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# Preventing Biological Invasions: The Role of Economic Instruments

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# Résumé

Les espèces envahissantes ont été reconnues comme étant un des principales menaces sur la biodiversité au niveau mondial, ainsi qu'une source de dommages importants pour plusieurs secteurs économiques (Kettunen et al. 2009; Millennium Ecosystem Assessment 2005; Pimentel et al. 2005). Etant donné que la plupart des invasions biologiques sont la conséquence du commerce et d'autres activités économiques, plusieurs auteurs ont souligné l'intérêt de gérer le problème avec les outils économiques classiquement appliqués à d'autres types de pollution (Emerton and Howard 2008; Perrings et al. 2005; Williamson et al. 2011). Pourtant, les espèces envahissantes diffèrent des externalités classiques de plusieurs manières. Ce mémoire examine les particularités des invasions biologiques, afin d'en cerner les implications en termes de régulation par les instruments de marché. En particulier, vue l'incertitude concernant plusieurs paramètres du problème, quels instruments économiques pourraient, *a priori*, être conçus et mis en œuvre pour réduire le risque d'invasion, et quelles seraient les limites de ces instruments en pratique ? Quatre types d'instruments sont examinés : les taxes et tarifs, les permis échangeables, les contrats d'assurance et les systèmes de cautionnement (« *environmental performance bonds* »). La performance probable de chaque instrument par rapport à cinq critères – notamment, l'efficacité à atteindre l'objectif, le rapport coût-efficacité, la facilité du contrôle et d'exécution, l'adaptabilité face aux nouvelles connaissances et conditions, et la capacité de stimuler l'innovation – est aussi examinée.

## Abstract

Invasive alien species have been recognised as one of the main threats to biodiversity worldwide, as well as a cause of significant economic losses in various sectors (Kettunen et al. 2009; Millennium Ecosystem Assessment 2005; Pimentel et al. 2005). Given that biological invasions are a consequence of trade and other economic activities, several authors have suggested the problem could be tackled with economic instruments conventionally applied to other types of pollution (Emerton and Howard 2008; Perrings et al. 2005; Williamson et al. 2011). However, invasive alien species differ from classical externalities in several respects. This thesis examines the peculiarities of biological invasions compared to other pollutions and whether these distinguishing features preclude their internalisation via economic instruments. In particular, given the uncertainty that characterises different parameters of the IAS problem, what economic instruments can, *a priori*, be designed and applied to reduce the risk of invasion, and what would their limitations be in practice? Four instrument types are explored: price-based instruments such as taxes and tariffs, tradable permit schemes, liability insurance, and environmental performance bonds. The likely performance of each instrument with regard to five evaluation criteria – dependability, cost-effectiveness, ease of monitoring and enforcement, adaptability to changing knowledge and conditions, and the potential to foster innovation – is also discussed.

# Contents

**List of Figures**



**List of Tables**

## Preventing Biological Invasions: The Role of Economic Instruments

# Introduction

Invasive alien species (IAS) have been recognised as one of the main threats to biodiversity worldwide, as well as a cause of significant economic losses in various sectors (Kettunen et al. 2009; Millennium Ecosystem Assessment 2005; Pimentel et al. 2005). In Europe alone, the documented costs of IAS amount to 12.5 billion EUR annually, and this is considered a significant underestimate of the actual costs (Kettunen et al. 2009, 27). Most biological invasions are a consequence of trade and other economic activities. In some cases, non-native species are themselves the object of trade – for example, ornamental plants or species introduced for aquaculture – while in others they are inadvertently introduced on other imported commodities, packaging, or vehicles (Perrings et al. 2005, 212). Several authors have therefore suggested that invasive alien species should be treated as an environmental externality, both analytically and in terms of regulatory responses (e.g. Emerton and Howard 2008; Perrings et al. 2005; Williamson et al. 2011). As with other pollutions, economic instruments could be applied to recover the costs of potential damage from the introducers or users of IAS, in line with the polluter-pays principle, or to provide adequate incentives for these agents to undertake the optimal prevention efforts.

Several policy documents recommend the use of economic instruments with regard to IAS, but do not offer specific guidance on their implementation, nor consider in detail their practical applicability to biological invasions. For example, among the 'ten strategic responses to address the problem of IAS', the *Global Strategy on Invasive Alien Species* calls on countries to develop economic policies and tools, including "price-based instruments to ensure that importers/users of known IAS take account of the full social cost of their activities" and requiring "importers/users of known IAS to have liability insurance to cover the unanticipated costs of introductions" (McNeely et al. 2001, 32). The development of incentive measures to minimise the risk of invasions is also mentioned in a few decisions of the Conference of the Parties to the Convention on Biological Diversity (CBD).[1] A report for the European Commission assessing options for a future EU legislative framework on IAS notes that "a smart policy mix of regulations and incentives (positive and negative) is needed to encourage public and private actors to shift towards low-risk practices and to internalise environmental costs associated with invasions" (Shine et al. 2010, 147). Among the possible instruments to be considered in this respect the report mentions taxes, charges, cost-recovery mechanisms, environmental liability and insurance.

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[1] E.g. Decision VII/13 (2004), https://www.cbd.int/decision/cop/default.shtml?id=7750 and Decision VI/23 (2002), http://www.cbd.int/decision/cop/default.shtml?id=7197 , accessed 5August 2013.

This thesis explores to what extent the problem of invasive species could be internalised with the help of economic instruments conventionally applied to other externalities. In particular, it sets out to answer the following research questions:

> - *How do invasive alien species differ from other pollutions? To what extent can they be treated analytically as a conventional environmental externality?*
>
> - *Given the uncertainty that characterises different parameters of the IAS problem, what economic instruments can be designed and applied? For which introduction pathways (and hence economic sectors) might such instruments make sense, and what would be the limitations in practice?*
>
> - *How are such instruments likely to perform, with regard to a set of criteria?*

While economic incentives could potentially be applied at different stages of the invasion process, this study will only focus on instruments aimed at preventing invasions. Strategies aimed at minimising the risk of invasion are in general considered more effective than attempts to eradicate or control an invasion after its occurrence (Leung et al. 2002) and prevention is also at the top of the management-options hierarchy advocated by the CBD.

Four instrument types will be examined: taxes and charges, tradable permit systems, liability insurance, and environmental performance bonds. The study will address three introduction pathways: species intentionally introduced in containment but that are subsequently released or escape, species entering a new region as undetected 'passengers' on deliberately introduced species, and species inadvertently introduced as stowaways on a transport vector. Particular attention will be paid to four economic sectors, namely horticulture and ornamental plants trade, aquaculture, pet trade and aquaria, and shipping.

<u>Methodology</u>

With the exception of a few cost-recovery mechanisms, market-based solutions to the problem of biological invasions have so far remained in the realm of theory. In the absence of data on the practical application of such tools to IAS, these questions will be examined with reference to the ecological literature on the invasion process, the more limited economic studies on IAS, and the broader theoretical literature on the application and relative performance of economic instruments in the context of other externalities.

In addition to the findings from the existing literature, the results of a mini-consultation of industry representatives, political stakeholders, and IAS experts will also be incorporated in the analysis. A short survey was sent to representatives of the above economic sectors in order to assess what instruments would be deemed applicable and acceptable by these stakeholders, and what the constraints would be from the industry's perspective. The response rate from industry stakeholders has, however, been very low. A separate set of questions was addressed to members of the IAS Working Group established by the European Commission (comprising experts from research organisations, national ministries, and environmental NGOs) and a few additional experts. The experts were asked to indicate which factors they see as significant impediments to the application of economic instruments with regard to IAS and how each policy instrument considered in this study is, in their opinion, likely to perform against a set of evaluation criteria.

Chapter outline

The first chapter describes the nature and extent of the IAS externality and provides an overview of the invasion process, the economic activities fostering invasions, the impacts of IAS on biodiversity and ecosystem services, and the state of the art in evaluating the costs associated with biological invasions.

The following chapter examines the specificity of invasive species compared to other externalities, in particular the uncertainty characterising various parameters of the invasion problem. The implications for the applicability and design of economic instruments are discussed, notably the difficulty of setting IAS 'emission' targets, of assigning responsibility to specific polluters, and of creating the incentives that would induce a sufficient reduction in the risk of invasion.

The third chapter considers the information requirements and other conditions for the applicability of each instrument and the types of pathways that would, *a priori*, satisfy these conditions. I review the few existing studies on the use of specific economic instruments to address invasives and discuss the lessons that can be drawn from the application of each instrument to other analogous problems. With reference to the existing literature, I discuss the expected performance of each instrument with regard to five criteria: dependability (or effectiveness in reaching the goal set), cost-effectiveness, ease of monitoring and enforcement, adaptability to changing knowledge and conditions, and the potential to foster innovation. Finally, the views of stakeholders and experts on the potential use and performance of the various instruments, gathered through the written surveys, are presented.

# Chapter 1. The problem of biological invasions: causes, impacts, and regulatory responses

The design of prevention-oriented instruments requires an understanding of the causes, introduction pathways, stages and consequences of biological invasions. This chapter presents a brief overview of the invasion process, the economic activities fostering invasions, and the impacts of invasive species on biodiversity and ecosystem services, in order to set the stage for the conceptualisation of IAS as an environmental externality and the analysis of economic instruments that could be applied to internalise it.

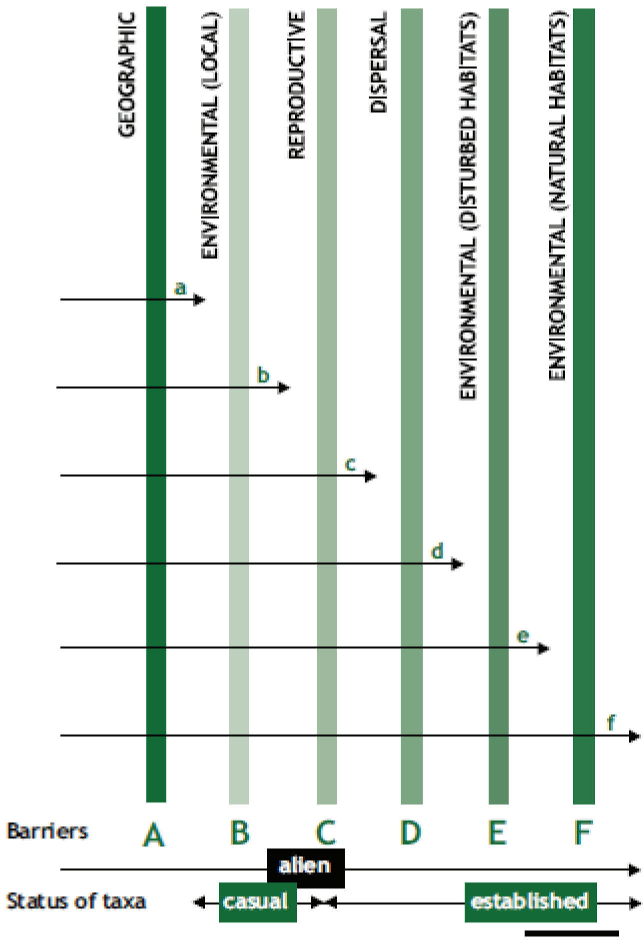
## 1.1. Definition

The Convention on Biological Diversity requires contracting parties to "prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species" (Article 8(h)). The Guiding Principles on the article's implementation (annexed to Decision VI/23) define an *alien species* as a "species, subspecies or lower taxon, introduced outside its natural past or present distribution". This "includes any part, gametes, seeds, eggs, or propagules of such species that might survive and subsequently reproduce." The definition implies that the concept of "alien" ought to be applied at the appropriate biogeographic scale, irrespectively of political or administrative boundaries (Shine et al. 2010, 74). Invasive alien species are defined in the Guiding Principles as "alien species whose introduction and/or spread threaten biological diversity". The present study employs the CBD definitions, but focuses only on the human-mediated introductions of species beyond their natural range and not on natural spread.

## 1.2. The invasion process

To become invasive, a species must overcome a series of biotic and abiotic barriers which define the phases of the invasion process (Richardson et al. 2000, 97), as illustrated in Figure 1. Introduction occurs when "a species (or its propagule) has overcome, through human agency, a major *geographical barrier*" (McNeely et al. 2001, 17). This implies that the species has been entrained in a so-called introduction pathway, i.e. a human-mediated process that facilitates the species' movement, and survived transit (Keller et al. 2011, 2). The naturalization (or establishment) phase begins when *environmental barriers* do not prevent an individual's survival and when various *barriers to reproduction* are overcome. In other words, a species is considered established when it develops a self-sustaining population, i.e. a population maintained by reproduction alone, without the need for additional introductions (Sol 2007, 127-128). This implies that the alien species has found an appropriate niche to survive in the host region and that its population size increases at a rate that is high enough to overcome the effects of demographic, environmental and genetic stochasticity (ibid., 128). To become invasive, an established species must subsequently overcome *barriers to dispersal* within the new region, as well as the resistance posed by *abiotic and biotic factors* of the recipient environment (Richardson et al. 2000, 97-99; McNeely et al. 2001, 17). These authors also differentiate between the environmental barriers alien species encounter in human-modified or disturbed habitats and environmental barriers in natural or seminatural habitats.

**Figure 1. The invasion process**




*Source*: McNeely et al. 2001, p.17, based on Richardson et al. 2000.

The proportion of introduced species that make it through each step of the invasion process is difficult to predict and varies with the taxonomic group of the organisms in question and the characteristics of the ecosystem to which they are introduced (Keller et al 2011, 2). A rule of thumb proposed by Williamson (1996) in connection to terrestrial plants – known as the 'tens rule' – holds that approximately 10% of introduced species are likely to become established in the new environment, 10% of those established are expected to spread, and only 10% of the spreading non-natives will have negative impacts and hence become invasive; in other words, about one in 1000 introduced species are likely to become invasive (Lockwood et al. 2007, 218-219). Its validity has recently been called into question by several studies (ibid.). Moreover, this rule considers only the number of invasive species and does not differentiate between the relative magnitude of impacts that different species may cause (Lockwood et al. 2007, 219). The scientific debate around the 'tens rule' highlights the significant uncertainty involved in trying to predict the outcomes of non-native species introductions.

A key research focus of invasion ecology has been the quest to identify traits that determine a species' invasion potential (often referred to as 'invasiveness'), i.e. the ability to overcome the various barriers described above (Pysek and Richardson 2007; Sol 2007; Lockwood et al. 2007; and references therein). Identifying the traits associated with invasiveness is important from a prevention and risk-assessment perspective (Keller et al. 2011, 6). Biological invasions present ecologists with a paradox: why do non-native species, "whose initial populations are generally small and genetically depleted,… succeed to establish themselves in environments to which they have had no opportunity to adapt" (Sol 2007, 127)? One set of explanations posits that invasion success can be linked to species' evolutionary responses post-introduction, but the hypothesis requires further empirical confirmation (ibid., 132). Alternatively, successful invaders may benefit from certain characteristics that pre-adapt them to survive and reproduce in the invaded environment (ibid., 127).

