A strategic protection approach to biosecurity: Policy implications of an 'immune system' model for addressing the risks and consequences of invasive species

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Like the human immune system, a biosecurity system is a constellation of responses to external attacks comprising of many facets, a number of which can change to optimize the response to these unwanted intrusions. When either system hits the wrong target, or is inhibited or crippled somehow, the consequences for the body and the economy can be dire. Like an immune response, an effective response to an invasive alien species incursion may be the result of a series of failed attempts or past experiences rather than being perfect the first time. In view of the enormously complex environment in which responses are made, this paper discusses institutional changes that may facilitate an adaptive approach to biosecurity policies where governance is viewed as a multi-disciplinary, interactive experiment acknowledging uncertainty.

Key Words: Adaptive governance, invasive species, biosecurity.

"The government solution to a problem is usually as bad as the problem"

Milton Friedman

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1. Introduction

It is now recognised that invasive species are one of the premier threats to the environment. The term 'invasive species' is applied both native and non-native (or alien) organisms that have the capacity to become invasive, whereby their abundance exceeds an accepted environmental standard. Despite mounting evidence of the damage some species are causing and are capable of causing at an environmental, economic and social level, the non-excludable benefits of invasive species risk management and mitigation has given rise to a general under-provision of biosecurity services throughout the world. 'Biosecurity' is used here as a generic term that can be applied to any method of invasive species management, be it preventing introductions, detecting incursions and eradicating resultant populations, or managing new species as long-term problems, curtailing their impact and preventing their further spread (Waage *et al.* 2005).

There are many parallels that can be draw between effective biosecurity systems and the human immune system. Both are effective constellations of responses to external attacks that house a multitude of different facets, many of which can change to optimize the response to unwelcome intrusions. While the immune system is a network of cells, tissues, and organs that work together to defend the body against invasion, a biosecurity system relies on networks of individuals, communities and institutions to defend geographic regions from invasive species. The human body provides an ideal environment for many microbes, and it is the job of the immune system to keep them out or, failing that, to seek out and destroy them. To do so, it must maintain reactive and adaptive capacities to minimize the damage caused by the invader(s), while at the same time providing the highest levels of protection to other areas of the body.

Governance of and within a modern trading region, be it a nation or component State or Province, involves similar challenges. The highly-complex nature of intra and inter-regional transactions with the potential to generate invasive species externalities requires a malleable, adaptive approach to regulation if incursion risk is to be managed effectively. The process of 'adaptive governance' involves the evolution of new institutions capable of generating long-term, sustainable policy solutions to highly-complex problems. It is achieved through effort coordination from previously independent systems of users, knowledge, authorities, and organized interests (Scholz and Stiftel 2005). In this paper, various institutional changes are suggested that would facilitate an adaptive governance process in two broad areas: (1) species exclusion, and (2) management of established species. The nature of the invasive species problem requires changes both within and beyond regional boundaries to be considered.

The paper is structured as follows. Section 2 provides background material on invasive species management in the Australian context and highlights key areas in which existing structures are in need of change. Section 3 discusses possible improvements in international institutional structures that could be expected to deliver more effective species exclusion, and Section 4 suggests intra-regional measures that could be taken to improve the management of species that have already become established. Section 5 draws some conclusions.

2. Background

The human body provides an ideal environment for many microbes, and the immune system's role is shield the body from invasion, and where this shield is pierced to expel or destroy the invader before it causes too much damage. When the immune system misses the target, hits the wrong target or is crippled, it can have dire consequences for the body (NIH 2003). In extreme cases these may be irreversible, involving the loss of one or more components of the body, or even death. Like any system involving human interactions with their environment, the stability dynamics of the immune system emerge from three complementary attributes: resilience, adaptability and transformability (Walker *et al.* 2004). The more resilient a system the greater its capacity to absorb and/or to cope with disequilibria, and the more adaptable it is the better are system components able to influence resilience. In the event that circumstances push a system to the limits of resilience, its transformability characteristics will determine if it is possible to configure and entirely new stability landscape with components of the redundant system supplemented with new elements. System longevity is of paramount importance in the case of a human immune system, and desirable resilience and adaptability properties will avoid the trauma associated with the need for a fundamental system transformation.

