

ANALYSIS

Take a risk: Preferring prevention over control of biological invaders

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ABSTRACT

Scientists have argued that invasive species can be managed most cost effectively with greater investments in prevention. Further, under ideas like the precautionary principle it is reasonable to expect that a cautious manager would use more prevention relative to control because it keeps more invaders out. Yet, this is not typically done. In many cases, private and public resources are invested primarily to control existing invaders rather than to prevent new invasions. Managers frequently wait until after invaders have arrived and then scramble to limit the damages. We believe these paradoxical decisions can be understood by recognizing the link between typical human preferences for risk bearing and the technology of risk reduction. We demonstrate quantitatively how managers perceived to be cautious or averse to risk tend to shy away from prevention relative to control. This counterintuitive result arises because control is a safer choice than prevention because its productivity is relatively less risky: it works to remove existing invaders from the system. In contrast, the productivity of prevention is more uncertain because prevention only reduces the chance of invasion, it does not eliminate it, and invasion may not occur even in the absence of prevention. Managers' averse to risk will inherently avoid as much uncertainty as possible, whether the source of uncertainty regards ecological outcomes or economic productivity. Implications for environmental decision making are clear. In invasive species management, if managers act as though they are risk averse, their caution can backfire when it leads to more control rather than prevention. The social consequences of this choice are a greater probability of future invasions and lower social welfare. Our results suggest that social welfare is highest when managers were willing to "take a risk" with prevention.

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1. Introduction

It is frequently argued that environmental, medical, and economic disruption caused by many forms of pollution would be reduced most cost effectively with greater investments in prevention; yet in many cases, private and public resources are invested primarily to control existing problems rather than to prevent new problems. In the US and many other countries, this is especially true for the form of biological pollution known as invasive species (U.S. General Accounting

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Office, 2002; Wittenberg and Cock, 2005). Such nonnative species around the world, including rat (*Rattus rattus*), West Nile virus in North America, leafy spurge (*Euphorbia esula*) in North America, and North American gray squirrel (*Sciurus carolinensis*) in Europe, spread and pose substantial risks to the environment and society (Mooney et al., 2005). Any manager, including government, industry, non-governmental organization, or private citizen, trying to control these risks may invest resources in prevention to reduce the likelihood of establishment of new invader populations or in control to reduce the population of established invaders, or both (Perrings et al., 2005). In addition, these risk reduction investments depend on the technical relationship between prevention and control (i.e., technical compliments or substitutes), and the decision maker's preferences over risky events and time.

Under ideas like the precautionary principle (Sandin, 1999; Foster et al., 2000), we might expect that a cautious manager would use more prevention relative to control because it keeps more invaders out. Yet, this is not typically done. Rather managers frequently wait until after invaders have arrived and then scramble to limit the damages (Leung et al., 2002; Carlton and Ruiz, 2005). Compounding the issue is widespread confusion and controversy about what is meant by precautionary approaches (Cooney, 2004). Ecologists and economists have different mindsets when thinking about the idea of precaution. To many ecologists with whom we have talked, precaution means "prevention". To them, it is the outcome that matters-a safe and protected environment-in which prevention is the key objective and control is used if necessary. Whereas to many economists, precaution implies a certain preference for risk, namely risk aversion. Here they assume it is the preference structure that matters-a risk averse manager who chooses to maximize welfare given a set of risk reduction technologies. This divergence in mindsets provides another illustrative example on why communication between the disciplines matters for better science.

Here we explore one potential source of that confusion-the different conceptions of precaution and risk typically used by ecologists and economists. We believe the neglect of preventative measures can be understood by recognizing the link between typical human preferences for risk bearing and the technology of risk reduction. We show this by simulating the prevention and control strategies of resource managers, differentiated by their increasing level of aversion to risk. Here risk is defined in two dimensions: (1) the probability and level of damages caused by an invasive species, and (2) the opportunity costs of spending scarce resources on the invasive species which may or may not be able to invade and become established, causing economic damage. Formally, a manager who is more risk averse is less willing to accept an actuarially fair gamble (i.e., one with an expected value of zero) than some other manager (see for instance Machina, 1987; Gollier, 2001). A more risk averse manager, then, prefers relatively more certain risk reduction strategies-ones that result in less risky benefits for the costs-compared to riskier strategies in which the benefits are less definite.