Thanks to improved data availability in recent decades, the role of various traits has been tested in comparative multispecies studies (Pysek and Richardson 2007, 98). Such studies follow three main methodological approaches: 1) comparing traits of species that become invasive with those of species from the same geographical source region that fail to invade; 2) comparing traits of native species in a target area with those of alien species that invaded that area; 3) comparing the traits of invading alien congeners which exhibit different levels of invasiveness (see the review by Pysek and Richardson 2007, 101-106 and references therein). This research suggests that certain traits can be used to predict invasion success – such as capacity for rapid growth, large reproductive capacity, tolerance to a wide range of environmental conditions, effective competition with local species (Emerton and Howard 2008, 14; Keller et al. 2011, 7-8) – but that the traits conferring an advantage in terms of invasion potential vary with habitat type and the stage of the invasion process (Pysek and Richardson 2007, 121; Lockwood et al. 2007, 251-254). Moreover, interactions between traits (often neglected in such studies) have been shown to explain some of the variation in invasion success (Keller et al. 2011, 7).

In addition to species' attributes, the occurrence and impacts of invasions also vary with ecosystem invasibility, i.e. an ecosystem's intrinsic susceptibility to invasion (Lonsdale 1999, 1523). An analysis of the determinants of plant invasions in Europe found the degree of habitat disturbance and resource availability to be good predictors of invasion levels (Pysek et al. 2010). Highly disturbed habitats such as arable land, coastal sediments, trampled areas, and ruderal vegetation were found to be highly invasible. Such habitats are also characterised by a fluctuating availability of resources (e.g. fertilizers on arable land). Conversely, habitats that are least disturbed and do not experience significant external inputs of resources are the least invasible (Pysek et al. 2010, 73-76).

A growing body of evidence – from both probability models and experimental studies – suggests that the most important determinant of invasion success and impact is propagule pressure (Reaser et al. 2008; Simberloff 2009; Lockwood et al. 2005; and references therein). This is a composite measure of introduction effort capturing the absolute number of individuals involved in any single release event (propagule size) and the number of discrete release events (propagule number) (Lockwood et al 2005, 223).

Propagule pressure is believed to increase the probability of a species' successful establishment by reducing the risk of extinction posed by demographic and environmental stochasticity (Simberloff 2009, 90). Firstly, the release of a large number of individuals enables the incipient alien population to overcome inevitable decreases in survival or reproduction caused by stochastic events. Secondly, repeated release adds individuals to an incipient population that may have been too small (or ill-timed) to ensure long-term establishment (ibid., 224). Propagule pressure may also be positively associated with the level of genetic variation in the introduced population, increasing the population's chances of adapting to new selection pressures in the recipient location (Ahlroth et al 2003, cited in Lockwood et al. 2005, 224). Finally, releases at different locations help ensure that at least some individuals find favourable environmental conditions for establishment (Lockwood et al. 2005, 224).

Reaser et al. (2008) emphasise that prevention policies should target propagule pressure. This is also the factor that most economic instruments aimed at IAS-prevention would have to tackle. The role of propagule pressure in the design of such instruments is further discussed in Chapter 3 with regard to instrument base.

## 1.3. Introduction pathways

The problem of invasive species entails two distinct processes: the conscious introduction of species (usually associated with an expected economic benefit, such as higher agricultural profits, public enjoyment of new exotic species, or the expectation that an alien species would fulfil a function that native species cannot fulfil as effectively) and inadvertent introductions, which may be less amenable to management (McNeely 2001, 4). The distinction has implications for the prevention-oriented measures at the policy-maker's disposal. For example, intentional introductions imply that the causes of invasion are more tractable, but also potential resistance from stakeholders who stand to lose from regulation that restricts their opportunity to introduce certain exotic species. Accidental introductions of species 'hitchhiking' on other commodities imply a higher degree of uncertainty regarding the causes and responsibility for IAS-induced damage. Such implications will be further examined in the next chapters. We begin with an overview of the causes of invasions and proposed typologies.

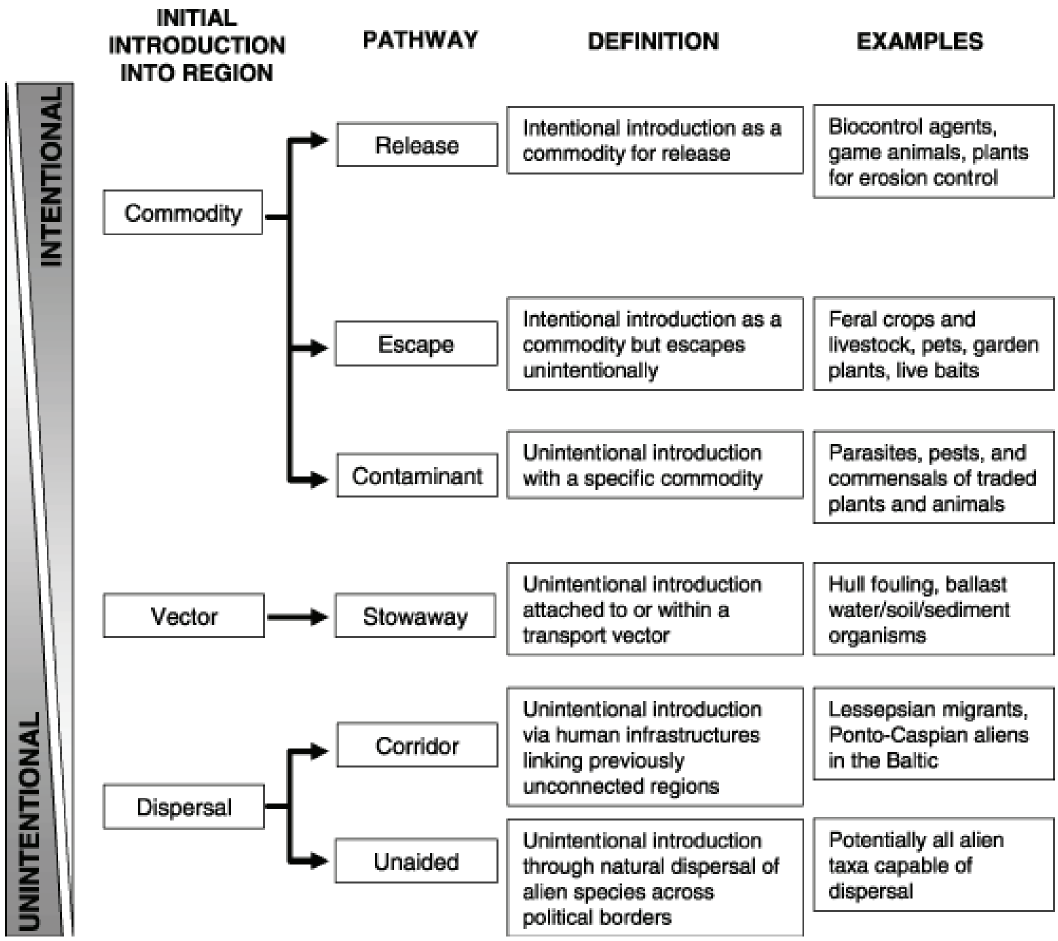
The processes and activities that result in the conveyance of species beyond their native range are referred to as introduction pathways (Hulme et al. 2008, 403). An organism may be introduced through multiple pathways, but a majority of invasive alien species in Europe (62.5%) are associated with a single pathway (Hulme et al. 2008, 407). Each pathway is characterised by several transport *vectors*, i.e. specific means of organism translocation. Human activities, largely associated with globalization, are continuously giving rise to new pathways and vectors, as well as increasing the number of invasive species introduced via already established pathways (Wittenberg and Cock, 2001; Perrings et al, 2005).

The Convention on Biological Diversity uses a dichotomous categorisation of pathways, distinguishing between intentional and unintentional introductions. Hulme et al. (2008) propose a typology based on three broad mechanisms of alien species introduction: intentional introductions as an imported commodity, unintentional or accidental arrival on a transport vector, and natural spread from a neighbouring region. The three mechanisms result in six major pathways, with varying degrees of human intentionality: 1) deliberate release into the environment, 2) escape of species intentionally introduced in containment, 3) contaminant of a deliberately introduced species, 4) stowaway on a transport vector, 5) dispersal by the species themselves along infrastructure corridors, and 6) unaided dispersal. The framework is illustrated in Figure 2.

Intentional releases of non-native species include, for example, the introduction of new crops or organisms for soil improvement, release of mammals and birds for hunting, fish introductions to increase or diversify catch, release of biocontrol agents, and plants introduced for land rehabilitation (e.g. erosion control or post-mining activities) (Keller et al. 2011; Nentwig 2007; Maynard and Nowell, 2009). The care and supplementary feeding offered to intentionally introduced species during transport, together with repeated introductions and/or the release of a high number of individuals encourage the subsequent widespread establishment of such species (Hulme 2008 et al., 407).

The category 'escape' covers a variety of situations with varying degrees of intentionality, ranging from natural events, such as a flood that washes alien plants from a pond into a river, to an owner who throws the weeds cleared from a pond into the neighbouring stream (Hulme et al. 2008, 405). There are numerous examples of animals that have escaped fur farms and established feral populations, such as the South American nutria (*Myocastor coypus*), the East Asian racoon dog (*Nyctereutes procyonoides*), and the American mink (*Mustela vison*) (Nentwig 2007, 17-18).

**Figure 2: A typology of introduction pathways by degree of intentionality**




*Source*: Hulme et al. 2008, p.406.

The risk of unintentional introductions grows hand in hand with the expanding global and regional movement of people and goods. The contaminant pathway is responsible, among others, for the introduction of the majority of alien insects in Europe, seed contaminants, aquatic diseases introduced through ornamental fish, hyperparasites associated with biological control agents, a variety of microorganisms and plants via transported soil and aggregates, and commensal species such as seaweeds and crustaceans attached to oysters introduced for mariculture (Hulme et al. 2008, 405-407).

Unintentional introductions can also be independent of a commodity, but introduced directly as 'hitchhikers' on a vector of human transport, termed 'stowaway' (Hulme et al. 2008, 405). Such vectors include the interior and exterior of aircraft, ships (e.g. species in ballast water or attached to hulls), trains and automobiles (e.g. as seeds caught in mud on tires), as well as passengers and their luggage (Keller et al 2011, 3). Aquatic species are a common stowaway group, with many marine and freshwater species having caused damage after dispersal by ships. For example, a survey of alien species introduced by shipping into the North Sea region revealed that stowaway species such as crustaceans and bivalves were present in 38% of ballast water, 57% of ballast sediment samples, and 96% of ship hull samples (Gollasch 2002, 105). Many alien species whose introduction pathway is not known with precision are likely to be stowaways (Hulme et al. 2008, 407-408).

In recent decades, we have witnessed a significant increase in the potential for trade-related pathways to introduce invasive species, as the capacity to rapidly move greater volumes and a wider variety of commodities has increased (Maynard and Nowell 2009, 6). Live organisms associated with traded goods no longer need to survive for as long a period as they previously did in order to arrive at the destination in a viable condition (ibid.).

Dispersal by the species themselves can occur either along infrastructure corridors or unassisted by human activities. The corridor pathway refers to situations where organisms move along canals, railways, roads, and other human-created connectivity habitats. For example, the Suez Canal has allowed the introduction of species from the Red Sea into the Mediterranean (80% of all non-native fish, decapods crustaceans, and molluscs found in the Mediterranean arrived through this pathway) (Galil et al 2007, 67). The unaided pathway is characterised by the natural spread, without human intervention, of a non-native species previously established in a neighbouring or nearby ecosystem (Hulme et al. 2008, 406). Examples include the ongoing spread of the invasive horse-chestnut leafminer moth (*Camariella ohridella*) across Europe after having been introduced to a single small area (Keller et al. 2011, 3), the macro-alga *Sargassum* spreading from France to the UK, the Harlequin ladybird (*Harmonia axyridis*) from Belgium to the rest of Europe, and the ruddy duck (*Oxyura jamaicensis*) from the UK to Spain (Hulme et al. 2008, 409). Corridors and unaided pathways are responsible for a much lower number of species introductions than the other four pathways (Hulme et al 2008, 5), but the reported numbers are likely to be underestimates given the high rates of spread of introduced species (on average, 89 km and 50 km per year for terrestrial and marine ecosystems, respectively) (Grosholz 1996, Pysek and Hulme 2005, cited in Hulme et al. 2008, 409).

For plant invasions, the relative importance of intentional introductions has increased in recent decades as technological advances (e.g. seed cleaning) and quarantine measures reduced the efficiency of unintentional pathways (Kowarik and von der Lippe 2007, 31).

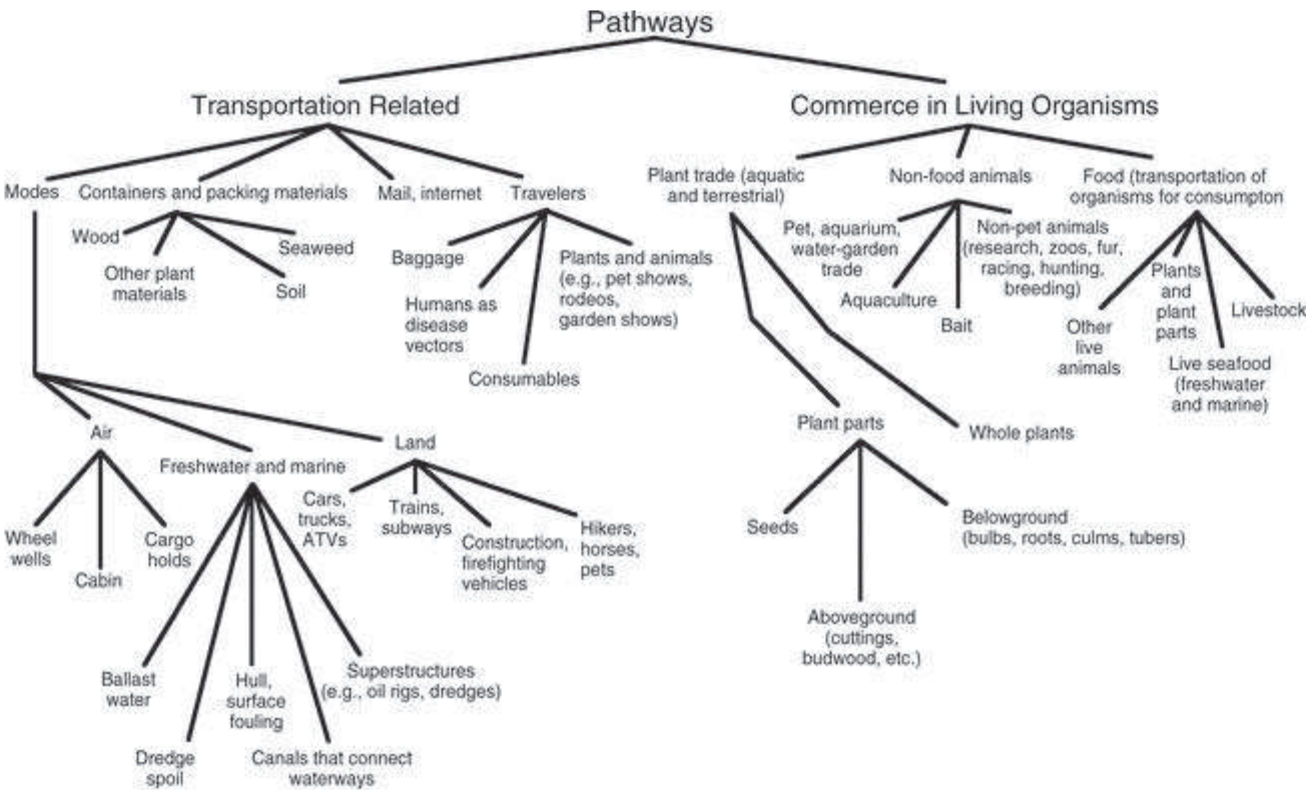
In addition to the pathways by which species are initially introduced to a new range, it is important to also consider the processes that facilitate subsequent invasion success via second releases or accidental transfer (ibid., 43). For example, hundreds of non-native tree species were introduced to Europe at the end of the 18th century, in tree nurseries or experimental forest plantations, but only those that were subsequently planted in large quantities at the landscape scale became successful invaders (ibid., 35-36).