The same can be said of Australia's "quarantine continuum" (as described in Nairn *et al.* (1996)) or biosecurity structure which manages the flow of potentially contaminated sanitary and phytosanitary materials into the country. The Australian climate and landscape is well suited to many pests and diseases, and when goods are exchanged across regional boundaries pathways for the movement of pests and diseases are opened. No physical transfer of goods is without risk, so the consumption benefits of inter regional trade are accompanied by potential costs. Using pre-border, border and post-border quarantine activities, the job of biosecurity policy-makers is to maximise the expected net benefit of trade by taking steps to enhance the resilience and adaptability of the system to real and potential invasions.

Policies that evolve with changes in the stability landscape and reduce the need for transformability will be conducive to system longevity. This is particularly important in regards to the avoidance of transformations involving the extinction of native flora and fauna species, local communities and industries as a result of species introductions.

Biological contaminations are a particular form of market failure. A negative externality is created by the actions of importers influencing the utility of other community members by exposing them to risk. Generally, the potential costs of invasive species transference are not reflected in the price of imported commodities. While the costs of invasion are borne by parties outside the market for the 'risky' imported goods, consumers pay only for production costs, transport to market and a profit margin. The costs of invasion may be felt in terms of market goods such as agricultural commodities, or non-market goods such as environmental and societal change. This means the unintended 'victims' of contaminated trade can be small in number, such as the members of an infant agricultural industry, or include every member of a community or society. Unlike consumers who have a choice of whether or not to consume an imported product, those outside the market bearing the potential cost of an alien invasive species invasion do not.

Market effects of invasive species may be direct or indirect. Direct effects include total cost and revenue implications for producers of goods that are hosts to the alien invasive species. Cost of production may increase due to the need for additional management activities to minimise damage to or loss of the commodity, and yield losses may continue to occur despite the additional management effort. Revenue losses may also include the loss of export sales. In many cases the loss of "pest-free area" status can have a profound impact on export revenue since the ability to sell products to markets around the world is compromised[1]. This does not necessarily mean that all exports of an affected commodity are lost. Although high-priced markets may be lost, the good can often be sold to lower price markets.

Non-market consequences of invasive species outbreaks such as environmental, socio-economic and socio-political effects present more difficult analytical challenges. In addition to an annual use value, a non-market good such as an environmental amenity, a rural community or cultural activity may also have non-use values such as existence, bequest or moral values. These are dependant on its continued existence, and extend over generations in time (Mumford 2001)[2]. Identifying and capturing these values using stated or revealed preference techniques which are both accurate and cost-effective remains a sizeable challenge for economists (Adamowicz 2004). Since the income elasticities for environmental goods are thought to be large and positive, the dynamics of environmental

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[1] The scope and timing of these costs will depend on the organism concerned. For instance, if the fungal disease Karnal bunt were to be discovered anywhere within Australia, wheat exports from all States would be temporarily banned regardless of origin in relation to the infected site (Wittwer *et al.* 2005). In other cases, the export of susceptible products is only banned from the immediate area of infection (or areas within a specified distance of an infected site). This is typically the case when the organism is established elsewhere in the country (WAQIS 1999). Where exported products have been processed or refined, there may be no loss of export revenue resulting from a pest outbreak.

[2] Environmental damage may go unnoticed for a long period of time before exploding into social consciousness. This is often driven by media forces. The situation is different for invasive species that are purely agricultural (or market) problems for these tend to be more incremental in spread since they are (in general) more noticeable.

externalities resulting from species invasions may be very important. The benefits of avoiding a given amount of environmental impact from a non-native species will be greater in 20 years than now, and greater still in another ten years[3].

From an environmental perspective, the global threat of species exchange has been acknowledged in the formation of the Convention on Biological Diversity (1991). Article 8h of this Convention requires parties to "prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species". In 1996, a United Nations conference brought together 80 governments and world experts to consider the nature of this problem, and concluded that it was "immense, insidious, increasing and irreversible" (Sandlund 1996). This conference, and subsequent consultations identified non-native species invasions as second only to habitat loss as the major threat to biodiversity and species extinction (Waage *et al.* 2005).