Intuitively, one might think that this means that a more risk averse manager would lean toward more prevention relative to control in the mix of risk reduction strategies because it keeps more invaders out. But here we demonstrate quantitatively how

the opposite (and typical) result can occur. Using an integrated bioeconomic model for zebra mussels (Dreissena polymorpha), a mollusk species native to Eurasia but which is a serious pest in North America, our results show how increased aversion to risk by managers can lead to less prevention and more control, which increases the probability of invasions and realized abundance of invaders, which lowers overall social welfare in comparison to a less risk averse decision maker. This counterintuitive result arises because our risk averse manager values a dollar spent on control (with certain benefits now) more highly than a dollar spent on prevention (with uncertain benefits). The productivity of prevention is more uncertain because a manager does not know if he really kept out an invasive species or whether it simply would never have arrived or would have died out on its own. Further, prevention only reduces the chance of invasion, it does not eliminate it. In other words, the opportunity costs (with respect to control) of investments in prevention drive the manager to lean toward control at the expense of prevention.

2. Methods

Following Shogren (2000), we conceptualize the management of an invasion by highly mobile invasive species with numerous transportation pathways (e.g., into the United States). A benevolent manager (resource manager) is limited to reducing the risk posed by the invasion through some combination of collective investments in more local or regional prevention and control, realizing that firms also adapt, i.e., invest to reduce their own risk.

The invader causes damages if it successfully traverses a number of interrelated processes: introduction, establishment, and growth of the invader. Not all species that invade become established, and not all established invaders cause damages (Kolar and Lodge, 2001). Once a species establishes itself, let the system be considered invaded. After establishment, the invader can increase in abundance. It is the abundance that directly relates to damages. Unlike most other forms of pollution, in which remedial efforts can have lasting effects, the reproduction of invasive species means that control efforts may be necessary in perpetuity.

Economic decision making in the model is nested. The resource manager makes collective decisions over prevention and control, while taking as given the firm's behavior (i.e. Nash behavior). In any period, a representative myopic firm takes as given the current state which is defined by invader abundances. Invader abundances cause damages to the firm. For example, with power plants, zebra mussels clog coolant systems. In response, the firm can adapt to the invader. This occurs when the firm is "small" relative to the landscape scale of the invasion and unable to prevent or control the invader such that they are forced to take the population dynamics as given. From the firm's perspective, adaptation is a strategy that recognizes the direct damages and responds by altering its inputs to reduce the consequences of the damage. The power plant, for example, adapts to the damage posed by zebra mussel by operating longer hours or burning more fuel than would be necessary without an invasion.

The manager can prevent future invasions in neighboring waterways and control the population growth of the existing population of the invader. The manager uses prevention to reduce the probability that invasion occurs. Once an invasion has occurred, the manager can use control strategies to reduce the abundance and therefore damages in the next period. If the location is uninvaded, prevention reduces the probability of invasion during the transition to the next period. If prevention is effective, no damage occurs; if ineffective, invaders may establish themselves and cause damages in the next period. In the invaded state, population growth increases the magnitude of damages. Control affects the probability of population growth (Finnoff et al., 2005; for full details including comparative static results see Finnoff et al., 2006).