The term ‘vector’ denotes the physical means or agent in or on which a species moves outside its natural range; for example, ships’ ballast water (Genovesi and Shine 2004, 9).

Another way of conceptualising the causes of introductions is a dichotomy between transportation-related pathways and vectors pertaining to commerce in living organisms, as proposed by Lodge et al. (2006, 2040) and illustrated in Figure 3. Vectors in the latter category involve an identifiable party proposing the introduction and a known species under consideration, and are thus more amenable to risk assessment (Shine et al. 2000, 49), while the first category is more diffuse and usually entails a high degree of uncertainty regarding the species potentially transported.

This study will focus on three pathway categories: species intentionally introduced in containment but that subsequently escape or are released, species entering a new region as a contaminant of deliberately introduced species, and species introduced as stowaway on a transport vector.

**Figure 3: Transportation- and commerce-related introduction pathways**




*Source*: Lodge et al. 2006, p. 2040.

## 1.4. Invasive species impacts

A recent report by the European Environment Agency (EEA) classifies the impacts of IAS into four categories: impacts on biodiversity, on ecosystem services, on human health, and on economic activities (EEA 2012). This section illustrates the extent of the ecological and economic problem posed by biological invasions, following the EEA typology. The state of the art in evaluating the costs of IAS and the implications for the design of economic instruments are discussed.

### 1.4.1 Impacts on biodiversity

According to Parker et al. (1999), the impacts of invasions can be assessed at five levels of biological complexity: (1) individual-level effects, such as changes in the morphology or behaviour of natives; (2) effects on population dynamics (e.g. abundance, population growth), usually resulting from impacts at the individual level; (3) genetic effects (either indirect, via altered patterns of natural selection or gene flow within native populations, or direct, through hybridization and introgression); (4) community impacts (on species richness and diversity); and (5) effects on ecosystem processes (such as nutrient availability and disturbance regimes).

The mechanisms underlying impacts on biodiversity include predation, competition, IAS-induced changes in habitat, hybridisation and the transmission of diseases (Kettunen et al, 2009, 12-13; EEA 2012, 11-13). Such processes can ultimately threaten native species with extinction or cause local population declines (Kettunen et al. 2009, 14; Clavero and Berthou 2005). For example, freshwater fish introductions are known to have caused extinctions and local extirpations of native freshwater species, via predation, hybridisation and the spread of pathogens and parasites (Vitule et al. 2009; Peeler et al. 2011). The grey squirrel (*Sciurus carolinensis*), American mink (*Mustela vison*), and signal crayfish (*Pacifastacus leniusculus*) out-compete and displace species native to Europe (Kettunen et al. 2009, 2). The chytrid fungus and the subsequent spread of chytridiomycosis are responsible for the decline of amphibian species worldwide (EEA 2012, 12-13). Biological invasions often involve cascading effects on biodiversity and complex interactions involving more than two species. For example, the predatory brook trout (*Salvelinus fontinalis*), introduced in Europe for sport fisheries and aquaculture, has replaced native salmonids in some waters, thereby affecting the reproduction of freshwater pearl mussel (*Margaritifera margaritifera*), an endangered species whose larvae attach to the gills of native salmonids (EEA 2012, 25-26).

IAS are also a main driver of homogenisation, i.e. increasing similarity in flora and fauna across previously distinct regions (Lockwood et al. 2007, 202). Although the introduction of non-native species can enrich species diversity at the local level, such increases have often been in favour of species that can thrive in human-modified environments and that are more likely to be transported and to survive in novel habitats, to the detriment of endemic species that are sensitive to the impacts of novel competitors, predators or pathogens (Lockwood et al. 2007, 202; McNeely 2001, 2-3).

Over 9% of the total number of species included in the IUCN Red List are under threat from IAS. Within the three highest-threat categories – vulnerable, endangered, and critically endangered – the proportion of species threatened by IAS is nearly 17%. Looking at the regional level, IAS pose a conservation threat to 13% of the threatened species naturally occurring in Europe (IUCN Red List of

Threatened Species version 2012.2). An analysis of the Red List Index (available for three taxonomic groups - birds, mammals and amphibians) shows that the negative impact of IAS pressures on species diversity has been increasing over time (McGeoch et al. 2010, 103-104).

In addition to their effects on biodiversity at the species level, IAS can adversely affect the functioning of entire ecosystems (Kettunen et al. 2009, 12; EEA 2012, 13). For example, Silver wattle (*Acacia dealbata*) forms dense stands that prevent the development of other species, increases soil nitrogen content, disrupts water flow and increases erosion along stream banks (DAISIE European Invasive Alien Species Gateway, 2008a). It is important to note that the full range and nature of IAS impacts on invaded ecosystems is unknown in a majority of cases (Kettunen et al. 2009, 13).

By driving certain species to extinction, biological invasions also imply a loss of 'option value', i.e. "the opportunities foregone as a result of loss of evolutionary or exploitation potential" (Pejchar and Mooney 2010, 162). Moreover, declines in biodiversity can translate into decreased ecosystem resilience – i.e. "the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks" (Walker et al., 2004) – and increased vulnerability to future invasions (Pejchar and Mooney 2010, 162).

### 1.4.2 Impacts on ecosystem services

Ecosystem services are "the direct and indirect contributions of ecosystems to human well-being" (TEEB 2010, 25). Invasive species affect the production, maintenance, and quality of ecosystem services through a number of mechanisms (Charles and Dukes 2007; Levine et al. 2003). IAS may affect an ecosystem's biotic components (e.g. by altering community structure and interactions between species or by causing species extinctions), alter the energy, nutrients, and water cycles, or affect abiotic factors such as disturbance regimes (e.g. increasing the risk of fires, erosion and flooding), the climate and atmospheric composition, as well as the physical habitat (Charles and Dukes, 2007, 223-226). In turn, such alterations affect the provision of ecosystem goods and services and, consequently, human well-being (ibid.).

Each of the ecosystem services identified in the Millennium Ecosystem Assessment (2005) framework – i.e. supporting, provisioning, regulating, and cultural services – can be affected by biological invasions. Whereas some IAS might impact only a specific ecosystem service, others may simultaneously affect a number of services, as they significantly alter ecosystem functioning (EEA 2012, 13). For example, the zebra mussel can affect supporting, regulating, and provisioning services in aquatic ecosystems (EEA 2012, 13-14). The rodent coypu (*Myocastor coypus*) damages crops, disturbs wetland vegetation by grazing, preys on the eggs of some endangered birds, disrupts riverbanks by burrowing, and is thought to play a role in the transmission of the bacterial disease leptospirosis (Vila et al. 2010, 138; DAISIE European Invasive Alien Species Gateway, 2008b). The black locust (*Robina pseudoacaria*), a nitrogen fixing species, can severely alter species composition and affect supporting services, while at the same time providing additional services such as erosion prevention on degraded slopes (EEA 2012, 14). In some cases, IAS produce synergistic impacts. For instance, the killer shrimp (*Dikerogammarus villosus*), an omnivorous predator which causes local extinctions of native species, hinders recreational use of invaded water bodies, and damages fisheries through the spread of parasites, has been shown to increase in abundance in the presence of the zebra mussel (EEA 2012, 69).

The effects of IAS on provisioning services are often the most easily discernible, as invasives can cause declines in agricultural production, fish catches, or the provisioning of water due to the blockage of waterways (Kettunen et al. 2009, 18). Occasionally, invasive species can also have positive impacts on provisioning services; for example, the racoon dog (*Nyctereutes procyonoides*) is useful for fur production, while the zebra mussel (*Dreissena polymorpha*) can play an important role in the provision of fresh water thanks to its high water filtering capacity (ibid.). It is important to note, however, that such species can simultaneously have negative impacts on other ecosystem services (ibid.).

Regulating services impacted by IAS include water regulation (e.g. Japanese knotweed, *Fallopia japonica* can cause local flooding), erosion control (e.g. invasive mammals can cause erosion by burrowing, while invasive plants may outcompete native vegetation that binds the soil), and resistance to wild fires (e.g. pampas grass, *Cortaderia selloana*) (Kettunen et al. 2009, 18-19; Pysek et al. 2009, 57). On the other hand, some IAS can also have positive effects, for example some are regularly used to stabilise the soil and control erosion (e.g. common cord grass, *Spartina anglica*) (Kettunen et al. 2009, 19).

Several impacts on cultural services have also been documented; IAS can reduce the aesthetic value of landscapes, hinder recreational activities, or damage landscapes of high cultural significance (Kettunen et al. 2009, 20). For example, the costs of Floating Pennywort (*Hydrocotyle ranunculoides*) to leisure and tourism in Great Britain have been estimated at 23.5 million GBP per year (Williams et al. 2010, 46-48). This aquatic plant, introduced to Britain from North America via the ornamental plants trade, renders infested waterways non-navigable and impedes fishing. At the same time, numerous culturally-appreciated species, from ornamental plants to common pets, are non-native and potentially invasive (Kettunen et al. 2009, 20).

Invasive species also interfere with supporting services such as primary production, nutrient cycling, and soil formation (ibid., 21).

### 1.4.3 Impacts on human health

IAS can function as disease vectors (e.g. the racoon dog, *Nyctereutes procyonoide*, the muskrat, *Ondatra zibethicus*) or directly affect human health by causing allergies and injuries (e.g. skin lesions upon contact with giant hogweed, *Heracleum mantegazzianum*, rhino-conjunctivitis and asthma upon contact with the allergenic pollen of common ragweed, *Ambrosia artemisiifolia*) (Kettunen et al.

2009, 19; EEA 2012, 14). For instance, around 100 alien invertebrate species introduced to Europe are known to affect human and animal health (Roques et al. 2009, 72).

### 1.4.4 Impacts on economic activities

By altering the quantity and quality of ecosystem services that underpin economic activities and human well-being, IAS ultimately translate into economic losses. For example, an analysis of the DAISIE database reveals a significant positive relationship between the number of non-native species with ecological impacts and those with economic impacts in Europe (Vila et al. 2010). At the same time, invasive species may yield benefits for certain sectors and individuals, which provides the incentive for their introduction in the first place. The costs and benefits, however, are not evenly distributed and typically accrue to different economic agents; those who benefit do not pay the costs and those who are negatively affected by IAS are not compensated for the value lost, making IAS akin to classical examples of externalities (Pejchar and Mooney 2010, 164; McNeely 2001, 14). De Wit et al.'s (2002) analysis of black wattle (*Acacia mearnsii*) in South Africa illustrates the conflicts of interest that are at stake: commercial wattle growers enjoy the financial benefits of black wattle (528 million USD) and the (potentially marketable) benefits of carbon sequestration (24 million USD), but most sectors of society bear the costs of a loss in water and biodiversity, an increase in fire hazard and the impacts of erosion (altogether estimated at 1426 million USD). Similarly, the introduction of brush-tailed possums (*Trichosurus vulpecula*) to New Zealand has been highly profitable for the fur industry, but the species also causes severe defoliation in native forests and is a vector for bovine tuberculosis (Pejchar and Mooney 2010, 164).

Emerton and Howard (2008, 41-42) classify the economic costs of IAS into 1) direct impacts on production arising from the effects of IAS on the host ecosystem; and 2) secondary or tertiary effects on other sites, sectors and times, such as impacts occurring due to associated changes in consumer demand or the relative price of inputs, as well as off-site impacts resulting from the loss of biodiversity and ecosystem services. Although direct production impacts are often the easiest to identify (Evans 2003), they typically cover multiple ecosystem services and are not always limited in space and time, making valuation difficult (Emerton and Howard 2008, 41). For example, IAS-borne diseases can have lasting effects on the host that are not always immediately visible, such as delays in the reproduction of livestock, while pesticides applied to eradicate pests can result in soil pollution (Evans 2003, 7). Furthermore, it is sometimes difficult to distinguish IAS-induced impacts from other phenomena (ibid.).

Indirect impacts include changes in consumer demands, reduced land rental prices, lower tax revenues, decreased food security, and decreased employment (Emerton and Howard 2008, 42; Jones and Kasamba 2008, 9). Incorporating these secondary and further knock-on effects of invasions into cost calculations is even more challenging, given that these impacts affect not only the site or sector within which an invasion has taken place, but extend to other parts of the economy (Emerton and Howard 2008, 42). Such impacts often outweigh direct production losses (Evans 2003, 8).

Quantifying the impacts of invasive species usually entails high degrees of uncertainty at different steps of the valuation, since it “requires the specification of a series of dose-response relationships which link a given level of biophysical or ecosystem change with a particular level of economic change” (Emerton and Howard 2008, 42). Calculating the damage costs of IAS involves two steps: firstly, identifying and quantifying all the effects of an invasion and secondly, assigning monetary values to these effects, with estimation errors intervening at each step (Gren et al. 2007, 12).

The magnitude of invasion-induced damage thus has to be assessed in terms of the value of the ecosystem services lost (or threatened) by IAS. Although significant advances in valuation techniques have been made in recent years,[2] the process of assigning monetary values to ecosystem services remains fraught with difficulties. An accurate assessment of the costs of IAS would have to consider the full range of impacts in a ‘Total Economic Value’ (TEV) framework. The TEV approach tries to capture “the sum of the values of all service flows that natural capital generates both now and in the future – appropriately discounted” (TEEB 2010, 188). As such, it requires consideration of both ‘use values’ (e.g. direct use of resources derived from ecosystems and indirect use of regulating services) and ‘non-use values’, such as the value people place on maintaining the option of benefitting from ecosystem services in the future or the satisfaction of knowing that a species or ecosystem exists (ibid.). Most economic valuations of IAS impacts have focussed on direct-use values, partly due to the availability of quantitative data on production losses and control costs in specific land-use sectors (Born et al. 2005, 332-333).[3]

Moreover, it is particularly difficult to determine that an introduced non-native species has *no* impact on the host ecosystem. While numerous alien species are said to have little or no detectable impact on native species, we do not know whether this is due to our limited ability to observe and quantify the impacts, or because there really is no effect (Lockwood et al. 2007, 206-207).