Despite recognition of the issue, there has been little progress towards an international invasive species immune system or defence against species transference. This is partly due to an inability to measure the extent of worldwide damage. The most widely-cited quantitative studies, Pimentel *et al.* (2000) and The Office of

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[3] Comprehensive empirical evidence for such a pattern of income elasticity is currently lacking (Whitby 2000), and two reasons have been forward as to why this might be the case. Firstly, there is a tendency for a strategic misrepresentation of preference when expressing utility derived from environmental goods, and secondly demand for specific environmental assets (or marginal changes in the health of an environmental asset) tend to be embedded within stated or revealed preferences for much broader environmental issues (Kristrom and Riera 1996; Whitby 2000). In contrast, agricultural goods may show opposite elasticities.

Technology Assessment (1993), estimate the annual economic damage inflicted by invasive alien species in the United States alone at US$97-137 billion. Pimentel *et al.* (2002) used a similar methodology to arrive at a global estimated damage figure of US$1.5 trillion per annum. These are certainly large numbers, but the methodologies used to calculate them limit their use for policy-making since no distinction is made between the costs of invasive species damage and government responses. Biosecurity policies require a more specific benefit cost approach to ensure responses to invasions achieve a net benefit across a target area (be it a region, country or group of countries).

Nevertheless, the damage estimates offered by OTA (1993) and Pimentel *et al.* (2000) have proven to be influential to policy-makers. The United States Executive Order of 2000, by which President Clinton established an inter-ministerial Invasive Species Council, was effectively built around them. Other literature, such as Bright (1998) and Baskin (2002), have exerted political influence through anecdotal 'horror stories' rather than quantitative damage estimates. In the absence of better information, this approach has been important in raising awareness of the potential magnitude of the problem. It has not been as important in influencing governance structures and/or facilitating cost effective invasive species management.

3. Species exclusion

The information constraint concerning invasive species-induced damage imposes transactions costs on the markets for potentially-contaminated commodities preventing parties from negotiating mutually beneficial solutions. For any rational, profit maximising individual entering into a contract to supply or purchase a good on an international market, it is impossible to account for every eventuality within the contract itself given the uncertainty surrounding the distribution of expected profits (Scholz and Stiftel 2005). A great deal of uncertainty surrounds the invasion process, and many of the 'risky' variables are actually endogenous. The openness of the economy, composition of trade flows, regulatory regimes, and the importance of agriculture, forestry and tourism all make it more or less resilient to invasion (Perrings *et al.* 2002). Habitat fragmentation, conversion and agricultural disturbances are also believed to affect susceptibly to invasion (Williamson 1996). Uncertainty is a particular concern when the number of suppliers exceeds one since an invasive species introduction is akin to non-point source pollution where proving cause and effect beyond a reasonable doubt requires an overwhelming amount of information. Other transactions costs are created by logistical factor in the negotiating process. For instance, bringing together a large number of spatially and often technically diverse overseas suppliers and potentially-affected groups from the domestic economy may be difficult.

A governance structure is therefore required to generate a solution. Traditional 'centralist' market failure corrective measures are difficult to impose due to valuation issues and institutional arrangements. The inability to quantify the negative externalities of trade makes a tool like Pigovian taxes difficult to implement. Ignoring international institutional arrangements for the moment, contamination risk posed by international suppliers to Australian markets can certainly be internalised by placing fees on 'risk creators' (McAusland and Costello 2004; Perrings *et al.* 2005). The problem is that there is no way of knowing what the efficient tax rate is in the absence of information about the total benefit (of trade abatement) function. Placing too much emphasis on the supplier to pay for the negative externality will lead to an under provision of imports, to the detriment of domestic consumers. On the other hand, placing too little responsibility at the hands of importers will lead to an overprovision of imports and a level of invasive alien species importation risk that is above a socially-desirable level[4]. The same information problems affect the ability of subsidies and 'command and control' (or the issuance of standards) to achieve efficient levels of trade.