The benevolent manager's stochastic dynamic problem is as follows. Let $W_{\theta,t}$ be the maximum discounted expected social welfare from the perspective of initial period t to the horizon T, where states in any period t are defined by current period invader abundance θ_t (state variable). Annual social net benefits w_t for any given state are a function of annual firm profits and annual costs of collective strategies. Firm profits π_t depend on revenues and input costs (analogous to adaptation here) subject to damages from current invader abundances. Firms are myopic and as such they do not consider future uncertain transitions in states. Each period the producer hires factors of production labor L_t and capital K_t in the production of output Q_t . In response to damages, the firm adapts $Z_t^P(\theta)$ through compensating factor employment to the consequences of an invasion (such that $Z_t^P(L_t(\theta), K_t(\theta))$ and adaptation reduces the magnitude of losses). Annual profits for the firm are,

$$\pi_{t}(\theta) = P_{Q}Q_{t}(\theta) - C_{L}L_{t}(\theta) - C_{K}K_{t}(\theta)$$

Invaders cause damages directly to the firm, reflected in these variables through the functional notation. P_Q is the (constant) price of Q, C_L the wage rate and C_K the rental rate of capital. Following Lichtenberg and Zilberman (1986), the inclusion of damages to production are captured through a Cobb–Douglas production function,

$$Q_t = \alpha L_t^a K_t^b (D_t(\theta))^c$$

where α , *a*, *b* and *c* are parameters and $D(\theta)$ a damage function relating the impacts of the invader population to monetary damages. An exponential specification of *D* allows greater abundances of invaders to increase the damage they cause, deviating *D* from its un-invaded magnitude of unity.

Unlike the firm, the manager considers the dynamics of the invasion process and can partially control entry and growth of the invader, knowing the private response of the firm given (in aggregate) by Z_t^P . The manager influences the transition process and reduces the damages associated with invasion in *future periods* through collective control X_t^G and prevention S_t^G . Together, social net benefits w_t are a function of firm output, output price, input prices, private adaptation, collective prevention and collective control,

$$w_{t,\theta,\hat{Z}_{t}^{p},X_{t}^{G},S_{t}^{G}} = (P_{Q}\,\hat{Q}_{t}(\theta) - C_{L}\,\hat{L}_{t}(\theta) - C_{K}\,\hat{K}_{t}(\theta)) - C_{X}X_{t}^{G} - C_{S}S_{t}^{G}$$

where hats indicate variables endogenous to the firm, C_S is the per unit cost of preventative measures and C_X the per unit control costs. Risk attitudes are included in the model by the inclusion of a von Neumann–Morgenstern utility function U. The curvature of the function allows the representation of a wide range of attitudes towards risk including risk neutrality, risk aversion and risk loving. In this paper, the focus is on increases in the degree of risk aversion from: risk neutral (RN), weakly risk averse (RA1), moderately risk averse (RA2), to highly risk averse (RA3) (see details below). The Stochastic Dynamic Programming (SDP) equation is,

$$\max_{X_t^G,S_t^G} W_{\theta,t} = U(w_{t,\theta,\hat{Z}_t^P,X_t^G,S_t^G}) + \rho \sum_i \Psi_{\theta,X_t^G,S_t^G,i} W_{i,t+1}$$

where $W_{\theta,t}$ is discounted cumulative welfare from the end time horizon *T* to the current time *t*, and the discount factor ρ is related to the discount rate *d* by $\rho = 1/(1+d)$. Ψ is the probability of moving from state θ to state *i*, given random invasion, stochastic population growth, and collective strategies S_t^G and X_t^G chosen to maximize $W_{\theta,t}$. Human and ecological behaviors influence both outcomes and transition probabilities so that for each state at each time interval, the model determines both optimal strategies and future trajectories.

In the simulation model, the functional form employed for the utility function allows a range of risk preferences (see Holt and Laury, 2002),

$$U(w_{t,\theta,\hat{Z}_t^p,X_t^G,S_t^G}) = \frac{1 - e^{-\alpha \left(w_{t,\theta,\hat{Z}_t^p,X_t^G,S_t^G}\right)^{(1-r)}}}{\alpha}.$$

