CHAPTER 3

ON ECONOMIC-COST MINIMIZATION VERSUS BIOLOGICAL-INVASION DAMAGE CONTROL

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Abstract. Recently, Batabyal et al. (2005) have used a queuing model to show that there is a *tension* between economic-cost minimization and inspection stringency in invasive-species management in the following sense: greater (lesser) inspection stringency with a larger (smaller) number of inspectors leads to higher (lower) economic costs. We use a *more general* queuing model to investigate whether there is, in fact, a tension between cost minimization and inspection stringency. Our theoretical analysis shows that there is no definite answer to this question. Therefore, we use numerical methods, and our numerical analysis leads to two conclusions. For many values of the model parameters that delineate the strictness of inspections, there *is* a tension between cost minimization and inspection stringency. In contrast, for most values of the model parameter that describes the volume of maritime trade handled by the port under study, there is *no* tension between cost minimization and inspection stringency.
Keywords: inspection; invasive species; maritime trade; queuing theory; uncertainty

INTRODUCTION

It is now common knowledge that maritime trade in goods comprises a substantial fraction of the world's total international trade in goods. Ships are the basic vehicle in maritime trade and therefore they are frequently used to carry all manner of goods in containers from one part of the world to another. International-trade theorists have shown that there are clear gains to the parties involved in such voluntary trade between the different nations of the world. Even so, with the passage of time, analysts have argued that the magnitude of these gains is likely to be less than what most researchers have hitherto believed. Why might this be the case? As Parker et al. (1999), Perrings et al. (2000a) and Batabyal (2004) have pointed out, this is

A.G.J.M. Oude Lansink (ed.), New Approaches to the Economics of Plant Health, 23-37

because in addition to transporting goods in containers between nations, ships have also managed to transport a variety of non-native plant and animal species (also known as alien or invasive species) from one geographical part of the world to another.

There are two main ways in which ships have transported invasive species from one part of the world to another. First, many marine non-native species have been introduced into a nation, often unwittingly, by ships discarding their ballast water. Cargo ships usually carry ballast water in order to increase vessel stability when they are not carrying full loads. When these ships come into port, this ballast water must be jettisoned before cargo can be loaded. This manner of species introductions is significant and, very recently, the problem of managing invasive species that have been introduced into a particular nation by discarding ballast water has received some attention in the economics literature[2].

The second way in which invasive species have been introduced into a particular nation is by means of the containers that ships frequently use to carry cargo from one country to another. In this regard, the reader should note that non-native species can remain hidden in containers for extended periods of time. In addition, material such as wood – that is often used to pack the cargo in the containers – may itself contain invasive species. In fact, as noted by Batabyal and Nijkamp (2005), a joint report from the United States Department of Agriculture (USDA), the Animal and Plant Health Inspection Service (APHIS) and the United States Forest Service (USFS) has pointed out that nearly 51.8 % of maritime shipments contain solid wood packing materials and that infection rates for solid wood packing materials are non-trivial (USDA-APHIS 2000, p. 25). For example, inspections of wooden spools from China showed infection rates between 22% and 24 % and inspections of braces for granite blocks imported into Canada were found to hold live insects 32 % of the time (USDA-APHIS 2000, p. 27-28).

Non-native species are of interest to both economists and biologists because when these species invade new habitats, they impose tremendous costs on the nations in which these new habitats are located. To see this, consider the following two estimates of the magnitude of the economic costs for one country, namely, the United States. First, the Office of Technology Assessment (OTA 1993) has determined that the Russian wheat aphid caused US$ 600 million worth of crop damage between 1987 and 1989. Second, Pimentel et al. (2000) have approximated the total costs of all non-native species at around $ 137 billion per year.

In addition to the economic costs that we have just mentioned, alien species have caused considerable biological damage as well. In this regard, Vitousek et al. (1996) have explained that alien species can change ecosystem processes, act as vectors of diseases, and diminish biological diversity. Further, Cox (1993) has observed that out of 256 vertebrate extinctions with a known cause, 109 are the outcome of biological invasions. The discussion in this and the preceding paragraph together tell us that invasive species have been and continue to be a great menace to society.

It is only very recently that economists have acknowledged the consequences of the problem of biological invasions. As a result, Perrings et al. (2000b, p. 11) have rightly pointed out that "the economics of the problem has...attracted little attention". An implication of this regrettable state of affairs is that our knowledge of the economic and the management aspects of invasive species is deficient. Now, from the perspective of a manager, there are a number of actions that this individual can take to address the problem of biological invasions. It is helpful to divide these actions into pre-invasion and post-invasion actions. The objective of pre-invasion or prophylactic actions is to prevent non-native species from invading a new habitat. In contrast, post-invasion actions involve the optimal regulation of a non-native species, given that this species has already invaded a new habitat.