Rather than seeking an efficient level of invasive alien species damage abatement, trade policies must be examined in terms of cost effectiveness. There may be scope to develop tradeable risk permit schemes for risk creating industries such as those proposed in Horan and Lupi (2005) for the regulation of ballast water contamination risk in the Great Lakes of North America. Information constraints make it difficult to determine a desirable initial quantity and allocation of permits, and negotiations between large numbers of permit holders may inhibit the market from operating effectively. However, in circumstances in which invasive species and their consequences are known with a high degree of certainty tradeable permits systems could prove effective. This is an issue in need of further investigation.

In any event, international institutional arrangements constrain market correction measures. Invasive alien species externalities resulting from trade can be partially internalised by Sanitary and Phytosanitary (SPS) measures. World Trade Organisation (WTO) Members are bound by the Agreement on the Application of Sanitary and Phytosanitary Measures (henceforth referred to as the SPS Agreement), and can therefore not impose SPS measures that restrict trade unnecessarily. By placing pre-import requirements on imported products the risk of contamination can

[4] Referring to Pigovian taxes, Coase (1960) famously argued such "…courses of action are inappropriate in that they lead to results which are not necessarily, or even usually, desirable" (p. 59).

be lowered to a level acceptable to the importing region, but these add to the cost of production for the exporter and reduce domestic consumer surplus gains from importation. Any Member imposing SPS measures on good imported from another must be able to justify the subsequent reduction in invasion risk using internationally recognised risk analysis methodologies. In outlining appropriate economic factors that a Member can take into consideration when imposing SPS measures only potential producer losses from invasive species associated with the pathway are listed as being "relevant" (GATT 1994), while consumer gains from trade are not considered[5].

Before considering possible evolutionary paths for international biosecurity governance structures, it is important to bear in mind the fundamental role that institutions play in 'qualitative coordination'. That is, in helping cooperating parties to align their knowledge and expectations (Langlois and Foss 1999). Because of the specificity and tacitness of much productive knowledge, one trading nation may have difficulties understanding what another is capable of supplying and how they stand to benefit from trade, and both countries separately and together may possess more knowledge than divulged in simple contracts to buy or sell products (Kogut and Zander 1992; Winter 1993; Langlois and Foss 1999). Net increases in social welfare can only be achieved through a balanced consideration of the benefits and costs of

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[5] In the case of Australia, interstate trade must also comply with the SPS Agreement. A Memorandum of Understanding between the Commonwealth of Australia and all States and Territories was signed on December 21st 1995 in which parties agreed "States and Territories shall not apply any relevant sanitary and phytosanitary measures within their jurisdictions which would not conform with the provisions of the SPS Agreement" (Commonwealth of Australia 1995, Article 11).

importation, and the challenge lies in arranging for the conveyance of sufficient scientific and economic information about the size and distribution of those benefits and costs. This includes information about the ability to influence the probability of invasive species contamination, and at what cost. When such information does not exist, there is a need for caution, particularly when the consequences of hasty decision-making can lead to irreversible consequences and/or the loss of irreplaceable assets (both in terms of environmental and social capital)[6]. But when it does, adaptability is a desirable property of the negotiation process.

In its current form, the SPS Agreement provides little incentive for parties to invest in pre-border import risk mitigation. A philosophy of domestic industry insulation in trade policy rather than net benefit maximisation can be viewed as a negative influence on the resilience and adaptability functions of biosecurity systems. In some cases, the diffusion of supply from controlled sources may reduce the capacity of invasive alien species to inflict damage on the domestic economy. In others however, increasing exposure to introduction risk by the tiniest margins could cause a substantial increase in expected damage. If non-market goods are at stake, then there may be a need to invoke some form of precautionary principle. Rather than policy-makers attempting to give static, consistent responses to complex, inconsistent invasive species problems, an integrated approach is called for that incorporates interdisciplinary interactions, stakeholder groups and generations (Costanza *et al.* 1998).

[6] Of course, a rather large problem exists for an arbiter in this process since the costs of evaluating legitimate and strategic information may be high if internal pressers within negotiating countries cause incentives to be misaligned.