### 1.4.5 The economic impacts of invasive alien species in Europe

A growing number of assessments attempt to quantify the economic impacts of IAS in Europe, but the results of various valuation studies are generally not comparable or cumulative given the differences in methodology and the range of impacts and taxa considered (see, for example, the critiques in Born et al. 2005 and Kettunen et al. 2009). Most studies take into account only one or a bundle of species, relate to a specific geographic setting and are difficult to scale up to higher territorial levels, and tend

[2] See, for example, The Economics of Ecosystems and Biodiversity (TEEB), http://www.teebweb.org/

[3] Nevertheless, valuations encompassing a broader range of values are in principle possible. See, for example, the analysis of Turpie and Heydenrych (2000) on residents’ willingness-to-pay to prevent the alteration of option and existence values of Fynbos vegetation in the Cape Floral Kingdom due to biological invasions.

to overlook the effects of invasions on non-market ecosystem services (Pejchar and Mooney 2010, 161). Overall, the monetary values reported in the existing studies should be considered as lower-bound estimates of IAS costs.

A few assessments of IAS costs at national level illustrate the considerable economic losses associated with invasives. Williams et al. (2010) report a total annual cost of IAS to the British economy (based on costs incurred in 12 sectors) of 1.7 billion GBP. The costs associated with invasion by 13 alien species in Sweden are estimated at 174 million to 546 million euro (Gren et al. 2007). In Germany, 20 invasive species with eight distinct types of impacts[4] give rise to annual costs of 100 million to 265 million euro (Reinhardt et al. 2003). Assessments outside Europe also report extremely high figures; for example, the costs of IAS were estimated at 120 billion USD a year in the United States (Pimentel et al. 2005) and between 13.3 and 34.5 billion CDN per year in Canada (Colautti et al. 2006).

A recent assessment of the documented monetary costs of IAS in Europe, based on 61 species and 14 species groups, shows that the economic impacts of IAS amount to 12.5 billion EUR annually, of which 9.6 billion EUR represent damage costs and 2.8 billion EUR are related to the control of IAS (Kettunen et al. 2009). The figures should be seen as a significant underestimate of the real situation, since available data on the monetary impacts of IAS remains limited and unevenly distributed among geographic regions and taxa (ibid., iv). Information is particularly scarce with regard to the costs of IAS to sectors such as tourism, health, and forestry (ibid., 39). Through a cost extrapolation based on information available for 25 species, taking into account the area affected by IAS and the known range of the given IAS in Europe, the authors arrive at a total cost of 20 billion EUR, which should still be seen as an underestimate as it only covers a limited number of species and services (e.g. it excludes the loss of biodiversity-related existence, bequest and option values caused by biological invasions).

Some estimates of the costs of IAS to different economic sectors in Europe are presented in Table 1.

**Table 1. Documented costs of IAS on different economic sectors in Europe**

| Economic Sector | Costs of damage (million EUR/year) | Costs of control (million EUR/year) |
|---|---|---|
| Agriculture* | 5480.2 | 29.9 |
| Fisheries/Aquaculture | 241.6 | No information |
| Forestry | 124.9 | 25.8 |
| Health* | 69.4 | 13.1 |
| Total | 5916.1 | 68.8 |

* Costs of epidemic animal and human diseases excluded
Adapted from Kettunen et al. 2009, 33.

[4] Impacts on human health, damage to forestry and silviculture, damage to agriculture, damage to fisheries and aquaculture, negative effects on biological communities, damage to waterways and watercourses, disruption of land routes, and threats to native species.

The available information on the monetary benefits of IAS considered in the study was also found to be limited. It appears that positive impacts are also accompanied by adverse effects on native species and/or ecosystems in a majority of cases (ibid., 28)

Given the extent of the potential damage, there is a clear need to intensify prevention efforts, as well as to internalise these costs. On the other hand, the above discussion also highlights the uncertainty that characterises the valuation of damage, especially prior to the invasion occurring. This implies that in many cases it will be difficult to set policy targets with regard to IAS, particularly an acceptable risk threshold, and to assess ex-ante the efficiency of various measures, an issue that will be considered in more detail in Chapter 2.

## 1.5. Economic sectors responsible for IAS introductions

As alluded to in the preceding sections, a wide range of economic activities are associated with the risk of introducing IAS into the wild, including agriculture, forestry, horticulture, trade in ornamental plants, seed trade, pet and aquarium trade, aquaculture, live-food trade, hunting, and shipping. Ultimately, all trade and transport activities can be responsible for the unintentional introduction of 'hitchhiker' and stowaway species.

Table 2 illustrates the role of certain economic activities in facilitating IAS introductions in Europe.

**Table 2. Dominant introduction pathways to Europe**

| Taxonomic group | Dominant pathways |
|---|---|
| Terrestrial invertebrates[1] | Horticultural and ornamental trade - 38%<br>Unknown - 19%<br>Stored products - 18% |
| Vascular plants[2] | Ornamental - 39.9%<br>Horticultural - 17.5%<br>Contaminant of seeds, mineral material, and other commodities - 17% |
| Aquatic invertebrates and fish (Inland)[3] | Fisheries (stock enhancement) - 30%<br>Aquaculture - 27%<br>Shipping - 25% |
| Marine biota[4] | Mediterranean: Suez Canal - 54%, Shipping - 21%, Aquaculture - 11%<br>Atlantic coast: Shipping - 47%, Aquaculture - 24%<br>Baltic Sea: Shipping - 45%, Aquaculture - 18% |

*Source:* [1]Roques et al. 2009; [2]Pysek et al. 2009; [3]Gherardi et al. 2009 ; [4]Galil et al. 2009.

When analysing the role of economic instruments in IAS prevention, this study will mainly focus on their applicability to four economic sectors: horticulture and ornamental plants trade, aquaculture, pet and aquarium trade, and shipping. The role of these industries in facilitating IAS introductions is outlined below.

### 1.5.1 Horticulture and ornamental plants trade

The ornamental plant trade has been recognised as the major pathway for plant invasions in many areas (Dehnen-Schmutz 2011, 1374). In Europe, 58% of the naturalised alien taxa recorded were species cultivated for ornament and horticulture but which escaped into the wild (Pysek et al. 2009, 51). In addition, 38% of alien insects, mites and nematodes introduced to Europe (Roques et al. 2009, 70), as well as a majority of alien bryophytes (Essl and Lambdon 2009, 36), are likely to have arrived as contaminants or stowaways on ornamental and horticultural commodities. Not all naturalised escapees have an ecological and/or economic impact,[5] but those that do tend to cause significant damage; for example, New Zealand pigmyweed (*Crassula helmsii*) and floating pennywort (*Hydrocotyle ranunculoides*), sold in garden centres and for aquaria (Heywood and Brunel 2011, 13).

The sector has a long tradition and has been growing in importance over the past century, to satisfy consumers' demand for novel, exotic plants (Dehnen-Schmutz and Touza 2008, 15-16; Heywood and Brunel 2011, 12). The traits that make a species attractive for cultivation – e.g. large flowers, long blooming season, low maintenance, wide adaptability, and ease of propagation – also increase its invasiveness potential (Anderson et al. 2006, Mack 2005, cited in Drew et al. 2010, 2839). Repeated local introductions via this pathway increase propagule pressure, while the care provided during cultivation (seed bed preparation, tillage, destruction of competitors and parasites, etc.) further increase the likelihood that a species will escape and naturalise, by shielding them from the effects of environmental stochasticity (Mack 2000, 114-115).

Based on data from Britain, Dehnen-Schmutz et al. (2007) show that the invasion success of deliberately introduced species increases with the number of nurseries selling the plant and the length of time it has been available on the market. The authors also find that the probability of invasion increases when seeds are sold at a lower price (ibid., 531). This suggests that market availability is a good proxy for propagule pressure and that price instruments may be effective in lowering demand, and hence propagule pressure (ibid., 532).

In several countries, taxa included on invasive species lists are still available on the market (e.g. Halford et al. 2011, 3; Dehnen-Schmutz and Touza 2008, 19-20; Drew et al. 2010, 2837). At the same time, species not yet identified as posing a risk may turn out problematic in the future (Dehnen-Schmutz 2011, 1374).

[5] Comprehensive data on the ecological and economic impacts of naturalised plant species in Europe is available only for some countries, where about 20% are thought to have an impact (Pysek et al. 2009, 56).

### 1.5.2 Aquaculture

Aquaculture production in the European Union amounts to 1.3 million tonnes, with a value of 3.2 billion euro (European Commission 2012, 26). Despite its economic benefits, the sector also accounts for 24%, 18%, and 11% of marine species introductions to the Atlantic coast, the Baltic Sea, and the Mediterranean, respectively (Galil et al. 2009, 96).[6] In addition, 27% of alien invertebrates and fish species introduced to European inland waters are attributable to this vector (Gherardi et al. 2009, 85). Similarly to ornamentals, introductions associated with this sector occur either via escapes from species deliberately introduced in aquaculture facilities or unintentionally as hitchhikers and pathogens carried by target species. IAS introduced through this pathway can affect the aquaculture industry itself (e.g. through the loss of stock and production due to disease transfer), but also have an impact on unrelated businesses and sectors, such as power plants and water treatment plants (affected by the zebra mussel) and tourism (see Jones and Kasamba 2008, 4-5, and references therein).

The aquaculture industry is based on a complex production chain, with varying risks of dispersing alien organisms in the wild at each step (Occhipinti-Ambrogi et al. 2008, 1). It involves the transportation of larvae from the country of origin to the rearing facility, hatching and larval production, farming of juveniles in different types of facilities (intensive closed, intensive open, extensive gated, extensive open), and the delivery of products to the market (ibid., 5-10). Regarding the alternative rearing facilities, intensive closed systems carry the lowest risk of dispersal, since they are enclosed, effluents are continuously treated, and there is little water exchange (ibid., 9). However, less than 10% of non-native species are farmed in such facilities, with higher-risk extensive open systems accounting for 20% of aquaculture production (ibid., 21).

A review of the negative ecological impacts of the 27 species most utilised in Europe for aquaculture and related activities found that a number of species have multiple impacts, while the possible impact of several commonly used species is largely unknown (Savini et al. 2010). For example, alien crayfish, *Procambarus clarkii* and *Pacifastacus leniusculus*, cause the largest number of impacts (crayfish plague dissemination, bioaccumulation of pollutants, changes in community structure, competition and predation on native species, habitat changes, food web alterations, herbivory consumption) (ibid., 1). Introduction of the signal crayfish (*Pacifastacus leniusculusis*) in the 1960s is responsible for the spread of crayfish plague in Europe and the virtual elimination of native European crayfish (*Astacus astacus* L.) from several regions of Europe (Peeler et al. 2011, 1297). Escaped salmonids such as *Salvelinus fontinalis* may cause genetic impairment of native stocks by hybridization, while cultures of the Pacific cupped oyster (*Crassostrea gigas*) and Manila clam (*Ruditapes philippinarum*) serve as introduction vectors for a large number of alien invertebrates and algae (Savini et al. 2010, 1)

[6] The values are only a best estimate, since the introduction vector for aquatic species is often uncertain (Savini et al. 2010, 4).

Peeler et al. (2011) highlight the role of the aquaculture industry in the transmission of aquatic animal diseases and the difficulty of screening out potential carriers. The risk that a species introduced for aquaculture will drive disease emergence cannot be fully assessed prior to introduction, since such parasites constitute 'unidentified hazards' (ibid., 1298). Historical evidence on the frequency of disease emergence may provide an estimate of such risks (Gaughan 2002, cited in Peeler et al. 2011, 1299), but this is not sufficient for an import risk assessment under current WTO rules (Peeler et al. 2011, 1299). The authors suggest the application of risk mitigation measures such as quarantining alien species with native ones or the introduction of fertilised eggs instead of live animals (ibid., 1300).

Often, responsibility for the introduction of an aquatic non-native cannot be accurately ascribed to a specific sector and vector (Minchin 2007, 305). Moreover, multiple sectors are sometimes involved at different steps of the invasion process. For example, the parasitic nematode *Anguillicola crassus* was inadvertently introduced to Europe in the 1980s with the deliberate introduction of its host, the eel *Anguilla japonica*, it escaped culture facilities, and widely affected stocks of European eel (*Anguilla anguilla*) (ibid.). Its subsequent spread to Britain and Ireland may have resulted either from water discharges by trucks carrying live eels, or from discharges of ballast water (ibid.).

### 1.5.3 Pet and aquarium trade

The pet and aquarium industry can cause invasions both via the release or escape of intentionally introduced species and by providing vectors for unintentional introductions of pathogens, parasites, and contaminants on pet supplies (Shine 2011, 3). Only a relatively small fraction of the thousands of species kept as pets in Europe have become invasive (Davenport and Collins 2011, 3). In European inland waters, 9% of alien invertebrates and fish are ornamental varieties (Gherardi et al. 2009, 85). Nine alien amphibian and reptile species and 27 alien bird species are escaped pets (Kark et al. 2009, 110), and the sector also accounts for 10% of alien mammal species established in Europe (Genovesi et al. 2009, 123). Worldwide, a third of the aquatic species inscribed on the list of 100 worst invaders by the International Union for the Conservation of Nature (IUCN) Invasive Species Specialist Group originate from aquarium or ornamental releases (Lowe et al. 2000, cited in Padilla and Williams 2004, 133). Some species continue to be traded despite being recognised as posing a high risk, for example, red-eared sliders (*Trachemys scripta*) which have been shown to outcompete native turtles (Perry and Farmer 2011, 135). The growing importance of internet trade in pet and aquarium species poses an additional challenge, given the complexity of regulating this pathway (Shine 2011, 4; Kay and Hoyle 2001).

### 1.5.4 Shipping

Shipping has been recognised as the major vector for aquatic invasions worldwide, accounting for about 60% of aquatic alien biota (Roberts and Tsamenyi 2008, 559; Gollasch 2007, 51). The first observations of vessel-transported exotics date as far back as the 17$^{th}$ century (Galil et al. 2009, 93). In inland waters, shipping is responsible for the introduction of 25% of species alien to Europe, as well as 30% of species that are alien to at least one European country but native to others (Gherardi et al. 2009, 84). In the marine environment, shipping accounts for the introduction of 47% of established alien species on the European Atlantic coast, 45% in the Baltic Sea, and 21% in the Mediterranean (Galil et al. 2009, 96). It has been estimated that ships may carry 4000 to 7000 taxa each day (Gollasch 2007, 50).