The small economics literature on biological invasions has, for the most part, focused its attention on the properties of alternate *post-invasion* actions. For instance, Barbier (2001) has pointed out that the economic effect of a biological invasion can be ascertained by studying the nature of the interaction between the native and the non-native species. He notes that the economic effect depends on whether this interaction involves interspecific competition or dispersion. Second, Eiswerth and Johnson (2002) have examined an intertemporal model of invasive-species stock management. These researchers note that the optimal level of management effort is responsive to ecological factors that are not only species- and site-specific but also stochastic in nature. Third, Olson and Roy (2002) have used a probabilistic framework to analyse the circumstances under which it is optimal to wipe out an invasive species and the circumstances under which it is not optimal to do so. Finally, Eiswerth and Van Kooten (2002) have demonstrated that in some situations, it is possible to use information supplied by specialists to develop a model in which it is optimal not to wipe out but instead regulate the spread of an alien species.

The regulation of a potentially detrimental non-native species *before* it has invaded a new habitat has been analysed by Horan et al. (2002), Batabyal et al. (2005) and Batabyal and Beladi (2006). Horan et al. (2002) examine the attributes of management approaches under full information and under uncertainty. Batabyal and Beladi (2006) study optimization problems stemming from the stationary-state analysis of two multi-person inspection regimes. Finally, Batabyal et al. (2005) note that there is a *tension* between economic-cost minimization and inspection stringency in invasive-species management in the following sense: greater inspection stringency with a larger number of inspectors leads to higher economic costs, and smaller inspection stringency with a smaller number of inspectors results in lower economic costs. The reader should understand that greater (smaller) inspection stringency reflects a heightened (diminished) concern for the potential damage from one or more biological invasions. Therefore, a port manager who places a relatively large (small) weight on invasion damage control will, *ceteris paribus*, want to inspect ships more (less) stringently.

Given the importance of the inspection function in invasive species management, the purpose of this paper is to investigate the generality of the ‘tension result’ in the Batabyal et al. (2005) paper. To undertake this investigation, we use a queuing model that is *more general* than the model used in Batabyal et al. (2005). Our theoretical analysis shows that there is *no* definite answer to the question as to whether there is or isn’t a tension between economic-cost minimization and inspection stringency. Therefore, we use numerical methods, and our numerical analysis leads to two conclusions. First, for many values of the model parameters that delineate the strictness of inspections, there *is* a tension between economic-cost minimization and inspection stringency. Second and in contrast, for most values of the model parameter that describes the volume of maritime trade handled by the port under study, there is *no* tension between economic-cost minimization and inspection stringency.

The rest of this paper is organized as follows. The next section provides a conceptual framework based on queuing theory and describes the queuing theoretic model that we use to analyse the potential tension between economic-cost minimization and inspection stringency. To keep the analysis comparative and meaningful, the following section focuses on one of the two economic-cost criteria employed in Batabyal et al. (2005). This cost criterion is the 'average wait of a ship in the port system' or AWS criterion. Next, this section conducts a detailed theoretical and numerical analysis of the aforementioned tension question. The final section concludes and offers suggestions for future research on the subject of this paper.

COST MINIMIZATION AND INSPECTION STRINGENCY

A conceptual framework based on queuing theory

The purpose of queuing theory is to analyse waiting lines or queues mathematically[3]. All queuing models have at least three characteristics. First, there is a probabilistic arrival process. Second, there is a stochastic service process. Finally, there is a fixed number of servers. In the queuing model of our paper, the arrival process is described by a Poisson process. Here, the time between successive arrivals follows an exponential distribution which has the property of being *memoryless*. Hence, it is common to use the letter M to describe the Poisson arrival process.

In general, the service – in our case inspection – times are random and not deterministic. Therefore, it is common to use the exponential distribution—and hence the letter M once again – to model these service times, and this what is done in Batabyal et al. (2005). However, because the primary aim of our paper is to investigate the generality of the central 'tension result' in Batabyal et al. (2005), in what follows, we suppose that the relevant service times are *arbitrarily* distributed. As such, we shall use the letter G to denote the *general* cumulative distribution function of these random service times. Finally, the fixed number of servers – in our case inspectors – is typically denoted by some positive integer, and in the present paper this positive integer is one.