In the paradigm of adaptive governance binary 'yes/no' policy-making must give way policies viewed as interactive experiments acknowledging uncertainty (Costanza *et al.* 1998). A greater adaptive capacity in the international trade negotiation framework may be achieved by moving away from a generalist approach incapable of capturing the complex array of information needed to achieve net societal gains. There is no escaping the fact that an element of risk is associated with every human action, and in order to undertake that action the personal benefit must be expected to outweigh personal cost. For instance, the consumption of a meal carries with it the risk of food poisoning, allergic reactions or choking, but for the body to function to a level of personal satisfaction it is necessary to take that risk. Measures can be taken to minimize the risk of undesirable occurrences, such as purchasing food from a trusted source, but no amount of care can reduce the risk to zero. At some point, as with potentially-contaminated imports, the benefits of consumption outweigh the potential costs.

A structure is required that draws together critical parties, relevant experts, authorities and organized interests into a specialized negotiating framework designed to elicit mutually advantageous trade agreements (Scholz and Stiftel 2005). If such a structure were to consider the welfare of trading partners equally alongside that of the domestic economy an additional layer of complexity would be added to trade decisions which may produce some surprising results. As James and Anderson (1998) clearly demonstrated, consideration of the consumer surplus generated by international competition in some commodities calls in to question the reasoning behind WTO-legal SPS measures. In additional to the traditional gains from trade, net benefits may also be generated in the country from which imports are sourced[7]. In terms of economic development this is a desirable situation where the source country is a developing economy. However, if SPS measures in the home economy are relaxed to allow the imports across the border the risk of contamination is effectively moved offshore. In order to minimise contamination risk, or to truncate the expected damage distribution resulting from contaminants requires home economy investment in biosecurity activities offshore. This will make the international suppliers more costly. But provided price differentials between imports and domestically produced goods are sufficiently high the aggregate level of invasive species control may actually increase with trade and produce a fall in the rate of trade-related species transference[8]. Conversely, when the difference in price between imports and domestically produced goods are relatively low a more protectionist stance towards imports may be warranted.

The simple concept of considering the costs and benefits of actions may also be applied to other international institutions affecting trade and invasive alien species, particularly those with a tendency to focus solely on potential harmful effects. A supply side bias may lead to corrective actions with far worse consequences than

[7] Foreign consumer surplus is set to decline due to the price rise induced by re-directing a proportion of supply to the export market.

[8] Of course, the political reality is that the populations with which an economy like Australia trades do not pay taxes in Australia or vote in Australian elections. But an objective bilateral approach to trade negotiations may, at least to some extent, influence trade decisions, particularly when it is a developing nation making a market access request. The extent to which this may lead to more or less investment in invasive alien species worldwide is ambiguous, but warrants further investigation.

species transference. This was graphically illustrated in the 2001 foot and mouth disease outbreak in the United Kingdom (UK). Upon the detection of the disease, the requirement of Office International des Epizooties (OIE) (or the World Organisation for Animal Health) Members to "stamp out" foot and mouth disease came in to force. Foot and mouth disease is listed as a priority disease for OIE Members, and as such it's detection in any Member country requires the immediate closure of trade in all potentially contaminated livestock products and the extermination of infected and potentially infected animals. Consequently, access to affected areas was severely restricted as attempts were made to contain the disease and eradicate livestock that may have been exposed. This is estimated to have cost the UK tourism industry in the order of £2.3 billion in 2001 alone (Blake *et al.* 2003).

In hindsight, perhaps a more adaptive, case specific approach to the management of livestock diseases and consideration of the net effects of management actions may have led to a less severe economic consequence. For instance, had a vaccination scheme against foot and mouth disease been implemented rather than an eradication campaign the cost and revenue implications of the disease for the UK agricultural sector, including export restrictions, are estimated to have been in the order of £1.2 billion (Harvey 2001)[9]. Effects on domestic tourism would have been negligible, as would the effects on domestic consumers of meat and livestock products due to

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[9] If testing procedures capable of detecting vaccinated livestock that are also carriers of the disease were to be developed this estimate would need to be revised downwards.

supplies from the European Union[10]. Adherence to the OIE rules rather than an exploration of the benefits and costs of all alternative actions meant that no ceiling was placed on the costs of the response.