Two main modes of introduction are associated with this sector: biofouling (the attachment of organisms to vessels' hulls) and ballast water. Ballast (initially made up of sediments, but currently of water) is necessary to provide vessel stability (Galil et al. 2009, 97). Ballast water is taken into tanks or empty cargo holds when the cargo is offloaded and discharged when loading cargo or fuelling (ibid., 97). Species with a high potential for causing damage in the receptor environment, such as toxin-producing phytoplankton and human pathogens – are frequently transported in ballast water (Gollasch 2007, 52). Some of the world's worst invaders are associated with this sector, for example the zebra mussel (*Dreissena polymorpha*) which causes damage to fisheries and aquaculture facilities, hinders aquatic transport, affects native mussels through competition, and causes severe habitat alterations (DAISIE European Invasive Alien Species Gateway, 2008c).

The International Convention for the Control and Management of Ships' Ballast Water and Sediment (discussed in the following section) seeks to minimise the invasion risks associated with this pathway.

## 1.6. The policy framework

The Convention on Biological Diversity (CBD) adopted in 1992 requires Parties, as possible and as appropriate, "to prevent the introduction of, or control or eradicate, those alien species which threaten ecosystems, habitats or species" (Article 8h). The Guiding Principles for this article's implementation encourage Parties to apply the precautionary approach in their efforts to identify and prevent unintentional introductions, as well as decisions concerning intentional introductions, and sets out a three-stage hierarchical approach to IAS management: prevention, eradication, control. Invasive species have been addressed in numerous Decisions of the Conference of the Parties.[7]

The International Plant Protection Convention (IPPC) provides a framework for international cooperation to "secure common and effective action to prevent the spread and introduction of pests of plants and plant products, and to promote appropriate measures for their control." To the extent that they qualify as pests, IAS fall under the convention's scope. The IPPC develops international standards for pest-risk analysis and phytosanitary measures (Shine et al. 2000, 22).

The Agreement on the Application of Sanitary and Phytosanitary Measures (the SPS Agreement) adopted by the World Trade Organisation in 1995 allows WTO members to adopt national measures

[7] See http://www.cbd.int/invasive/cop-decisions.shtml , accessed 6 August 2013.

"to protect human, animal and plant life or health from the risks arising from the entry, establishment or spread of pests, diseases, or disease-carrying organisms or disease-causing organisms and to prevent or limit other damage within the territory of the Member from the entry, establishment or spread of pests" (ibid., 25). The agreement aims to ensure that national measures for these purposes are not a form of disguised protectionism. It requires the use of international standards as the basis for SPS measures, risk assessment based on scientific principles and evidence, consistency in the application of appropriate levels of protection, the use of least trade-restrictive alternatives, mutual recognition of members' SPS measures, and transparency through notification of trade measures (ibid., 25-27).

The International Maritime Organisation (IMO) has adopted the International Convention for the Control and Management of Ships' Ballast Water and Sediments in 2004, with the aim of preventing, minimising and ultimately eliminating "the risks to the environment, human health, property and resources arising from the transfer of harmful aquatic organisms and pathogens via ships' ballast waters" (Gollasch et al. 2007b, 586). The convention shall enter into force 12 months after the date on which it has been signed by at least 30 states, representing not less than 35% of the world's merchant shipping tonnage (ibid.). As of August 2013, 37 states had ratified the Convention, representing 30.32% of merchant shipping tonnage.[8] The Convention introduces two prevention regimes, to be sequentially implemented. In a first step, commercial ships engaged in international traffic are required to exchange a minimum of 95% of ballast water volume in the open ocean. A different performance standard would be phased in over a certain period of time, setting limits for the concentration of living organisms present in the discharged ballast water.

At EU level, invasive species are addressed in several legislative acts, including the Habitats[9] and Birds Directives[10], the Wildlife Trade Regulation[11], and the Aquaculture Regulation[12]. The Habitats and Birds Directive require member states to ensure that deliberate introductions of non-native species into the wild are regulated and if necessary, prohibited, so as not to prejudice natural habitats or the native fauna and flora (Shine et al. 2010, 37). The Wildlife Trade Regulation (primarily concerned with trade in endangered species) provides for the suspension of imports into the EU of species whose introduction poses an ecological threat to the EU's native fauna and flora. The import of four animal species has been banned so far (ibid., 34). The Aquaculture Regulation is the only EU instrument to address introductions by a specific sector (ibid., 35). Member states are required to take all appropriate measures to avoid adverse effects on biodiversity resulting for the introduction,

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[8] Ratification status available at http://www.imo.org/About/Conventions/StatusOfConventions/Pages/Default.aspx, accessed 7 August 2013.

[9] Council Directive 43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora

[10] Directive 2009/147/EC of the European Parliament and of the Council of 30 November 2009 on the conservation of wild birds

[11] Council Regulation 338/97/EC, Commission Regulation (EC) No. 865/2006 laying down detailed rules for its implementation

[12] Council Regulation (EC) No 708/2007 of 11 June 2007 concerning use of alien and locally absent species in aquaculture

translocation and spreading of organisms used for aquaculture. The introduction of an alien species is subject to the issuing of a permit by the receiving member state (Article 6.1). For non-routine movements[13] a permit will only be issued if a species-specific risk assessment determines the risk of invasiveness to be low, or if mitigation procedures or technologies are available to reduce the level of risk to low (Article 9). A list of species used in aquaculture for a long time are exempted from these requirements. Member states wishing to restrict the use of such species on their territory must justify the restrictions through a risk assessment (Shine et al. 2010, 36).

National measures concerning IAS that affect the free movement of goods within the EU must also be compliant with Single Market legislation, which prohibits quantitative restrictions on imports and exports unless justified on the grounds of protecting human, animal, or plant health. The limited jurisprudence of the European Court of Justice has provided some guidance, but a degree of legal uncertainty continues to prevail as to the exact types of IAS-related restrictions member states may impose (Miller et al. 2006, 42-43; Shine et al. 2010, 46). One important principle reaffirmed by ECJ case-law on the matter is that of proportionality; IAS-related trade restrictions are justifiable provided that their objective cannot be achieved as effectively by measures that are less trade-restrictive (Shine et al. 2010).

The European Commission has been considering policy options for a new legislative instrument dedicated to IAS and the proposal is to be issued later this year.[14]

At national level, intentional introductions are usually regulated through permit requirements and species listing systems that differentiate between alien species on the basis of risk (Shine et al. 2000, 52-55). The most commonly applied list systems are 'black lists' of high-risk species whose importation is prohibited, 'white lists' of species assessed as harmless, and intermediate 'grey lists' that usually comprise species whose invasiveness is unknown or divide species into categories along a gradient of risk (ibid., 54). As Shine et al. (2000, 62-64) underscore, list systems are an "inherently reactive" tool and can never be fully accurate;[15] species are usually included on a black list after having been shown to be invasive (ibid.). Border control, inspections and quarantine measures are applied, with varying degrees of effectiveness, to curtail unintentional introductions.

A recent assessment of EU member states' policies (Sonigo et al. 2011) found a "fragmented policy field" regarding IAS. Prevention policies usually involve restrictions or prohibitions on the trade or internal transfers of prioritised alien species. Fourteen member states regulate imports through legally-binding black lists (ibid., 213). Unintentional introduction pathways remain poorly regulated in most member states (ibid., 77-83). Tools for assessing IAS risks were assessed as "relatively new and

[13] Namely, "the movement of aquatic organisms from a source which has an elevated risk of transferring non-target species and which, on account of the characteristics of the aquatic organisms and/or the method of aquaculture, may give rise to adverse ecological effects" (Shine et al. 2010, 36).
[14] See http://ec.europa.eu/environment/nature/invasivealien/, accessed 4 August 2013.
[15] For a discussion and empirical analysis of the errors and uncertainty associated with species lists, see McGeoch et al. (2012).

poorly developed” in most member states, while early-warning and alert measures are in place in only a few countries (ibid., 213-214).

A number of policy documents allude to the development and implementation of incentive measures – including economic and financial instruments – to address the problem of biological invasions, but do not offer specific guidance on the design of such instruments. Some examples are presented in Box 1.

**Box 1: Policy documents recommending the use of economic instruments with regard to IAS**

**COP 7 Decision VII/13 (2004)**[16]

“The Conference of the Parties

…

6. *Invites* relevant Parties to the Convention on Biological Diversity and other Governments, as well as national, regional and international organizations to:

….

(f) **Consider the introduction of positive incentive measures** for the prevention, mitigation, eradication or control of invasive alien species and the use of native species taking into consideration effectiveness in control and impact on the other native species in land and water management and other programmes;

(g) **Proactively engage relevant stakeholders and indigenous and local communities** in the eradication, the prevention of introductions, and mitigation of impacts of invasive alien species, including by awareness-raising and training **as well as through the design and implementation of appropriate incentive measures**;…”

**COP 6 Decision VI/23 (2002)**[17]

“The Conference of the Parties

…

12. Encourages Parties and other Governments, in undertaking this work and, in particular, when developing priority actions, to consider the need to:

…

b. **Develop financial measures, and other policies and tools, to promote activities to reduce the threat of invasive alien species**;…”

**Global Strategy on Invasive Alien Species (IUCN)** (McNeely et al. 2001)

**Ten strategic responses to address the problem of invasive alien species**

***Element 4. Develop economic policies and tools***

“Because biological invasions often indicate market failure, an important part of any strategy to manage IAS is to make markets work for conservation wherever possible, and to provide alternate solutions if markets do not exist and cannot be created. Therefore, **GISP encourages countries to incorporate economic principles into their national strategies for addressing IAS**, building on the following main principles:

➢ ***User pays***: make those responsible for the introduction of economically harmful invasive species liable for the costs they impose.

➢ ***Full social cost pricing***: ensure that the prices of goods and services whose production or consumption worsens the damage of invasives reflect their true cost to society.

➢ ***Precautionary principle*****:** because of the potentially irreversible and high costs of invasives, it is important to base management and policy on the precautionary principle.

...

[16] https://www.cbd.int/decision/cop/default.shtml?id=7750, accessed 5 August 2013.

[17] http://www.cbd.int/decision/cop/default.shtml?id=7197, accessed 5 August 2013.

Particular policies that governments may wish to develop to reflect these principles include:

➤ *Developing appropriate property rights*: ensure that use rights to natural or environmental resources include an obligation to prevent the spread of potential IAS;

➤ *Estimating social costs*: assess the economic costs of actual or potential IAS;

➤ ***Assigning liability***: require importers/users of potential IAS to have liability insurance to cover the unanticipated costs of introductions or of activities that risk introductions;

➤ *Promoting empowerment*: enable people injured by the spread of IAS to seek redress;

➤ ***Applying price-based instruments*****:** to ensure that importers/users of known IAS take account of the full social cost of their activities, **apply economic instruments such as commodity taxes, differential land use taxes, user charges or access fees**;

➤ ***Applying precautionary instruments*****:** where the risk of damage depends on the behaviour of importers/users of IAS, **apply precautionary instruments such as deposit-refund systems or environmental assurance bonds**."

**European Strategy on Invasive Alien Species: Convention on the Conservation of European Wildlife and Habitats (Bern Convention) (2004)**

"**Explore use of economic instruments** to generate sustainable funding for IAS prevention, monitoring and mitigation (e.g. guarantee systems, insurance or levies involving professional breeders or traders, pathway and vector levies for transport bodies etc.)."

# Chapter 2. Invasive Alien Species as a form of pollution: similarities and differences to other externalities

## 2.1. Conceptualising IAS as externalities

An externality occurs when the production or consumption decisions of one economic agent affect the utility of another agent in an unintended way and the affected party is not compensated for this impact (Perman et al. 2011, 121). Since the agent is not bound to provide any compensation, the effects caused will be unintentional and external to the agent's decision-making (ibid., 124). Biological invasions can be treated analytically as the external effects of various economic activities; the individual or company whose activities may promote the introduction, establishment and spread of potentially invasive species does not bear the costs of the damage such species might cause to the wider economy and biodiversity, or the costs incurred for their eradication or control (Perrings et al. 2005, 212; Emerton and Howard 2008, 21-22; Williamson et al. 2011, 2). When the prices and profits that agents face do not internalise the full costs of invasions, there are no (economic) incentives for agents to take into account the risk of invasions in their decision-making (Emerton and Howard 2008, 22).

At the same time, policies to prevent or control IAS display the characteristics of 'public goods'. Their provision is 'non-rival' in so far as additional beneficiaries do not increase the overall costs nor reduce the measures' benefits to others, and 'non-excludable' in the sense that no individual (payers and non-payers alike) can be prevented from enjoying the benefits (Touza et al. 2007, 354; Perrings et al. 2002, 4). These two characteristics result in an under-provision of policies for managing potentially invasive species, if left to market forces alone (ibid.). Prevention and control of IAS can also be considered a 'weakest-link' public good, as the benefits are determined by the least-effective provider (Perrings et al. 2002, 4).

If invasive alien species are akin to 'conventional' externalities, it follows that the policy prescriptions for avoiding their damage can mirror those designed to address other environmental problems. Several factors specific to biological invasions compound, however, the problem and render the applicability of economic instruments less straightforward. Nevertheless, parallels can be drawn to other cases of decision-making under uncertainty. We begin with an overview of the uncertainty characterising various parameters of the invasion problem.

## 2.2. Risk and uncertainty in invasive species management

In contrast to situations involving 'risk', where all the possible consequences ('states of the world') of a decision are known and probabilities can be assigned to each possibility, uncertainty is characterised by the impossibility of assigning probabilities to each possible outcome (Perman et al. 2011, 456). Here, we can further distinguish between situations in which all possible consequences can be enumerated but their respective probability of occurring are unknown, and situations of radical uncertainty where it is not even possible to enumerate all outcomes (ibid.).

For some activities and commodity groups, policy-makers will have sufficient data to predict the likelihood of invasions in a risk framework. In many other cases, however, regulators will find themselves in a situation of uncertainty; it will not be possible to anticipate how a particular alien species will act in the recipient ecosystem (and hence the probability that the species will successfully transit through each stage of the invasion process) and the value that society will attach to the resulting changes (Keller and Lodge 2010, 224; Perrings et al. 2010, 8). As Horan et al. (2002, 1303) underscore, "a probability density function cannot be constructed for one-time events with no historical precedents".

Wätzold (2000) distinguishes between five types of uncertainty based on the behaviour of emissions in the natural environment: accumulation uncertainty, diffusion uncertainty over time, diffusion uncertainty in space, synergy uncertainty, and uncertainty regarding the ensuing damage. Biological invasions entail some elements of each. Accumulation uncertainty refers to the fact that emissions may accumulate in the environment unobserved before their negative effects become visible. Biological invasions are usually characterised by considerable time lags between the introduction of an alien species and its subsequent establishment and spread (Keller et al. 2011; Essl et al. 2011). Lag phases may be in the order of decades or even centuries, and vary considerably by species and host habitat (Emerton and Howard 2008, 12). Lag phases are generally a function of the time necessary to exceed critical thresholds of available propagules which depends, in turn, on propagule size and the number of introduction events, the type of introduction pathway, the match between an alien species' habitat requirements and the conditions in the recipient environment, the length of generation times, or the time necessary for genetic adaptations to new environmental conditions (Essl et al. 2011, 205). This multitude of potentially interacting factors makes it difficult to predict the lag phase between introduction of a particular species and successful invasion (ibid.) as well as to causally link *ex-post* an invasion to a particular introduction event. Since it is not always possible to predict how far and at what rate a species will spread after establishment, invasions can also be said to display diffusion uncertainty in space.