Using the language of queuing theory, the inspection regimes analysed by Batabyal et al. (2005) correspond to the $M/M/1$ and the $M/M/2$ queuing models. In words, Batabyal et al. (2005) have analysed inspection regimes in which the arrival of ships is described by a Poisson process, the time it takes to inspect a ship is exponentially distributed, and the number of inspectors equals either one or two. The inspection regime that we analyse in this paper corresponds to the $M/G/1$ queuing model. This model is more general than the Markovian queuing models in

Batabyal et al. (2005) because the random inspection times are now arbitrarily and not exponentially distributed.

A model of inspections in invasive-species management

Consider a stylized, publicly owned port in a particular coastal part of some nation. Ships with ballast water and/or cargo in containers arrive at this port either to load or to unload cargo, and if they have arrived to load cargo they then transport this cargo to a port in some other part of the world. The arrival of these ships coincides with the arrival of potentially damaging plant and animal species. We assume that the arrival rate of these plant and animal species is proportional to the arrival rate of the ships. Therefore, we shall not model these species directly. Instead, we shall focus on the ships that bring these species to our port by means of either their ballast water or the containers that are used to carry the cargo. The arrival process of the ships in our port represents the arrival process for the queuing-theoretic inspection regimes that we study in this paper. Now, consistent with the discussion in an earlier section, we assume that the ships in question arrive at our port in accordance with a Poisson process with rate λ. Note that all else being equal, a higher λ means two things. First, our port is now handling more cargo or a higher volume of maritime trade. Second, because the arrival rate of the various non-native plant and animal species is proportional to the arrival rate of the ships, a higher λ also means a larger volume of potentially injurious biological organisms and hence a higher likelihood of one or more biological invasions. From this discussion, the reader will note that λ serves as a proxy for both the volume of maritime trade and the likelihood of biological invasions.

Our port manager would like to prevent invasions by the possibly deleterious plant and animal species entering the port under study. Therefore, arriving ships will need to be inspected before they can either load or unload cargo. Ships are inspected on a first-come-first-served basis and an inspector is assigned to each dock in our port, and hence, in what follows, we shall study a *representative* dock inspector's decision problem. In addition, we shall think of the inspection function broadly. For some ships, only the ballast water will need to be inspected. For other ships, only the containers carrying cargo will require inspection. Finally, for a third category of ships, both the ballast water and the containers will need to be inspected. This tells us that inspections will generally require varying amounts of time. To account for this in a general way, we permit the inspection times to be not only random but also to be arbitrarily distributed. The port system under study consists of ships that are being inspected, ships that are waiting to be inspected, the representative dock inspector, and the port manager.

Now, the stringency of inspections is generally an increasing function of the amount of time it takes to complete inspections. Therefore, to model this idea, we assume that there are two possible inspection regimes in our port. In the first or inspection regime (*A*), the mean inspection time is ν_A and the variance of this time is τ_A^2. In the second or inspection regime (*B*), the average inspection time is ν_B

and the variance of this time is τ_B^2. Furthermore, we assume that $\nu_A > \nu_B$ and that $\tau_A^2 < \tau_B^2$. These two inequalities tell us that inspection regime A is *more* stringent than inspection regime B. Why? Because relative to regime B, on average, regime A requires that more time is devoted to inspection. In addition, the variability of the time spent inspecting ships in regime A is also less than the variability of the time spent in regime B.

We now have all the necessary parts for our two queuing-theoretic inspection regimes. The reader should note the way in which we have mathematically characterized the central question of this paper: When attempting to prevent a biological invasion by inspecting the ballast water and/or the containers of ships, which inspection regime, A or B, ought our port manager to have in place? We now proceed to the theoretical and the numerical analysis of the inspection regime choice question for the *AWS* cost criteria that we identified in the last paragraph of the introductory section.

THE COST CRITERION

AWS criterion

Inspection activities that result in the prevention of a biological invasion by non-native plant or animal species clearly result in benefits to the citizens of the coastal region under study. However, during the time that arriving ships are being inspected, there is neither loading nor unloading of cargo, and hence in general, economic activity resulting from maritime trade is at a standstill. This temporary stoppage of economic activities imposes costs on the economy of our coastal region. We can measure this cost by computing the average wait of a ship in the port system. In this way of looking at the problem, the longer (shorter) this average wait in the port system or AWS, the larger (smaller) the costs from the interruption of economic activities. Consequently, a port manager who is concerned primarily about the economic costs that are imposed on society by the activities of the representative inspector will want to keep AWS as low as possible. In contrast, a port manager who worries more about the potential damage to society from a biological invasion will want to have the more stringent or inspection regime (A) in place. In what follows, we assume that our port manager has this AWS (proxy for economic cost) criterion in mind when (s)he is choosing between regimes A (more stringent) and B (less stringent).