This implies an inherent unwillingness to create adaptive elements within the existing OIE structure, but the formation of international institutional structures in general should be viewed as an evolutionary process. International strategic management theory provides some clues as to how international institutions might reach the stage of structural streamlining which private multinational companies have. The structures of large corporations operating over many geographical boundaries are largely determined by two competing imperatives. The first is cost minimisation, which is the prime motivation for corporations to extend their production system to utilise relatively cheap capital and labour markets in overseas economies. The second is the quest to be locally responsive, such that organisations will always also seek to tailor their product to different geographical markets according to national or regional tastes (Bartlett and Ghoshal 1998; Ramia 2002). It follows that if social *net* welfare maximisation were akin to profit, institutions governing international trade and guarding against the spread of invasive alien species may gradually trend towards structures and processes capable of adapting to the idiosyncratic nature of trade issues.

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[10] In fact, supply disruptions on the UK domestic market due to the foot and mouth disease outbreak were short-lived, and observed price changes were relatively modest. The loss to producers associated with European competition is estimated to have been approximately £50 million (Thompson et al. 2002).

4. Managing established invasive species

4.1 Private control benefits

The externality problem not only applies to the exclusion (or non-exclusion) of invasive alien species, but also to invasive species that have already entered a region and become established. Inevitably, species will breach the quarantine continuum from time to time and not be discovered until they have spread to the extent that eradication is either technically or economically unfeasible. When the spread of a species is slow, as in the case of many weed species, they may be presumed harmless for hundreds of years before they are recognised as a problem (Preston *et al.* 2002). Once a problem species has been identified the failure of one individual to control a host-specific species of agricultural significance within their area of influence creates a negative flow-on effect for all neighbouring regions containing the host due to the increased likelihood of transference. Similarly, if one agent undertakes control measures in their area they are unable to exclude neighbouring areas from enjoying a portion of the benefits. This situation characterises established invasive species control at a local, regional and a State level. Given the difficulties in achieving an efficient level of control in the presence of externalities, cost-effective control is a more appropriate objective.

The provision of cost-effective control services can and will benefit from a spirit of cooperation between affected parties, but generating cooperative spirit is complicated. The diversity of parties involved and the inherent uncertainty and variability within biological systems make incentive alignment difficult. Achieving adequate representation of parties affected by an established invasive species in regulatory institutional arrangements may be difficult. All members of spatially diverse, heterogenous agricultural industries are not necessarily represented by overarching industry bodies. The same is true of environmental groups, and even cultural groups within society. Assuming these issues are overcome and an appropriate aggregate amount of invasive species control can be agreed upon as a standard, the amount of individual control effort required to maintain this standard will vary across time periods. Providing group members with relevant information on biosecurity risks, externalities associated with inaction and industry reputation may provide incentive enough for most to act in accordance with the collective good (Herb *et al.* 2002; Dietz *et al.* 2003). However, the continuity of control can be put in jeopardy by despondent parties defecting from the spirit of cooperation and reverting to arrangements that were designed with less information[11].

It is increasingly recognised that modern governance should be dispersed across multiple centres of authority rather than centralised, particularly where heterogeneity is a system feature. The promotion of horizontal integration to facilitate a more polycentric approach and reduce transactions costs may provide a catalyst for cooperative approaches within industries affected by spreading invasive species. Grower cooperatives in which invasive species management decisions are made collectively will have the effect of (at least partially) internalising the externalities created through a lack of control since the group as a whole suffers the consequences. The transactions costs incurred by such strategies will be largely dictated by spatial characteristics of the industry or industries. In Australia where component enterprises of an industry or group of industries can be separated by large distances and be

[11] Maladaptation to disturbances typically accounts for a high proportion the costs of governance (Williamson 2005).

characterised by different cost structures, lateral integration may be advised on a regional or sub-regional level rather than a State or national industry level[12].

Arrangements in Western Australia may serve as a model for future cooperative arrangements between industry members. State legislation, specifically the *Agricultural Produce Commission Act 1988* (WA), enables the formation of "Producer Committees" to oversee activities deemed by the Agricultural Produce Commission (APC) to be in the interests of a gazetted Agricultural industry, including the control of invasive species[13]. Activities can be funded through the imposition of a fee for service on Members of the industry affected, including producers, wholesalers, exporters and retailers (Section 16). Producer Committees determine the size of a fee for service imposed upon their constituency, and the funds collected are held in the State Treasury to be drawn upon as needed. As at the 30 June 2005 there were 14 producer committees established under Section 11 of the Act (APC 2005), and industry subscription to the Act continues to expand. However, there are currently no broad acre cropping and grazing industries gazetted under the act[14].