Synergy uncertainty denotes the unpredictable effects that emissions may have when present in combination with other emissions. Newly introduced alien species may interact (sometimes in unpredictable ways) with other native and non-native species present in the host environment. Such interactions may be interfering, i.e. the presence of non-native species may hinder the establishment success of subsequently introduced species, or facilitative – for example, by causing habitat disturbance, already-established alien species may reduce the propagule pressure needed for later introductions of other alien species to succeed (Lockwood et al. 2005, 227). Such interactions may be synergistic, meaning that the joint impact of several introduced species is greater than the summed impacts of each individual species (Simberloff and Von Holle 1999, 29). Simberloff and Von Holle (1999, 22) coined the term 'invasional meltdown' to describe the process whereby "a group of nonindigenous species facilitate one another's invasion in various ways, increasing the likelihood of survival and/or of ecological impact, and possibly the magnitude of the impact".

Uncertainty also surrounds the damage caused by biological invasions. An important peculiarity of invasive species is that they are a self-perpetuating form of pollution, in contrast to other forms of polluting substances whose damaging effects generally decrease in severity over time once the polluting activity has ended (Keller et al. 2011, 11). Once the invasion process is set in motion, alien species continue to reproduce and spread even after discontinuation of the emissions flow (Perrings et al. 2000, 6-7). Since IAS reproduce, the ultimate damages resulting from an introduction may be only weakly related to the size of imports (Costello et al. 2007). Moreover, for many species, the growth function and associated damage is unknown prior to introduction and extrapolations based on the species' growth dynamics in its native region are not always a reliable indicator of dynamics in the host region (ibid.).

Not only are the ecological effects of IAS difficult to predict and quantify, but, as outlined in the preceding chapter, the problems associated with ecosystem services valuation make it difficult to account for these effects in monetary terms.

## 2.3. Flow-damage and stock-damage pollution

A common distinction in the pollution control literature is between *flow-damage* and *stock-damage* pollution. The former refers to situations in which damage arises only from the rate at which emissions are discharged into the environment; such damage therefore instantaneously drops to zero if the emissions flow is brought to an end (Perman et al. 2011, 143). In the latter category, damages depend solely on the stock of the pollutant at a given point in time; it implies that emissions are produced at a rate exceeding the environment's assimilative capacity (ibid.). The stock itself is typically assumed to be outside the policy-maker's control, who tries to regulate emission flows (ibid., 149). Efficient control of a stock-damage pollutant would have to take into account the trajectory of emissions over time and the rate of decay of emissions (ibid., 153).

It follows from the above discussion that invasive alien species, although broadly similar to stock-damage pollution, are not entirely straightforward to conceptualise as such. The 'emissions flow' consists of the number of alien species released in an environment (i.e. propagule pressure). Damage arises if the introduced alien species succeeds in progressing through all stages of the invasion process, and further varies depending on the rate of spread (and hence area affected), biotic and abiotic characteristics of the host environment, and the potential for eradication. The function linking emissions to damages is thus not always easy to specify given the complexity of the invasion process which involves multiple stages with varying (or even unknown) probabilities associated with each stage. The aim of control instruments in the IAS case is to reduce the likelihood of invasions and the resulting damage if invasions do occur. Putting an end to (or reducing the rate of) introductions – i.e. the emissions flow – precludes (or lowers the likelihood of) damage, provided that the invasion process has not already been set in motion by previous introduction events.

The stock of alien species in a given environment is relevant in several respects. Firstly, it may have already attained a level at which invasion will occur (following a time-lag and in the absence of eradication) despite a discontinuation of the emission flow. Secondly, the effect of additional introductions may depend on the stock of previously introduced individuals of the same species, if the population of an alien species builds up over time and a successful invasion occurs when the population has become large enough to overcome demographic and environmental stochasticities (Sol 2007, 128). Thirdly, the effect of newly introduced species may depend on the existing stock of *other* alien species in the host environment. The latter may be an externality of the same activity, or may have been introduced via other commodities or economic sectors. From the perspective of instrument design, this shows the problems involved in apportioning responsibility among potential polluters.

## 2.4. Implications for the applicability of economic instruments to internalise the effects of invasions

The various uncertainties characterising the invasion process have implications for setting the (efficient) targets of acceptable pollution levels, designing the instruments aimed at internalising the externality, and assessing the comparative merits of potential instruments. In certain cases, uncertainty will also render decision models based on maximisation of expected utility inappropriate.

### 2.4.1 Difficulties in setting the emission targets

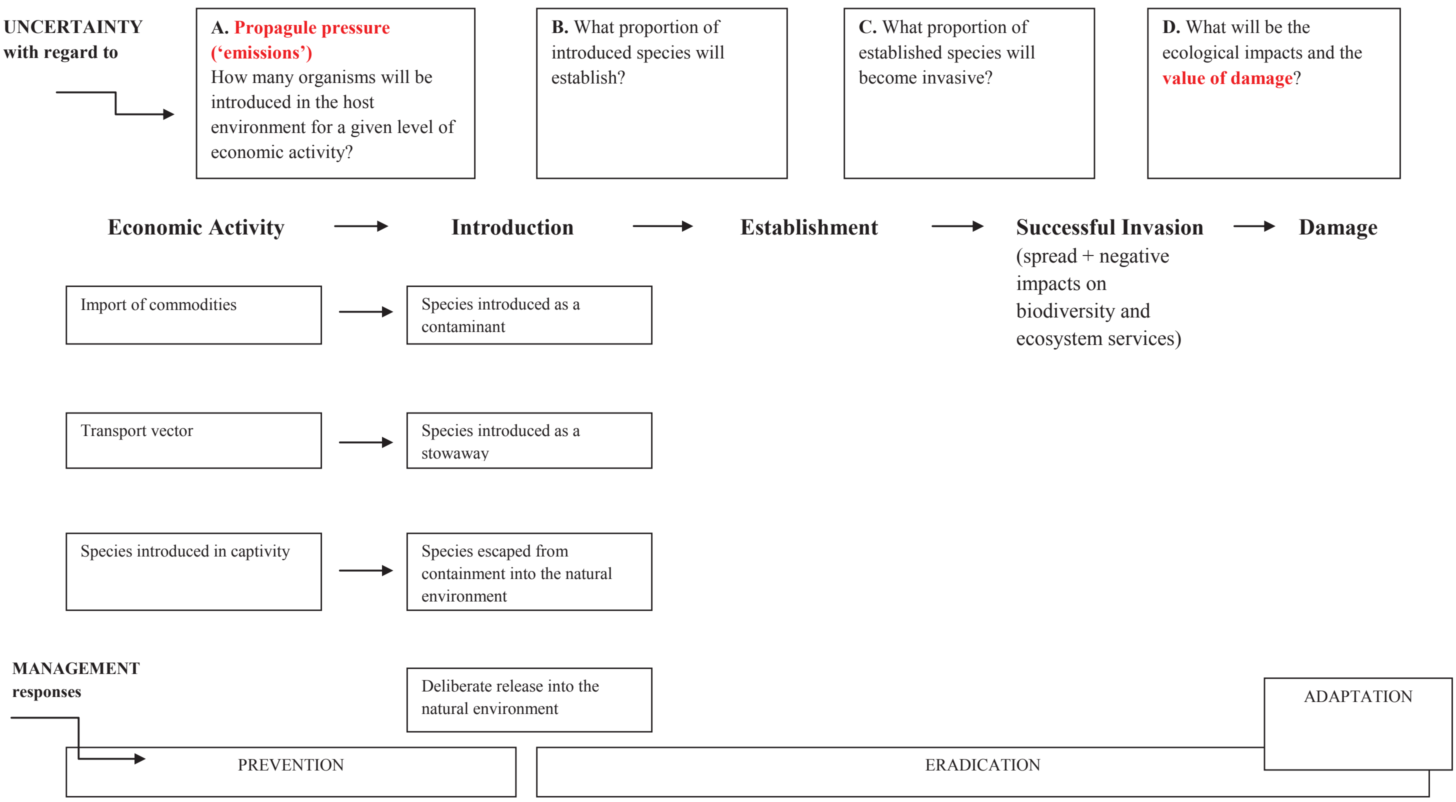
As with other externalities, the goal of invasive species control is to reduce their damage to an acceptable level. As discussed above, contrary to other emissions where the level of damage associated with a given flow or stock can be known with certainty, IAS management decisions will usually be formulated in terms of risk: what prevention measures are necessary (and optimal) in order to reduce the *likelihood* of damage to an acceptable level? Given that many alien species (or vectors thereof) have high economic value, the acceptable risk level will seldom be set to zero. For example, in the case of species introduced as contaminants on imported commodities, the vectors can rarely be eliminated, therefore “the general goal of risk management is usually to reduce the number of organisms transported to a level that leaves an acceptably low risk of invasion” (Keller and Lodge 2010, 229). Hence, the regulator sets an acceptable risk level and then has to work backwards through the different stages of the invasion process in order to determine which level of economic activity (import volumes of a commodity, frequency of use of ports by ships, etc.) corresponds to that risk level. In other words, the ultimate target is the (likelihood of) damage, but the specific prevention-oriented instruments would generally be aimed at reducing propagule pressure. Figure 3 illustrates the successive stages of the invasion process, the uncertainty regarding successful transition from one stage to the next, and the link between emissions and damage. The regulator needs to know the function linking the quantity of 'emissions' in box A to D.

Given the stochasticities associated with various steps of the invasion process, it is usually difficult to determine what level of propagule pressure guarantees a sufficiently low risk of invasion. Notwithstanding these complexities, proxies for propagule pressure, such as the amount of ship traffic, have proven to be good predictors of invasion success in certain situations (Lodge et al. 2006, 2044 and references therein).

Setting *economically-efficient* targets is even more cumbersome, since their identification requires knowledge of the functional forms and parameter values of the benefits and damages of pollution (or the costs and benefits of pollution abatement), not only near the current position of the economy, but across the whole range of possibilities (Perman et al. 2011, 230). Abatement costs comprise the benefits lost by preventing IAS introductions, as well as the cost of implementing prevention measures. While knowledge of the abatement costs of individual firms is not necessary, efficient targets cannot be determined in the absence of information about the aggregate emissions abatement cost function (ibid., 248).

As discussed above, the value of damages avoided through IAS prevention may be difficult to estimate. Invasive species are also a type of pollution whose damage function is usually non-convex (i.e. not increasing at an increasing rate) (Simpson 2010). Once the species has successfully invaded, further emissions (i.e. introductions of the same species) cause no incremental damage. Parallels can be drawn to other ecosystem processes involving threshold effects and uncertainty, such as lake eutrophication as discussed in Carpenter et al. (1999). Non-convexity of damage complicates the policy-maker's task in so far as "the equalization of marginal benefits with marginal costs [of control] may no longer be unique" (Perman et al. 2011, 174). This raises the information requirements of setting efficient targets, since "knowledge of the behaviour of costs and benefits over the whole domain of feasible values of emissions (or emissions abatement) is required, rather than just local information about relative magnitudes of costs and benefits in the neighbourhood of where the economy happens to be currently" (ibid.).

**Figure 4. Uncertainty regarding transition through the invasion process**



Given the uncertainties involved and the potential for large irreversible losses, the regulator will usually need to factor in other criteria than efficiency alone. For example, Bishop (1978) proposed that a 'Safe Minimum Standard of conservation' be applied to decisions concerning activities that pose a threat to biodiversity. The Safe Minimum Standard assumes that species extinctions are so costly that they warrant rejection of any activity that results in extinction. The reasoning behind this assumption is that, in a state of radical uncertainty, we cannot know what value humans may attach to any of the existing species in the future: "first, there is social ignorance about future preferences, needs and technologies. Second, there is scientific ignorance about the characteristics of existing species as they relate to future social possibilities and needs" (Perman et al. 2011, 473). In the IAS case, this would entail setting a risk target that is low enough to preclude invasions that may lead to extinction of native species. Some authors have suggested recourse to a modified Safe Minimum Standard, whereby the course of action that precludes extinctions should be adopted, except when it entails unacceptably high costs (ibid.). In the IAS context, this would imply, for example, a prioritization of pathways and vectors, such as accepting a higher risk threshold for alien species with very high economic value and/or which cannot be substituted with native species.

### 2.4.2 Who are the polluters who should pay?

Given that biological invasions are highly stochastic events and also involve time lags, linking damages to a specific polluter is seldom possible. For example, in the case of aquatic invasions introduced via the transport vector, the regulator cannot directly observe the quantity of vessel-specific emissions, nor determine which particular vessel is responsible for an invasion when it ensues (Jones and Corona 2007; Horan and Lupi 2005). This means that strict liability and economic instruments which require information on the amount of emissions associated with each polluter are not appropriate to tackle biological invasions, at least in the case of unintentional introduction pathways.

A number of authors therefore model biological invasions as a form of non-point source pollution and recommend instruments based on ambient pollution levels (Jones and Corona 2008) or a proxy for the quantity of polluter-specific emissions (Horan and Lupi 2005). Even in the case of instruments based on ambient emission levels, the discovery lag between introduction and observable damage implies that the wrong economic agents could be paying for current damage levels, hence the instrument might not create the right incentives (Jones and Corona 2007, 540). The proposed instruments are examined in more detail in the next chapter.

### 2.4.3 Implications for the choice and design of instruments

Problems with estimating invasion damages *ex-ante* make it difficult to determine the rate of an introducer-pays tax to be imposed at the time of introduction (Barbier et al. 2013, 134). Moreover, the magnitude of the tax would depend on the present value of expected damages incurred when the alien species becomes established (ibid.). The discounted damages would thus vary depending on the time between introduction and establishment, but the lag phase cannot always be predicted (ibid.). Perrings et al. (2010, 10) also highlight that discounting the avoided damage at any positive rate implies that costly prevention measures will be rejected, although the current costs of such measures may be low relative to the cost of future damage.

Uncertainty regarding the abatement cost function also affects the dependability of instruments. When the regulator does not know with certainty the location of the abatement cost function, the consequences of applying price-based (taxes and subsidies) and quantity-based instruments (licences and marketable permits) differ. The amount of abatement that would result from any given rate of an emissions tax will not be known with certainty, as it will depend on the unknown position of the abatement cost function (Perman et al. 2011, 234). Quantity-based instruments are dependable in terms of achieving a set quantity of abatement, but there will be uncertainty regarding the size of abatement costs (ibid.).