Let us now calculate AWS for the two $M/G/1$ inspection regimes that we are analysing in this paper. From equation 3.17 in Taylor and Karlin (1998, p. 563) we conclude that the two expressions we seek are given by

$$AWS_A = \nu_A + \{\lambda(\tau_A^2 + \nu_A^2)\}/\{2(1-\lambda\nu_A)\} \quad \text{and} \qquad (1)$$
$$AWS_B = \nu_B + \{\lambda(\tau_B^2 + \nu_B^2)\}/\{2(1-\lambda\nu_B)\}$$

respectively. We know that inspection regime A is more stringent than inspection regime B. Mathematically, this means that $\nu_A > \nu_B$ and $\tau_A^2 < \tau_B^2$. Using the first inequality we conclude that $2(1-\lambda\nu_A) < 2(1-\lambda\nu_B)$. However, because $(\tau_A^2 + \nu_A^2)$ may be bigger or smaller than $(\tau_B^2 + \nu_B^2)$, knowing that $\nu_A > \nu_B$ and that $\tau_A^2 < \tau_B^2$ does *not* allow us to conclude anything definitively about the relative magnitudes of AWS_A and AWS_B. Put differently, when our port manager authorizes the use of the more stringent A inspection regime in the port under study, it is *not* necessarily the case that economic costs measured by the AWS criterion will be higher. This tells us that when one works with the $M/G/1$ queuing model, in the general case, there may or may not be a tension between economic-cost minimization and inspection stringency. Hence, a key finding in Batabyal et al. (2005) does *not* generalize to the case in which the inspection times are arbitrarily and not exponentially distributed.

Now, to show that there is no straightforward resolution of the tension question, we conduct an exercise with specific numerical values for the various model parameters of interest. To this end, let the arrival rate of ships be $\lambda = 1$ per unit time. Also assume that the parameters of the two inspection regimes are $(\nu_A, \tau_A^2) = (0.5, 0.2)$ and $(\nu_B, \tau_B^2) = (0.4, 0.9)$. Then, using equation (1), it is easy to see that $AWS_A = 0.5 + \{0.45\lambda/(2-\lambda)\}$ and $AWS_B = 0.4 + \{1.06\lambda/(2-0.8\lambda)\}$. When $\lambda = 1$, these expressions reduce to $AWS_A = 0.95$ and $AWS_B = 1.28$.

These two expressions lead to two conclusions. First, examining the expression for $AWS_A(AWS_B)$ we see that as the arrival rate of ships λ approaches 2 (2.5), economic costs measured by the $AWS_A(AWS_B)$ criterion become infinitely large. In other words, there is a definite upper limit on the volume of maritime trade that our port can handle, and when this limit is approached, the economic costs of inspections become prohibitively large. Second, when the parameters of our model take on the values specified in the previous paragraph, our port manager will prefer the more stringent inspection regime (*A*) over the less stringent inspection regime (*B*). This is because when this more stringent regime is in place, the economic costs of inspections are lower, i.e., $AWS_A = 0.95 < 1.28 = AWS_B$. We have just identified a case in which there is *no* tension between economic-cost reduction and the stringency of inspections or biological-invasion damage control. It is instructive to analyse this tension question in three different ways and we now proceed to this tripartite analysis sequentially.

The tension question in terms of the volume of maritime trade

Let us study – for the model parameter values specified above – the dependence of the magnitude of the economic costs (measured by AWS) on our proxy for the volume of maritime trade, i.e., on λ. We begin by equating the two expressions for AWS obtained previously. Doing this and then simplifying the resulting expression gives us a quadratic equation in λ. That equation is

$$0.78\lambda^2 - 1.58\lambda + 0.4 = 0. \quad (2)$$

The two solutions to equation (2) are $\lambda_1^* = 1.73$ and $\lambda_2^* = 0.30$. Figure 1 plots the economic-cost criterion AWS on the vertical axis against selected values of the arrival rate of the ships or λ on the horizontal axis. Looking at Figure 1, the reader can easily verify that when $\lambda < 0.30$ or when $\lambda > 1.73$, our port manager will prefer to have inspection regime *B* in place rather than inspection regime *A*. Why? Because inspection regime *B* results in lower economic costs as measured by the AWS criterion. Put differently, when $\lambda < 0.30$ or when $\lambda > 1.7$, there *is* a tension between economic-cost reduction and the stringency of inspections or biological-invasion damage control. In contrast, for all λ in the closed interval $[0.30, 1.73]$, there is *no* tension between economic-cost reduction and inspection stringency.