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[12] Spatial divergence may become less of an influence on negotiation costs over time as average farm sizes increase (Kingwell and Pannell 2005).

[13] The APC consists of four Members who are appointed by the Minister for Agriculture, Forestry and Fisheries. The Minister appoints one member of the Commission to be the chairperson. Tenure of appointment is for a period not exceeding three years (APC 2005).

[14] This is partly be due to the imposition of a 10 per cent charge on the fee for service collections to fund administration and maintenance of accounts (APC 2005). Added flexibility in this charge may be needed if the Act is to include larger industries.

Several invasive species control activities are currently funded through the APC, all of which involve established species such as Mediterranean fruit fly. To date, the legislation has not been used to secure funds that might be used in the event of exotic, or alien invasive species outbreaks, but there is nothing in the Act itself which would prevent such actions being undertaken in future. Having been sourced directly from the private beneficiaries of control, a precautionary pool of resources would avoid bureaucratic costs of 'public' institutions and reduce time lags (King and Pitchford 2001). Reaction time is a critical factor in eradication success (Olson and Roy 2002).

However, this is only an advantage when the response is desirable to a majority of industry represented by a Producer Committee. Preference of cooperative Members may vary sharply across regions, and measures may be required which guard against situations where a distribution of expected on-farm impacts are 'skewed' (Hart and Moore 1996). Conceivably, spatial diversity within cooperatives may cause opinions with regard to appropriate uses of collective funds to be varied, but to a lesser extent than centralised governance structures. Indeed, this is one of the key advantages to multi-layered governance where heterogeneity presides due to relative flexibility. The optimal level of decision-making bodies may be lower than economies of scale dictate (Gatzweiler 2005). It follows that the number of jurisdictions is potentially huge, as are the scales at which they operate, and there is no certified level of permanence in their existence (Hooghe and Marks 2003). They may form, disband and re-form as required by the demand for governance.

4.2 Public control benefits

The APC approach does not preclude cost sharing between public and private sources when the benefits of controlling an invasive alien species are non-excludable. Public goods are created through the control of some polyphagous species affecting both farmed and wild hosts. Where this is the case, cooperative arrangements need the capacity to attract public monies to finance an appropriate share of management activities if and when they are undertaken.

Australia is at the forefront of response policy design with the notion of cost sharing at the centre of eradication response philosophy with respect to invasive alien species of environmental, social and/or cultural significance. The Emergency Animal Disease Response Agreement (EADRA) (AHA 2002) and Emergency Plant Pest Response Deed (EPPRD) (PHA 2005) involve 'high-profile' invasive organisms being placed in one of four cost sharing categories relating to their significance in terms of potential damage to public resources and private industries[15]. The categories cover species whose impact is or is likely to be limited to agricultural industries to those with high environmental/social costs. If a species categorised under the agreement is detected in Australia, the category chosen dictates an appropriate split of eradication funding between government and private industry[16]. In effect, the uncertainty about the impact an invasion might have on affected parties is acknowledged in the fact that the size of an eradication campaign is not formally stated in the Agreement. Moreover, the externalities created by the removal of an invasion are internalised since all beneficiaries and the approximate share they receive are stated in advance of an invasion.

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[15] Details of the EADRA appear in Centre for International Economics (1998), and details of the EPPRD in Plant Health Australia (2001).

[16] Eradication is conditional on a benefit cost analysis being completed which indicates that a net social gain will result from a successful campaign.

The technical and economic feasibility of achieving eradication once an outbreak is detected greatly depends on the ability of both public and private parties to a cost sharing agreement to detect and report intruders at the early stages of invasion. To return to the immune system analogy, antibodies which continually search for invaders perform a vital role in terms of maximising the chances of mounting an immune response that is both timely and which poses the minimum possible trauma for the remainder of the body. So too does an effective surveillance network involving individuals with sufficient knowledge of biosecurity threats and sufficient exposure to potential hosts. A complex governance system involving cooperatives may house incentive structures for reporting that are somewhat more desirable than centralised systems. In the case of an agricultural industry biosecurity cooperative contributing to a cost sharing agreement, the encouragement to report detections will be strongest with an effective compensation scheme ensuring the future viability of those businesses that have acted in accordance with the collective good and reported detections as soon as they occur.