The function exhibits risk neutrality when parameter α approaches zero, and captures increasing relative risk aversion and decreasing absolute risk aversion when both parameters α and r are positive. For the baseline RN scenario, risk preference parameter values were $\alpha = 0.26 \times 10^{-6}$ and $r = 0.269 \times 10^{-6}$ (providing an Arrow-Pratt index of relative risk aversion of 0.00001, approximating risk neutral preferences). Across all degrees of risk aversion, Holt and Laury's (2002) estimated value of r=0.269 was employed, with arbitrarily increasing values of α from 0.029, to 0.29, to 0.39 to represent Arrow-Pratt indices of relative risk aversion for RA1=0.61, RA2=3.4 and RA3=4.5 (each evaluated at pre-invasion welfare levels). The parameter combinations provide values of risk aversion such that RA1 is very weakly risk averse, RA2 moderately risk averse and RA3 highly risk averse. For each degree of risk aversion welfare was normalized, and each combination of parameters represents increasing relative risk aversion and decreasing absolute risk aversion, consistent with observed data in Holt and Laury (2002).

Transition probabilities Ψ are Markov and modeled as a multi-state compound lottery. A continuum of states θ_t is allowed between 0 (unsuccessful invasion) and the carrying capacity K. In uninvaded states, the realized probability of invasion in the following period p_{t+1}^a is,

 $P^a_{t+1} = p^b e^{-nS_t}$

 p_{t+1}^a depends on the baseline probability of invasion p^b , and the manager's prevention effort S_t in the current period. Parameter *n* reflects the efficacy of prevention effort and *e* is the exponential function.

Given an invasion in (t+1), the probability of growth $q_{\theta,t+1}$ depends on initial population θ_{t+1}^b , which in turn depends on collective control efforts in the preceding period X_t and stochastic population growth (from random variable ε_t). The process proceeds in two stages. First, in *period* t, collective control reduces the abundance of reproducing invaders (i.e. the kill function) during the transition to (t+1), hence

$$\theta^a_{t+1} = \theta^b_t e^{-vX_t}$$

where θ_t^a are the residual of initial invaders θ_t^b that survive control measures and may reproduce. Parameter v describes the effectiveness of control. The accompanying stock growth uncertainty from random variable ε_t occurs through the logistic expression,

$$\theta_{t+1}^{b} = \theta_{t}^{a} + r\theta_{t}^{a} \left(1 - \frac{\theta_{t}^{a}}{K}\right) + \varepsilon_{t}$$

where K is the invader's carrying capacity, and r the invader's intrinsic growth rate.

Using this integrated bioeconomic model, we illustrate the potential for unintended consequences from risk averseness for zebra mussels in a hypothetical U.S. Midwestern lake. By one estimate, zebra mussels currently cost US industries an estimated US\$2 billion since 1989 (O'Neill, 1996, O'Neill pers. comm.). Regional and federal governmental agencies and power plants and water treatment facilities continue to experiment with new control measures to maximize the benefits of zebra mussel control, and prevention of new infestations remains timely because zebra mussels are still expanding their range within North America (Bossenbroek et al., 2001; Drake and Bossenbroek, 2004). Zebra mussels also cause substantial environmental impacts (Ricciardi and Rasmussen, 1998; Lodge, 2001).

Following Leung et al. (2002), we consider a hypothetical zebra mussel invasion of a lake and its impact on a representative electricity generation facility. While we are not attempting to model a specific situation, we parameterized the risk model with economic and biological data when possible using published sources on power plants, and zebra mussel invasions in Midwestern and other relevant waterways. Leung et al. (2002) and Finnoff et al. (2005, 2006) contain specific details on data collection for the parameters. For each level of risk preferences: RN, RA1, RA2, and RA3 four discount rates, d, d=0%, d=3%, d=5%, and d=15% were considered.

For ecological and parameters at the intersection of the economic and ecological components of the model, the baseline probability of invasion p^b extrapolates the monthly value used in Leung et al. (2002) into an annual value of 0.0828. The efficacy of prevention n, was found from manipulation of the probability of invasion equation and the assumption that a unit of prevention reduces the probability of invasion by 90%. An identical procedure was followed to find v. Arbitrary baseline values for the intrinsic growth rate (r=1) and invader carry capacity (K=1000) were employed and assumed to be representative of a generic invasion process following Leung et al. (2002). The critical linkage of these ecological variables to the economic component of the model also follows Leung et al. (2002) under the assumption that if the invader population were to achieve its carrying capacity, economic production would be reduced to 50% of its non-damaged levels with all other variables held constant.