## 2.5. Decision-making in the face of uncertainty: Expected Utility and alternative decision frameworks

While most of the existing literature on the economics of invasive species management assumes that regulators have the information necessary to assign probabilities and treat invasion risks within an expected utility framework (Gren 2008, 22; Mehta et al. 2010, 454), a few authors point out that the uncertainty characterising invasions renders the application of such decision models inappropriate (Horan et al. 2002; Moffitt and Osteen 2006). A number of studies have pointed out that the maximisation of expected utility does not account for individuals' behaviour when faced with low-probability events involving large losses (Kahneman and Tversky 1979). The probability of very unlikely outcomes tends to be either overestimated or assumed to equal zero (Horan et al. 2002, 1304). Moreover, "the deviation of the perceived from the actual risk in these cases generally depends on the value of the outcome": individuals will seek to avoid outcomes associated with potentially catastrophic and irreversible losses, even when the probability attached to such outcomes is extremely low (ibid.).

Horan et al. (2002) apply Shackle's (1969) 'potential surprise' model to IAS pre-invasion control. In their model, it is not known which species, among the set of potentially invasive ones, will actually invade and the set contains some unknown elements. The perceived likelihood that a species will invade is not measured in terms of probabilities, but by a potential surprise function reflecting the level of disbelief, or the degree of surprise, that individuals expect they would experience should one of the alternative outcomes be realised (Horan et al. 2002, 1306). If an invasion does occur, the ensuing damages are also uncertain and hence characterised by a degree of potential surprise. The potential surprise associated with a particular level of damage is conditional on the potential surprise associated with an invasion occurring. When evaluating an action (e.g. whether to allow a vessel to enter a port), the decision-maker's attention will be drawn to "the least unbelievable conjectured losses or gains from the activity", referred to as the 'focus losses' and 'focus gains' (ibid., 1307).

This means that "low-probability extreme outcomes that are considered possible (low potential surprise) will be overweighted relative to an expected value approach". Consistently with a precautionary approach to irreversible high damage, more resources will be committed to avoiding such outcomes (ibid., 1309). On the other hand, "if catastrophic events have a high potential surprise, then such events do not factor into the focus loss even if the potential damages are high" (ibid.). The authors thus show that a decision framework based on potential surprise leads to a different valuation of the marginal costs and benefits of prevention measures (and hence a different choice of optimal strategy) compared to the expected utility approach.

# Chapter 3. The role of economic instruments in preventing biological invasions

Whereas traditional regulatory approaches (or 'command and control' instruments) impose particular forms of behaviour or technological choices on firms and individuals, economic instruments seek to alter the incentives faced by these agents such that "the best private choices can be made to coincide with the best social choice" (Tietenberg 1990, 17). By allowing agents the flexibility to select the best means of attaining the environmental goals set, economic instruments can in theory ensure that the goals are achieved at lower cost (ibid.). The use of economic instruments in the field of biodiversity conservation has received growing attention in recent years (see, for example, TEEB 2011; Bräuer et al. 2006; Vatn et al. 2011). This chapter considers the potential role of taxes, tradable permit schemes, environmental liability insurance, and environmental performance bonds in the context of invasive species prevention. These instruments have so far not been applied to IAS management, but a few theoretical explorations of their use suggest that they could be of interest, at least for certain introduction vectors. For each of the instruments considered, the main information requirements and key conditions for their applicability are outlined, and I examine whether the invasive species externality satisfies these requirements. Each instrument's potential applicability to invasive species is analysed with reference to the few existing studies that specifically apply the instrument to IAS, as well as the broader literature on analogous environmental problems.

In a next step, I discuss the likely performance of each instrument with respect to five evaluation criteria, namely: dependability (or effectiveness with respect to the target set), ease of monitoring and enforcement, efficiency and cost-effectiveness, flexibility or adaptability to changing knowledge and conditions, and whether the instrument has the potential to stimulate innovation in abatement technologies (or in other measures that may help prevention). Given that the level of information available and *a priori* applicability of each instrument varies, some instruments and criteria will be examined in more depth than others.

The chapter concludes with the results of a small-scale survey of IAS experts and stakeholders regarding the applicability and likely performance of these instruments, to complement the conclusions drawn from the current literature.

## 3.1. Taxes and charges

### 3.1.1 Principles and information requirements

The taxation of environmentally harmful activities was first proposed by the economist Cecil Pigou in the *Economics of Welfare* (1920). Pigou proposed levying a tax equal to the marginal external cost of emissions in order to reduce emissions to their efficient level (Common and Stagl 2005, 415). The tax rate that would bring about this level is determined by the intersection of the marginal abatement cost and the marginal damage cost functions of pollution. The tax creates an incentive to abate emissions since it becomes "profitable for firms to reduce pollution as long as their marginal abatement costs are less than the value of the tax rate per unit of pollution" (Perman et al. 2011, 197). By equalising the marginal abatement cost over all abaters, the aggregate target level of emissions is also achieved in a cost-effective way (ibid., 198).

In the absence of information on the marginal damage function, the environmental authority cannot identify the economically efficient target, but sets an 'arbitrary standard', i.e. an emissions target deemed as acceptable or sustainable according to the best of current knowledge (Common and Stagl 2005, 418). To determine the tax rate that would attain this target at least cost, knowledge of the aggregate marginal abatement cost function alone is sufficient (Perman et al. 2011, 198-199). If the environmental authority knew neither the location of the damage function nor that of the abatement cost function, it would not be able to determine what level of emission reductions would be induced by any specific tax rate (ibid.). Nevertheless, it could still select an arbitrary tax rate and be confident that some degree of emissions reduction would be achieved at the lowest possible cost (ibid.).

To be effective, the tax basis must be "as close as possible to the behaviour responsible for the targeted environmental damage" (OECD 2001, 90). It must also be possible for the regulator to monitor emissions so that sources do not attempt to reduce their tax burden via inaccurately reported emissions (OTA 1995, 122).

A distinction is often made between revenue-raising taxes whose primary purpose is to raise revenues to cover the cost of environmental services, and incentive taxes designed to influence behaviour (OECD 1997, 16; EFTEC and IEEP 2010, 33). Invasive species policies implemented to date in some countries have, to a limited extent, made use of the former in order to partly recover the costs of biosecurity measures. Taxes specifically designed to induce optimal decisions on the part of economic agents have only been considered at a theoretical level. The practical experience and theoretical explorations of this instrument in the IAS context are reviewed in the following section.

### 3.1.2 Applicability to invasive species regulation

In the context of invasive species policy, a tax or charge could be applied to several bases: the alien organisms introduced (if directly observable), commodities which may accidentally introduce invasive species, the purchase price of alien species that may become invasive (e.g. ornamental plants and pets), and inputs correlated with invasion risk (e.g. ballast water management practices). Alternatively, the activities likely to (unintentionally) introduce invasive species could be taxed (e.g. shipping, horticultural trade).

To date, taxes and charges have not been applied as an incentive instrument in the context of IAS policy, but several countries implement cost-recovery charges and fees for intentional and unintentional introductions (Sonigo et al. 2011, 120-127). For example, fees for inspections and border control are levied in Austria, Bulgaria, the Czech Republic, and New Zealand (ibid.).

Knowler and Barbier (2005) consider the use of a Pigouvian tax to internalise the expected social cost of invasions in the ornamental plants sector. The authors develop a model of a commercial plant breeding industry that establishes nurseries of an imported alien species at several locations within a region, until the marginal profit to the industry from an additional nursery becomes zero (ibid., 342). Imports entail the risk of invasion, but prohibiting sales altogether would involve the cost of foregone consumer benefits and industry profits (ibid., 341). Invasion risk is modelled as dependent on plant characteristics and the number of nurseries selling the plant. It is further assumed that once an imported plant turns out to be invasive, its sales are instantly terminated. The regulator's problem is to alter the importers' incentives so that the industry grows to its optimal size and no further, i.e. to a number "that balances the trade-off between the profits of the commercial plant breeding industry and the expected losses associated with the risk of accidental introduction" (ibid.).

The model requires information on the invasiveness of each plant, in order to specify a hazard rate function describing the probability that an imported plant will become invasive over time and at certain numbers of nurseries. The authors illustrate the model using data on saltcedar (*Tamarisk* spp.) imports in North America and experts' judgments on the plant's invasiveness. They analyse four different model specifications based on different functional relationships between the number of nurseries and the hazard rate of invasion, combined with different values of estimated damage. The results show that once the risk of invasion is accounted for, the optimal number of nurseries is always lower than the long-run equilibrium where no consideration is given to invasion risk (ibid., 352). Sales of the exotic plant should be prohibited when the expected social costs exceed the marginal profits from marketing the species, for all possible numbers of nurseries (ibid., 346). However, in many cases only a modest reduction in the number of nurseries is required. The level of the tax that induces the optimal industry size is shown to be highly sensitive to differences in the marginal hazard function (ibid., 352). Hence, in the absence of correct information on the latter, the policy-maker would be unable to set the tax at a level that produces the right incentives.

Barbier et al. (2013) assessed the stakeholder acceptability of an annual license fee imposed on the horticultural industry in North America, relative to alternative regulatory measures. Stakeholders involved in the invasive species problem – including professional horticulturalists, hobby gardeners, representatives of the agriculture industry, experts, and conservationists – were asked to rank five policy options aimed at preventing invasions via the horticulture sector, namely:

1) Mandatory listing and banning of exotic plant species known to have become invasive;
2) Mandatory screening to assess the likelihood that a newly imported species would become invasive and a ban on all species found to have a high likelihood of invasion;
3) Voluntary screening and ban of all newly imported species with a high risk of invasion;

4) A mandatory introducer-pays tax, proportional to the risk of invasion and imposed on the sale of a newly imported species identified through screening as a likely invasive; and
5) A mandatory fixed annual fee imposed without any prior screening on all exotic plant sales (ibid., 135).

The two market-based instruments received the least support from stakeholders. The authors suggest that this might reflect a lack of familiarity with the use of economic instruments to address invasives, but may also be due to an awareness of the practical difficulties involved in designing and implementing such policies (ibid., 137). In particular, estimating the introducer-pays tax or annual license fee requires accurate information on the lag phase between introduction and establishment, since "the fee's magnitude will depend on the present value of expected damages incurred when the exotic species becomes established in the host environment" (ibid., 133-134). Considerable uncertainty also surrounds the extent of expected damage, as it is difficult to predict the rate of spread and the total area to become invaded (ibid.).

McAusland and Costello (2004) examine the optimal mix of tariffs and inspections of commodities that are likely to carry invasive species. Expected damages are assumed to be linearly correlated with the volume of imports. Since the externality is caused by the contaminated commodities and not by all imported goods, the first-best approach would be to tax only the former. But this would require that all imports are first inspected, and inspections are costly and imperfect. The policymaker's task is therefore to strike the optimal balance between the two control instruments, i.e. to balance "the cost of additional inspections and more rejections of incoming goods with the benefits of fewer infected units making it past inspections" (ibid., 975). The importing country sets a tariff corresponding to the sum of expected damages from undetected contaminated goods plus the costs of inspections. The authors show that the relationship between the optimal inspection level and predicted infectedness of imports reverses after a certain threshold of infection rates: for low infection rates, the optimal level of inspections is increasing in the infectedness of received goods, it then decreases for intermediate levels of infectedness, and becomes zero for very high levels, i.e. it becomes optimal to impose only a high tariff (ibid., 975-976). Note that this effect is due to changes in the opportunity cost of rejecting a unit of imports: as more contaminated units are detected and hence denied entry, the domestic price of these commodities, and "hence the marginal value of the last unit rejected for import", is assumed to rise (ibid., 962).

Mérel and Carter (2008) show that a two-part tariff consisting of a uniform fee on all imported units to cover the costs of inspections and a fine levied on the contaminated units detected performs better than a single tariff designed to reduce the overall volume of trade. Assuming that contamination rates are endogenous, i.e. shippers have the necessary technology to clean their shipments in order to reduce the amount of contaminants introduced, the two-part tariff provides the right incentive for optimal abatement efforts.

Certain IAS pathways (such as unintentional introductions of organisms via shipping) can be treated analytically as a type of non-point-source pollution, i.e. "a form of pollution in which neither the source nor the size of specific emissions can be observed or identified with sufficient accuracy" (Xepapadeas 2011, 355). Two main characteristics of the non-point-source pollution problem render its regulation difficult. Firstly, there is an informational asymmetry between the regulator and the polluting agents: it is usually prohibitively costly to accurately measure the emissions of individual sources directly (ibid.). At best, the regulator can observe the ambient concentration of a pollutant in the receptor environment and it is impossible to attribute with certainty a portion of this ambient value to a particular polluter (ibid., 358). Secondly, the dispersal and accumulation of this type of pollution is subject to a number of stochastic influences, such as weather events and technological uncertainty (Xepapadeas 1992, 22). Hence, although emissions should ideally constitute the instrument base, this is not practicable in the case of non-point-source pollution (Shortle and Horan 2001, 255).

The regulator is thus left with three approaches to tackle the problem (Xepapadeas 2011, 359): design instruments based on inputs or practices correlated with emission flows[18] (Shortle and Horan 2001), apply instruments based on ambient concentrations (Segerson 1988; Xepapadeas 1995), or invest more resources (i.e. costly monitoring technologies) in order to observe individual emissions and thus turn the problem into a point-source type (Millok et al. 2002). In principle, each of the three alternatives could be pursued in the case of IAS.

Several lessons can be drawn from existing analyses of non-point-source pollution control. In the case of input-based instruments, first-best solutions would only be achieved if the unobservable emissions were perfectly correlated with measurable inputs, but in reality inputs can only be an imperfect substitute for emissions given the stochastic factors and informational asymmetries that enter the problem (Xepapadeas 2011, 359; Shortle and Horan 2001, 263).

Note that the problem is not necessarily specific to market-based instruments, but would also confront regulators in the case of uniformly applied standards. For example, several states and the IMO have mandated ballast water discharge standards that require vessels to treat ballast water prior to discharge so that the concentration of living organisms therein does not surpass a defined threshold (for a review of the various national standards, see Albert et al. 2012). However, compliance is in practice demonstrated by the installation of ballast water treatment systems on board, which are assumed to guarantee a certain level of treatment effectiveness. Port authorities can also attempt to measure emissions of live organisms directly by sampling the discharged water, but this is problematic given the potential inefficiencies and inherent stochasticity of sampling techniques (Frazier et al. 2013; Gollasch et al. 2007).

[18] A model applying a marketable permits scheme based on biosecurity inputs (Horan and Lupi 2005) is discussed in the next section.

The ambient pollution approach involves charging all potential polluters a tax per unit of deviation between the observed ambient level of a pollutant and the desired level of ambient concentration (Xepapadeas 2011, 360-361). Socially optimal abatement actions would be induced without the need for direct monitoring of individual sources' emissions. Nevertheless, the effectiveness and acceptability of such an instrument may be hindered by the fact that rewards and penalties would depend on group, rather than individual, performance (Shortle et al. 1998, 580; Xepapadeas 1995, 486). Given that ambient taxes are dependent not only on an individual polluter's abatement efforts, but also on the emissions of other sources and various stochastic parameters, a "firm's response to an ambient tax will depend on its own expectations about the impact of its choices, the choices of others, and natural events on ambient conditions" (Shortle et al. 1998, 580). Moreover, ambient levels may not reflect contemporary emission levels, but past actions, hence firms undertaking the correct level of abatement may still be penalized by the ambient tax, and vice-versa (ibid., 581). This is highly relevant in the case of invasive species, where considerable time lags characterise the successive stages of invasion.