The issue of adequate compensation for parties affected by species eradications has long been an invasive species surveillance concern. Inadequate compensation payments for assets that may be destroyed in the process of eradication provides an incentive to conceal future detections on their properties for fear of ruin. To the extent that eradication costs are an increasing function of the time until detection, this will have the effect of inflating future costs for all parties. On the other hand, compensation payments above the market price of assets may lead to false reporting. This unfortunate circumstance occurred during the 2001 UK foot and mouth disease eradication program where an inflated compensation schedule led to over application for payments and competition between legitimate claimants and those reacting to financial incentives (Whiting 2003). Not only did this inflate the costs of eradication in terms of compensation payments, but added to an already distressful situation from an animal welfare perspective.

To the extent that these problems are attributable to the misaligned incentives of parties supposedly working towards a common goal, decentralising the governance structure and promoting producer cooperatives may improve biosecurity antibodies. Motivation to work towards the achievement of a common goal or standard can be generated through smaller group structures and a reduction in distance between cooperative Members (both in physical and social terms). A standard need not be set to a narrow schedule, but can serve as a strategic open target able to be translated at the individual Member level of decision-making, whilst at the same time providing a goal for the cooperative (Hinterberger *et al.* 2000; Bleischwitz 2003). In decentralised governance structures dominated by cooperatives, the relative proportion of the group made up by an individual Member tends to be large, creating a natural inclination to minimise disparities between individual and cooperative objectives. Hence the willingness to report detections will be much greater than under a centralised system, as will incentives to share the burden of an invasion response if and when required.

The extension of the cost-sharing concept between public institutions and private cooperatives across a range of biosecurity activities may also play a vital role in promoting functional diversity. Rather than simply emphasising eradication, cost sharing may be applied in the research and development of diversity-generating activities such as new control technologies, management strategies, data collection and processing, early-warning devices, prioritisation techniques, and so forth. To arrive at an optimal solution requires a learning-by-doing approach, and resources can not always be put to their most efficient use. In fact for the stability and the development potential of the biosecurity structure, functional redundancy represents a reservoir of adaptive responses and enhances evolutionary potential (Rammel and van den Bergh 2003). Having a range of tools and experience to draw upon when the unforseen occurs can be seen as paramount in the development of sustainable biosecurity governance.

5. Conclusions

Managing the risk posed by invasive and potentially-invasive organisms, be they a threat to either an individual or an economy, is a highly complex task. In that same way that immune system responses to invasion require the mobilisation the body's resources and careful targeting of responses, so too do biosecurity systems if they are to be successful repellents. Centralised structures of governance inhibit the development of resilience and adaptive capacities of response systems, and may therefore ineffectively manage biosecurity risks. Adaptive governance, the formation and evolution of institutions capable of generating stability and sustainability in governance, may be more appropriate for such a complex problem. A number of areas in this emerging branch of institutional economics may be drawn upon to enable economies to minimize the effects of harmful invasive species well into the future. This paper has not sought to use these to offer definitive solutions to the biosecurity maintenance issue, but has suggested evolutionary paths governance structures may take in the future to minimize the effects of invasions. In regards to the continued exclusion of species at an international level, the adaptive capacity of international institutions may be enhanced through the recognition of both the costs and benefits of trade decisions. Suggested changes to the management of invasive species at a national level generally involve moves towards polycentric governance. The promotion of producer biosecurity cooperatives to better cope with heterogeneity in terms of (potentially) affected parties may yield benefits in terms of both incentive alignment and burden sharing in response effort. These suggestions reflect the vital role institutions play in aligning the knowledge and expectations of interacting parties. Continued recognition of this role may yet produce a resilient, adaptive biosecurity governance structure that can mould itself around complex problems, and be compared with the immune system in terms of its effectiveness.

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