Given their arbitrary nature, we preformed a sensitivity analysis of the simulation results across ranges of key parameters at the intersection of the economic and ecological components of the model. Specifically, values of the intrinsic growth rate r, the carrying capacity K, the efficacy of prevention n, the cost of prevention C_S , the efficacy of control v, and the cost of control C_X were all varied from 10% to 350% of their baseline value.

Observed data were employed in the parameterization of the economic components to make the magnitudes of change in the results reasonable (see Finnoff et al., 2005 for complete details). Data on a small set of large electric utilities in the great lakes region were collected from generator's filings with the Federal Energy Regulatory Commission (FERC). Variables are firm and year specific, and measured at the level of the plant. All monetary variables were deflated, and those variables not directly observed determined through a calibration procedure.

3. Results

In the simulations, greater aversion to risk leads to less prevention (Fig. 1a) and greater control (Fig. 1b), in which mean annual levels are the values in each state weighted by the probability of being in that state. For small increases in aversion to risk the changes are barely discernable, but as the degree of risk aversion becomes more intense the effects become more pronounced. Large increases in aversion to risk lead to significantly larger changes in prevention and control, with resulting persistent increases in the probability of invasion. For example, with a 3% discount rate, the percentage change in the mean annual probability of invasion from its level under RN for RA1 is zero, while for RA2 it is a 40% percentage increase, and a 115% increase for RA3. Across all scenarios, a greater probability of invasion triggers a chain reaction-a greater population of the invasive species, which induces the firm to adapt more, which then raises costs that ultimately lead to lower overall welfare.

The results remain robust across wide ranges of key parameters. Fig. 2 corroborates the findings, showing mean annual percentage changes in variables from their value under RN to that for RA3 averaged across ranges of each parameter from 10% to 350% of their baseline value (where all other variables are held constant at their baseline value for each parameter variation). Fig. 2a demonstrates that across perturbations in each parameter, under risk aversion prevention always lies below the values under risk neutrality; whereas control lies above the values under risk neutrality. Abundances and the probability of invasion are always greater under risk aversion than risk neutrality (Fig. 2b) and while annual welfare is always less under risk aversion, firm adaptation (capital and labor employment) exceeds (slightly) its value under risk neutrality (Fig. 2c).

The averages presented in Fig. 2 provide some revealing intuition over the relative importance of the parameters at the intersection of the economics and ecology. Very low carrying capacities result in low damages, as such the manager neither prevents nor controls. This is seen in higher probabilities of invasion and abundances. But high carrying capacities result in high damages, prompting high levels of prevention and control, although the level of prevention/control is less/more with risk

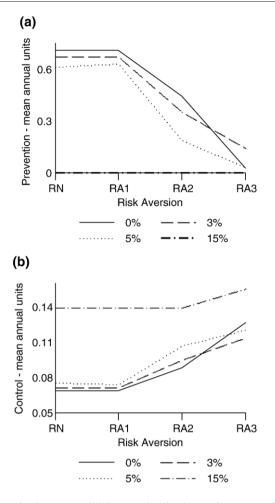


Fig. 1–The impacts of risk aversion in the endogenous risk framework. For a and b the horizontal axes are increasing levels of risk aversion as defined in the text. Units of collective prevention (a) and control (b) are the average number of prevention and control (e.g. molluscicide applications) events on an annual basis.

aversion. In both cases of low and high carrying capacities the firm does not have to adapt much as either there are small damages or the resource manager's prevention and control keep the firm's realized damage low. There are, however, significant welfare losses due to the resource manager's expenditures on prevention and control.

The results across the intrinsic growth rate are similar, although the difference between the results for risk neutral and risk averse management narrows as the intrinsic growth rate rises. This occurs because the more explosive the growth of the invader, the more certain realized damages become, prompting even the risk averse manager to invest more in prevention. Increased use of prevention in turns lowers the probability of invasion, abundances, and reduces the magnitude of the welfare loss.

