wildfires and pest infestations For this reason, accounting for risk in individual projects but not the portfolio as a whole could lead policymakers to assume more reversal risk than they intend.

How can dependencies be addressed? It might appear that the simplest option is to simply increase the size of the buffer. For instance, an offsets program facing one or more of these types of risks could use the buffer to be prepared for a worst-case scenario loss of carbon. But while the risk of such a significant loss of carbon is real, it may also be extremely rare. It may therefore be impractical, given the huge increase in cost this would imply, to require project developers to set aside high percentages of their offset credits to guard against relatively small, though still significant, risks of reversals. In addition, no program will be entirely risk free, and enormously large buffers that drive up costs could discourage investment in forest offset projects.

Another approach that could be taken is based on value-at-risk (VAR) management techniques often used in financial and insurance companies. In such an approach, the program manager stipulates, for the program as a whole, the probability of complete reversal they do not want the offset program to exceed. Say the manager wants the probability of complete reversal to be below 1%. In this case, the buffer for the program as a whole is set to cover the 99th percentile of possible losses. This amount is calculated from the distribution of possible losses for the program as a whole, and not for individual projects. It thus requires the dependencies between projects to be actively modeled in order to determine their contribution to overall risk.

This suggests a complementary risk management approach that could be used. Buffer contributions for each project could be determined based on the contribution of the new project to the overall risk of the portfolio of all offsets in the program. Just as financial managers assess the contribution an asset makes to the risk of the entire portfolio of investments, or an insurance company considers how a new policy or line of business impacts the solvency probability of the whole firm, so too should an offsets program manager consider how an additional project alters total overall risk. This, as we discussed throughout the paper, is a function of the dependencies between the new project and the other projects in the portfolio.

Because total risk will change as the portfolio of projects changes, the total overall buffer and contributions from at least new projects could be linked to an iterative risk reevaluation process in order to address the dependencies discussed here. The one drawback of these approaches is that they are very information intensive. Calculation of buffer contributions in this manner requires an understanding of the dependencies. Such relationships can be examined if historical data is available for the possible reversal risks in the relevant location, but often it may not be. Further, uncertainties surrounding the potential impacts of climate change on disturbance risks (Dale et al. 2001; Millar et al. 2007) will complicate calculations and require modeling of climate impacts. The other drawback is that the modeling of dependencies (and the modeling of climate changes) can be quite sophisticated and require tools, time, and resources managers do not have or wish to invest.

Despite this limitation, some dependencies could easily be inferred or given a first-order approximation that would improve risk management at the level of the entire offset program without requiring detailed analysis. For instance, projects located in spatial proximity are much more likely to face reversal risks that are positively correlated. An offset manager could thus seek, through buffer requirements or other design features of the program, to draw together projects that are geographically diversified. For example, a project that is located near one currently in the program would be penalized with a higher buffer requirement than one located further away.

Research will clearly be critical in helping to design policies to address reversal risk. Examples of particular phenomena potentially affecting forest offsets are introduced here, but the inclusion of a data collection component within an offset program would enhance identification and analysis of reversal risk across projects, across disturbance types, and over time. Unfortunately, even improved data on existing forest disturbance regimes may be of little assistance in understanding threats to forests from a changing climate. If managers suspect they face the type of dependencies discussed here, they may choose to implement more aggressive risk-management strategies or simply limit the total amount forest offsets can contribute to an overall abatement target. Policymakers will therefore need to weigh the available information on these risks when deciding upon the exact role that forest offsets are to play in climate policy, as well as the associated programmatic risk-management strategies that will be necessary address these risks.

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