The tension question in terms of the average inspection times

Very stringent inspections are time-consuming and they tend to increase the magnitude of the AWS criterion. Therefore, intuitively speaking, we would expect the answer to the question about whether there is or isn't a tension between economic-cost reduction and inspection stringency to be clearly related to the means and the variances of the A and the B inspection regimes. Therefore, in this section, we numerically investigate the functional dependence of AWS on the means (ν_A, ν_B) of the two inspection regimes, and in the next section, we shall conduct a similar exercise from the standpoint of the two variances (τ_A^2, τ_B^2).

We know that $\nu_A > \nu_B$ and that $\tau_A^2 < \tau_B^2$. Further, in our subsequent numerical analysis, we assume that $\nu_A = a\nu_B, a > 1$, and that $\tau_A^2 = b\tau_B^2, 0 < b < 1$. In words, the means and the variances of the two inspection regimes are linearly related to each other and the two constants of proportionality (a,b) satisfy certain

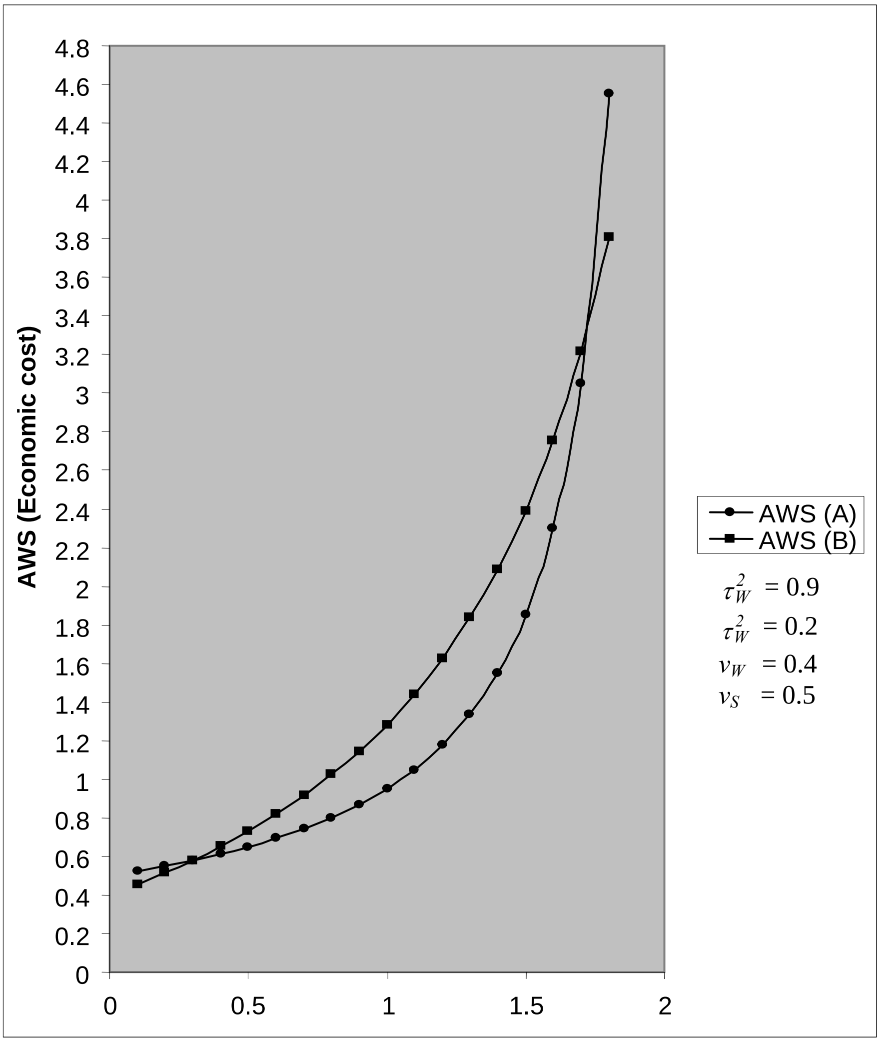

Figure 1. *AWS for inspection regimes A and B as a function of lambda (arrival rate of ships)*

straightforward restrictions. Specifically, because $\nu_A > \nu_B$ we have $a > 1$. Similarly, because $\tau_A^2 < \tau_B^2$ it makes sense for b to lie in the open interval $(0,1)$. The reader should think of the parameter a as a measure of the difference in the stringencies of the two inspection regimes A and B. That is, as a increases, inspection regime *A* becomes more stringent than the B inspection regime. Similarly, the parameter b describes the difference in the variability of the two inspection regimes. Hence, as b approaches zero inspection regime *A* becomes more reliable relative to inspection regime *B* and as b approaches unity regime *A* becomes less reliable relative to regime *B*.