If prevention is very ineffective (low *n*), the resource manager does not prevent and is forced to rely only on control under both risk aversion and risk neutrality. Although control is relatively effective in this low *n* case, it is expensive as the probability of invasion is high (with no prevention), which lowers welfare. With very effective prevention (high *n*), the risk

averse manager prevents/controls more/less than low *n* since the strategy is less risky, but again this prevention is lower relative to risk neutrality.

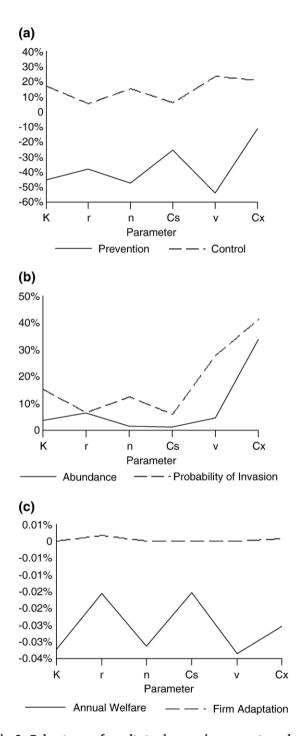


Fig. 2–Robustness of results to changes in parameter values. For a, b and c the vertical axes are average annual percentage changes in the variables of interest from their values under risk neutral (RN) preferences to their values under risk averse preferences (for RA3 and d=3%). The average annual percentage changes are calculated as the average across ranges of each parameter (from 10% to 350% of their baseline value) on the horizontal axis (all other parameters held at their baseline value).

Across the range of prevention cost, C_s , low unit costs prompt greater use of prevention and less control, although under risk aversion prevention/control is less/more than under risk neutrality. At high costs C_s , prevention is too costly and not used under risk aversion or risk neutrality. Now control is employed at high levels and there is little difference between its use under risk aversion or risk neutrality.

The influences of the efficacy of control, v, and the cost of control, C_x , are similar to the effects for prevention, although the degree varies. With little effectiveness of control (low v) and regardless of risk preferences, the manager uses high levels of control (with high expenditure) and no prevention (given all resources spent on control). This occurs because with low v, those invaders admitted to the system can only be eliminated using many resources; this use crowds out the resources spent on prevention. But as control becomes more effective its employment declines (by more under risk neutrality than risk aversion) and as these expenditures fall prevention rises (by less under risk aversion than risk neutrality).

If control is cheap (low C_X), it is used heavily under both risk aversion and risk neutrality (more under risk aversion) and prevention is not. As it becomes more expensive, control use declines and prevention rises, by more under risk neutrality than risk aversion. The difference between risk aversion and risk neutrality declines with greater costs of control. Across the entire range of C_X , welfare under risk aversion always lies below that of risk neutrality; while the difference between the two declines as C_X rises, welfare falls.

4. Discussion

Implications of these results for environmental decision making are lucid given the assumptions of our model. In invasive species management, if managers' act as though they are risk averse and apply excessive caution in their management strategies, their caution can backfire when it leads to more control rather than prevention. The social consequences of this choice, at least in our modeled example, are a greater probability of future invasions and lower social welfare. Given that we account for the opportunity costs of preventionkeeping species out that would not have been a problem-our results suggest that social welfare is highest when managers were willing to "take a risk" with prevention. Paradoxically, the practice of what economists call 'risk neutrality' turns out to be most consistent with what environmentalists call a 'precautionary' approach, and to yield the outcome with highest social welfare. Risk neutrality accepts that there is scientific uncertainty, and formally integrates this into decisions. The precautionary approach, which suggests that uncertainty should not inhibit our ability to take actions to protect the environment, is followed best by managers' exhibiting risk neutrality. Below we elaborate on the interactions that produce these results.

In our model, the manager chooses between the two options in the portfolio: prevention and control. In theory, greater risk aversion has two effects on each component of this portfolio. First, what can be termed a direct effect with respect to optimal choices over prevention and control exists—by definition, if one is more risk averse, holding on to a dollar is more attractive (e.g., a sure bet) than spending it on either prevention or control since both are affected by random invasion and stochastic population growth. A more risk averse manager gets relatively greater utility out of a sure thing. As prevention is less of a sure bet, the direct effect to shy away from it is stronger than the direct effect to shy away from control.