Now, using the parameter values from the previous section, we have $\lambda = 1, \nu_B = 0.4, \tau_B^2 = 0.9,$ and setting b at its mid-point, i.e., $b = 0.5,$ we obtain $\nu_A = 0.4a$ and $\tau_A^2 = 0.5\,\tau_B^2$. Using these values of the various parameters in equation (1), we get $AWS_B = 1.2833$, and AWS_A is a function of the parameter a and is given by $AWS_A = 0.4a + (0.45 + 0.16\,a^2)/(2 - 0.8a)$. Setting these two values equal gives us a quadratic equation in a, and that equation is

$$0.16\,a^2 - 1.83a + 2.12 = 0. \quad (3)$$

The two solutions to equation (3) are $a_1^* = 1.31$ and $a_2^* = 10.11.$ Now for $AWS_A = 0.4a + (0.45 + 0.16\,a^2)/(2 - 0.8a)$ to be positive we must have $a < 2.5$. This tells us that $a_2^* = 10.11$ is an inadmissible solution in our case and we are left with $a_1^* = 1.31$ as the only economically meaningful solution to equation (3).

Figure 2 plots the economic-cost criterion AWS on the vertical axis against selected values of a on the horizontal axis. Looking at figure 2 we see that when $a = 1.31$ our port manager is indifferent between the two inspection regimes. Further, for all $a < 1.31$, the use of the more stringent A inspection regime results in lower economic costs as measured by the AWS criterion. Finally, for all $a > 1.31$, the use of the less stringent B inspection regime leads to lower economic costs. This tells us that when $a > 1.31$ there *is* a tension between economic-cost reduction and biological-invasion damage control. In contrast, when a lies in the interval $(1, 1.31]$ there is *no* tension between economic-cost reduction and inspection stringency.

The tension question in terms of the variances of the inspection times

Many stochastic models exhibit significant qualitative differences depending on the variability of the underlying distributions. Therefore, we now numerically study the functional dependence of AWS on the variances – τ_A^2, τ_B^2 – of the A and the B inspection regimes. Recall that we have $\tau_A^2 < \tau_B^2$ and $\nu_A > \nu_B$. Also, we once again have $\nu_A = a\,\nu_B, a > 1,$ and $\tau_A^2 = b\,\tau_B^2, 0 < b < 1.$ The interpretation of a and b is as indicated in the previous section. Using the previous section's