Second, an indirect effect exists which serves to either attenuate or accentuate the direct effect. The direction of this indirect effect depends on whether prevention and control are technical complements or substitutes. If technical complements, investments in prevention increase the marginal effectiveness of control (and vice versa). If substitutes, the use of one strategy lessens need for the other. In general, however, it is ambiguous whether the indirect effects work with or against the direct effects, which is why we use numerical simulation.

The dominant influence of the direct effect from prevention in our model is expressed in the selection by more risk averse managers of a portfolio with less prevention and more control. To a more risk averse manager a dollar spent on control is worth more than a dollar spent on prevention because the expected marginal effectiveness of control exceeds the expected marginal effectiveness of prevention. There is less uncertainty in the application of control-it removes existing invaders from the system. There is more uncertainty in prevention because it only reduces the chance of invasion (if it occurs at all); it does not eliminate it. For this reason, the direct effect on prevention dominates the indirect effect; more risk averse managers' use less prevention. Since prevention and control act as substitutes, less prevention implies more control (here the large positive indirect effect on control dominates its negative direct effect).

There are also serious dynamic consequences of managers' preferences towards risk. Within the mean annual changes discussed, over time the choices made by more risk averse managers deviate from those of less risk averse managers by the greatest extent at the beginning and end of the planning horizon. During the earliest periods of the planning horizon prevention on average is not used by more risk averse managers (while control is employed at a high level). Similarly, towards the end of the planning horizon more risk averse managers on average stop employing prevention at an earlier date than less risk averse managers. This serves to increase the probability of invasion at the beginning and the end of the planning horizon. In turn, this results in population growth by the invader, adaptation by humans, and lagged control investments that ultimately lower overall welfare.

In conclusion, risk cuts two ways. A manager who addresses risk faces both the risk posed by invasive species (to the environment and to human well-being) and the technological risk associated with the methods used to reduce risk. Since prevention is technologically a riskier input relative to control, managers averse to risk tend to go with the safer bet—control. In effect, our results suggest that to protect human infrastructure and the environment as measured by the probability of invasion, managers should not be overly cautious. They must be willing to take a risk with prevention. As would be expected, managers who are risk neutral make choices that maximize social welfare. Paradoxically these risk neutral choices—which lean towards prevention (in relation to the choices of a risk averse manager)–produce results consistent with the precautionary principle. Risk preferences as defined by economists govern human behavior towards risk. The precautionary principle as defined by environmentalists relates more to desired outcomes (treating long run or uncertain threats more seriously today). Without attention to both concepts and terminology, there is a high probability that economists and environmentalists will misunderstand each other when addressing risks.

Another important aspect of these results is that even with the perfect foresight of the SDP model, the benevolent yet risk averse manager's choices turn out poorly over the long run. Of course, in the real world, perfect foresight does not exist, and real results of such policy choices would likely result in much worse outcomes. This suggests that the more unknown is the likely magnitude of future invasions, the worse decisions a risk averse manager will make. Lowering the uncertainty associated with future invasions could well work to improve social welfare even under risk averse managerial decisions. In fact, the technology of invasion forecasting has improved dramatically in recent years (Daehler and Carino, 2000; Clark et al., 2001; Leung et al., 2002; Kolar and Lodge, 2001, 2002; Drake and Bossenbroek, 2004; Rejmanek et al., 2005), but has not yet been strongly incorporated into management and policy. Once this improved ability to anticipate future invasions is adopted by managers, social welfare should improve, even under risk averse social planning. In addition, our current application is for zebra mussels only, although one might think about interpreting our analysis as pertaining to a generalized aquatic invader, or a suite of species. The robustness of such a presumption, however, remains an open question, worth addressing in future work. If adoption of these technologies were combined with a shift toward more risk neutral decision making, greater investments in invasion prevention would occur and would pay long term dividends for society.

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