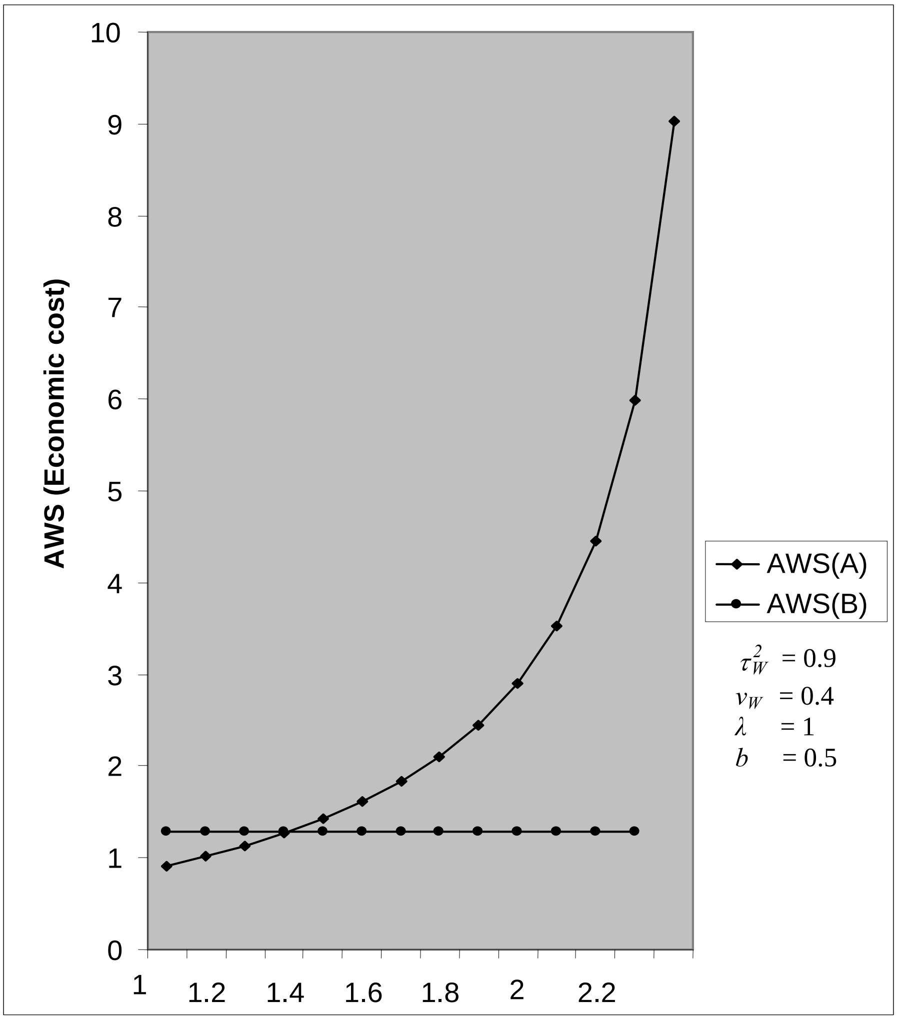

Figure 2. *AWS for inspection regimes A and B as a function of a (the relative stringency of inspections)*

parameter values, we have $\lambda = 1, v_B = 0.4, \tau_B^2 = 0.9$. Now setting $a = 2$ and using equation (1), we get $AWS_B = 1.2833$, and we can write AWS_A as a linear function of b; that function is $AWS_A = 2.4 + 2.25b$. Looking at these two values of the economic-cost criterion it is obvious that there is no value of b for which our port manager would be indifferent between the two inspection regimes being considered.

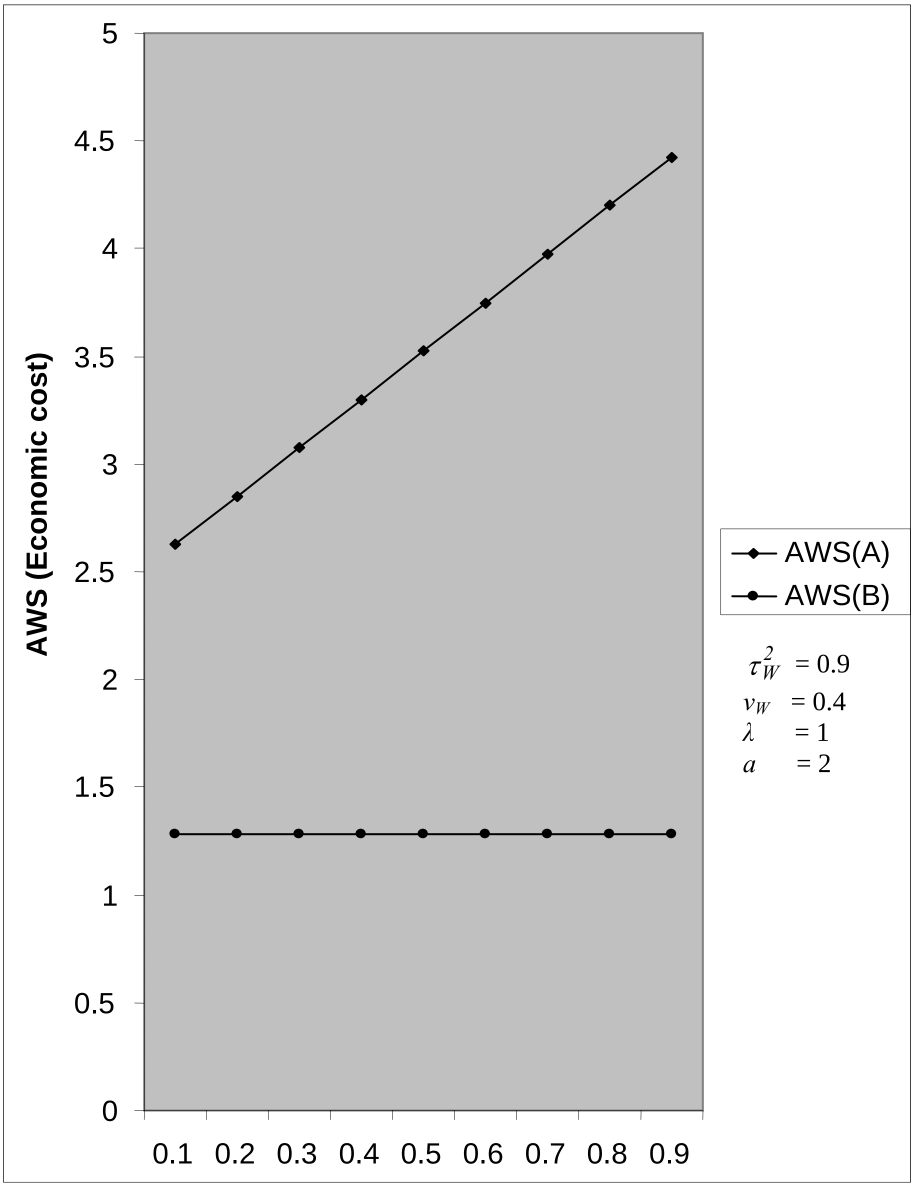

***Figure 3**. AWS for inspection regimes A and B as a function of b (the relative variability of inspections)*

Figure 3 plots the economic-cost criterion AWS on the vertical axis against alternate values of b on the horizontal axis. Looking at Figure 3 we see that AWS

is *always* lower when the less stringent B inspection regime is used to inspect arriving ships in our port. Put differently, for *all* values of b – which measures the difference in the variability of the two inspection regimes – there *is* a tension between economic-cost minimization and biological-invasion damage control.

Our analysis thus far in this section leads to three conclusions. First, our theoretical examination shows that the question as to whether there is or isn't a tension between economic-cost reduction and inspection stringency cannot be resolved unambiguously. Second, for many possible values of a and for *all* possible values of b there *is* a tension between economic-cost reduction and inspection stringency. Finally and in contrast with the second point, for several possible values of λ or the 'volume of maritime trade' parameter, there is *no* tension between economic-cost reduction and inspection stringency.

CONCLUSIONS

Maritime trade in goods by means of ships often results in biological invasions of novel habitats by non-native plant and animal species. Therefore, if an apposite authority such as a port manager's aim is to preclude biological invasions, then (s)he must inspect arriving ships for possibly injurious biological organisms. Given this context, we used the *M/G/1* queuing model to investigate the generality of a central result in Batabyal et al. (2005). This result tells us that there is a tension between economic-cost reduction and inspection stringency or biological-invasion damage control. Our theoretical analysis showed that in the more general case in which inspection times are arbitrarily and not exponentially distributed, there is *no* definite answer to the question as to whether there is or isn't a tension between economic-cost minimization and biological-invasion damage control. In addition, our numerical analysis with arbitrary values for the key model parameters identified specific ranges for these parameters for which there is a tension between economic-cost minimization and biological-invasion damage control. The upshot of our combined theoretical and numerical analysis is this: whether or not there is tension depends very much on the specifics of a particular situation.

For real applications, we would need to obtain values for the arrival rate of ships and the means and the variances of specific inspection regimes. In the USA, information about the arrival rate of ships can be obtained from the administrative offices of individual ports such as Long Beach and, on occasion, from governmental agencies such as the Office of Mobile Sources of the Environmental Protection Agency (EPA). Similarly, information about actual inspections in the USA can be obtained from documents that are periodically produced by the Congressional Research Service and from the Animal and Plant Health Inspection Service (APHIS).

The analysis in this paper can be extended in a number of directions. We now suggest two possible extensions of this paper's research. First, it would be useful to use the *M/G/1* queuing model to set up and solve an optimization problem in which the port manager chooses the mean inspection time to optimize a specific objective function. Second, it would also be useful to analyse the tension question of this paper in a scenario in which excessively long inspection times result in some ships not entering the port under study. This would involve the analysis of a $M/G/1$ queuing model with 'balking'. Studies of maritime-trade-driven biological invasions that incorporate these aspects of the inspection function into the analysis will provide additional insights into a management problem that has considerable economic and biological implications.

NOTES

[1] Batabyal acknowledges financial support from the USDA's PREISM program by means of Cooperative Agreement 43-3AEM-4-80100 and from the Gosnell endowment at RIT. The usual disclaimer applies.
[2] For more on this, see Nunes and Van den Bergh (2004), Yang and Perakis (2004) and Batabyal and Beladi (2006).
[3] Textbook accounts of queuing theory can be found in Taylor and Karlin (1998), Ross (2003) and Tijms (2003).

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