Regarding information asymmetries, non-point-source pollution involves a moral hazard problem: since the actions of polluters cannot be perfectly monitored, they may misreport their level of abatement in order to increase profits (Xepapadeas 1991, 114). The most effective instruments would therefore be those that provide incentives for accurate monitoring and self-reporting on the part of polluters (Shortle and Horan 2001, 267). Xepapadeas (1995), for example, proposes a mix of ambient and Pigouvian taxes which would induce polluters to reveal their emissions and at the same time emit at the socially optimal levels. The author shows that, when ambient pollution concentration is subject to stochastic shocks, polluters would reveal their true emissions and pay the corresponding tax, in exchange for a reduction in the ambient tax.

The application of non-point source pollution models to the problem of biological invasions is illustrated by Jones and Corona (2008). Building on Segerson (1988), the authors propose a port-specific ambient tax to ensure that vessels undertake the optimal cleaning efforts to avoid introductions of invasive species through ballast water. As with typical non-point source pollution problems, it is impossible to directly link damage from invasives with specific vessels. Moreover, the probability of introduction cannot be perfectly linked by the policymaker to an observable vessel characteristic or management practice (ibid., 535). The shipper can invest in pre-entry management to lower the number of exotic species released into the port, but it is assumed that these cleaning efforts cannot be accurately monitored by the policymaker. The latter also cannot determine whether high population levels of an exotic species in the port's waters are due to high numbers of individuals released by vessels or favourable environmental conditions (ibid, 537). Given this uncertainty and information asymmetries, the only way to induce socially optimal cleaning efforts is to hold each vessel responsible for the entire damages of an invasion (ibid.). The policymaker need only be able to estimate the ambient concentration of pollution, i.e. the population size of specific alien species, by sampling port waters. The authors first consider the incentive mechanism proposed by Segerson (1988) – imposing on each vessel a tax based on changes in the ambient population of alien species in the port. Should the population fall below a threshold level, a lump sum subsidy is also paid to each vessel. The authors show that, while the instrument achieves socially optimal shipper behaviour in the short-run without the need for vessel-specific information, this does not hold in the long run (ibid., 538). To ensure long-run efficiency, the instrument should also induce the optimal exit/entry decision by vessels which, the authors show, can only be achieved with vessel-specific taxes and subsidies. Jones and Corona therefore propose adding a random exclusion mechanism to the Segerson mechanism: the policymaker will either impose an ambient tax (without any subsidy), or randomly choose one vessel from those wishing to enter the port and pay that vessel a subsidy not to enter.

A key assumption in the model is that the shippers can accurately estimate the effect of their abatement actions on ambient population levels. This might not necessarily be the case. Moreover, the polluters' incentives might be distorted by the discovery time lag characteristic of biological invasions: current population levels may reflect high levels of past introductions, rather than the contribution of current port users (ibid., 540). The authors argue, on the other hand, that this would not be a problem in so far as the same vessels or firms use the port repeatedly. It may also be too difficult for the regulator to measure the size of an exotic species population in the port, and/or to estimate the value of associated damage.

Fernandez (2008) considers a system of joint and several liability combined with taxes or subsidies to regulate two vectors of aquatic bioinvasions – ballast water and biofouling – on North America's Pacific coast, when damages are uncertain and there is information asymmetry between shippers and the regulating port. The regulator sets an optimal level of ballast water and biofouling emissions in the port and pays each vessel a subsidy per cubic metre of emissions. The value of the subsidy depends on the vessel's anticipated liability share for the damage that may result from an invasion, but the true anticipated liability is known only to the shipper (as it corresponds to its abatement efforts). In the absence of additional incentives, the shipper may report a false liability share in order to increase its expected profits (ibid., 313). In addition to the per-unit subsidy, the regulator therefore also pays the shipper a lump-sum subsidy, inversely related to the per-unit one. It is shown that this mechanism provides the right incentives for the shipper to reveal its true estimated liability share and to select the socially optimal level of emissions. The author also shows that a mirror-instrument, composed of a per-unit tax plus lump-sum tax, achieves similar results. The model is illustrated using reference values from previous studies on the costs of biosecurity measures, probabilities of invasion, and expected damage. The author also notes that the proposed policy is administratively feasible in the United States context and that the instruments could be implemented by adjusting some of the existing regulations and programmes (ibid., 316).

In some cases, tariffs designed to internalise invasive species costs may have adverse effects on the economy and the environment. Margolis et al. (2005) highlight the difficulties of distinguishing between tariffs aimed at reducing invasives and disguised protectionism. Costello and McAusland (2003) show that tariffs on agricultural commodities can in fact increase a country's susceptibility to invasions, if the price distortions induced by these measures result in an expansion of agricultural activity in the importing country.

These attempts at modelling the IAS externality and addressing it with price-based instruments suggest that there is scope for the use of incentive taxes in this field, but subject to the availability of information on key parameters. Imposition of a tax would make sense when the goal is to minimise invasion risk, rather than eliminate it. Setting the tax rate such that only an optimal number of introductions occur is likely to prove problematic in most cases, hence the instrument might not be dependable. For example, it has been noted that demand in the pet industry is very inelastic to prices (Kroeger 2007, cited in Perry and Farmer 2011, 137), and this is likely to hold for other sectors as well, such as horticulture and ornamental plant trade (but see Dehnen-Schmutz et al. 2007).

Observing the tax base (quantity of alien species introduced, biosecurity inputs, etc.) in order to charge the correct amount is also problematic in some cases. As Perry and Farmer (2011, 137) underscore, unless the tax is correlated with actual risk levels, its effect could be counterproductive: "the lowest cost operators most able to buy permits or pay taxes may also be among the riskiest practitioners, thereby crowding out the safest operators". In the context of pet trade, Perry and Farmer also argue that instruments applied at the point-of-entry will be ineffective in preventing invasions unless they also take into account the varying risk levels associated with agents' behaviour further downstream. For example, simply reducing the number of imported specimens of a given exotic pet is not sufficient, since the risk that the species will escape from containment depends on the actions of pet sellers and pet owners post-introduction (ibid.). This would also apply to other vectors such as aquaculture and ornamental plants, and illustrates the predictability problem specific to biological invasions: unlike 'conventional' emissions that are directly correlated with end damage, the link between propagule pressure and invasion damage is confounded by other risk factors intervening at different steps of the invasion process (see Figure 4 in the preceding chapter).

Taxes and fees calibrated according to risk levels have the potential to induce risk-reducing behaviour on the part of importers and users, provided that the risk level is correctly estimated. Perrault and Muffett (2002) propose levying a 'pathway user fee' proportional to the risk associated with each pathway. The authors do not set out the details of such a system, but note that the fee could be reduced if users, for example, demonstrate compliance with codes of conduct. Given the complexity of assessing and differentiating between risk levels, and of setting a fee that guarantees a specific level of risk reduction, it would probably be difficult to design the system such that a predetermined optimal aggregate level of risk is achieved. Nevertheless, fees modulated by risk level could provide incentives for operators to adopt certain best practices, so that some reduction in overall risk is achieved. It could be of interest, for example, in the shipping sector (to encourage uptake of effective ballast water treatment technologies), aquaculture (to encourage compliance with practices that diminish the risk of escapes onto neighbouring farms), horticulture, etc. As a revenue-raising instrument, the fees could contribute to a fund for covering the costs of eradication and rapid-response measures.

### 3.1.3 Expected performance

Dependability

If a particular target level of emissions (or risk) is sought, the degree of dependability is contingent on the accurate setting of the tax rate (OTA 1995, 122). It will generally be difficult to determine what level of propagule pressure guarantees a sufficiently low risk of invasion, and what tax or charge would reduce propagule pressure to the desired level. Moreover, targeted firms might not always respond to the incentive mechanism the way economists predict that rational economic actors would behave (ibid.). A tax on activities likely to introduce IAS might not sufficiently deter individuals from carrying out the activity, while an increase in the purchase price of alien species (such as ornamental plants and pets) might not affect consumers' demand for these products. In general, the appropriate tax rate could be determined by trial and error, however, continuous adjustments might not be politically and administratively feasible (ibid.).

Application of the instrument may, on the other hand, have a positive effect in terms of awareness-raising, for example by making buyers of horticultural products aware of the risk posed by the purchased species.

The instrument's effectiveness in preventing invasions also depends on how closely the taxed quantity is to the targeted goal (in our case, minimising the risk of invasion). A tariff on the volume of commodities that may harbour IAS is likely to be ineffective, since merely reducing imports of the commodity itself would not be close enough to the externality of concern. Moreover, as Costello and McAusland (2003) show, a tariff could in fact be counter-productive from a general equilibrium perspective, by increasing ecosystem invasibility in the importing country.

Taxes and charges would, however, have more appeal in terms of cost-recovery, as they could contribute to funds earmarked for biosecurity, eradication, and control measures.

Ease of monitoring and enforcement

In general, a tax instrument places relatively high burdens on the regulatory authority, who must predict how individual polluters will react to a given tax rate and how the predicted reductions in emission levels would affect media quality (OTA 1995, 181). This is all the more relevant in the case of invasive species, where the process linking species introductions to damage is complex and uncertainty is usually high.

In the case of an ambient tax, observing the ambient population levels of non-native species may be problematic. Data on the costs and accuracy of available monitoring and detection technologies would be needed in order to assess performance on this criterion more precisely.

In order to apply charges proportionate to the IAS risk levels of commodities and activities, the regulating authority would have to conduct pathway- or vector-specific risk assessments. However, some authors have noted that current data on transport-related pathways and some intentionally introduced species falls short of the information needed for a complete risk-assessment (Lodge et al. 2006, 2040). Improvements in risk-assessment methodologies and other data-collection efforts on IAS risks would thus facilitate implementation of this instrument (and of any other prevention tool, be it market-based or command and control).

Efficiency and cost-effectiveness

As discussed in Chapter 2, in most cases it would be impossible to determine the economically-efficient target, and hence calculate the tax rate that would achieve that target, for IAS prevention. In theory, taxes are a cost-effective instrument since they allow firms discretion over the level and means of abatement undertaken, but it is difficult to assess performance on this criterion in the absence of specific information on how the regulated actors would respond to the tax.

Adaptability to changing knowledge and conditions

Policy adaptability is an important criterion in the case of invasive species, where the perception of risk regarding a given species or pathway may change considerably over time. This may be due to new detections of IAS, revised risk assessments, improved means of eradication that may lead to a re-evaluation of expected damage, changes in the public's perception of an alien species' benefits and their willingness to accept a given risk level, etc. Such changes would trigger a reconsideration of the pollution target and/or of the contribution of a given pathway to this target. The tax rate or the tax imposed on a specific firm would need to be recalculated. It is difficult to estimate ex-ante to what extent this would be problematic. In general, tax instruments are considered relatively inflexible, since stakeholders tend to show resistance to changes in tax rates (Perman et al. 2011, 235).

Innovation

In general, taxes are perceived as dynamically efficient instruments, since they provide incentives for firms to develop abatement technologies in order to reduce their tax burden (Perman et al. 2011, 219). For certain pathways, the solution to biological invasions might not be technological in nature, but the potential for IAS-related innovation exists in some sectors. For example, ballast water treatment systems are being developed and a tax on ballast water discharges could further stimulate efforts in this regard. The shipping sector would have an incentive to develop treatment technologies with even higher effectiveness than that mandated by the current standards set by the Ballast Water Convention. A (risk-based) tax on intentionally introduced alien species would encourage the search for lower-risk substitution species. For example, in the horticultural sector plant breeders could develop alternative cultivars with traits that reduce or eliminate invasiveness (Anderson et al. 2006; Drew et al. 2010). Similarly, the aquaculture industry could develop technologies and facilities that mitigate the risk of escape or disease transmission.

Tax instruments that create incentives for introducers to accurately report their emission levels – such as those proposed by Xepapadeas (1995) or Fernandez (2008) and discussed above – would presumably also encourage the development of improved detection capabilities.

It is difficult to anticipate how the industry would respond to a tax and to what extent innovative forces could be harnessed by it, but in principle we may expect the instrument to perform well on this criterion.

## 3.2. Tradable emission permits

### 3.2.1 Principles and information requirements

Tradable permit schemes organise the exchange of rights to emit a particular pollutant into a receptor environment, or to use a given natural resource (Common and Stagl 2005, 426). The regulating authority establishes an aggregate pollution target or acceptable resource-use level – be it allocatively efficient or an 'arbitrary standard' – and distributes among potential polluters, or users of the resource, a number of permits corresponding to the target set. Each economic agent is only allowed to emit, or use, a quantity corresponding to its permit holding. Trading emerges when individual agents have different marginal valuations of the permit, due to differences in marginal abatement costs (Perman et al. 2011, 205). Firms with relatively high marginal abatement costs will seek to buy additional permits when the price is lower than the marginal cost of abatement, while lower-cost abaters will be motivated to sell some of their permits (ibid.). The incentive to reduce emissions arises from the fact that emissions generate an opportunity cost for the polluter: the firm incurs a cost by emitting an extra unit of the pollutant rather than selling its permit to another firm (ibid., 203). Tradable permit schemes are in theory both cost-effective and dependable (provided that there is adequate monitoring), and the regulator need not know the costs of abatement of individual firms (Common and Stagl 2005, 430).

In general, the following conditions must be met for tradable permits to perform as desired. The policy objective sought must be "quantitative or predictably linked to activities measurable by a limited number of flows" (OECD 2001, 84). The physical quantities constituting the permit base must be precisely specified, linked as closely as possible to the environmental objective set, and capable of being accurately measured or estimated and verified (OECD 2001, 24). Moreover, only pollutant units that represent equivalent risks and are thus fungible can be traded on a one-to-one basis (OTA 1995, 151). The most appropriate instrument base are emissions themselves, provided that "they can be metered and controlled deterministically" (Horan and Shortle 2011, 61). When this is not the case, an alternative emissions-proxy is traded, but these "must be reasonably accurate predictors of environmental impacts on the time and spatial scale selected for management" (ibid.). The regulator must be capable of monitoring emissions (or the alternative permit base) in order to verify that firms comply with their permit holdings (Commons and Stagl 2005, 430). There must be enough emitters in order for trading to arise and each must have the means to adjust its emissions level, otherwise there would be little gain from the use of a market-based instrument (OECD 2001, 85). There is little scope for trading permits if firms have similar abatement costs or no choice in practice over the means of meeting the targets imposed (ibid., 88).

As outlined in Section 3.1.2, non-point source emissions complicate the policy-maker's task, as they are highly stochastic and imperfectly observable (Horan and Shortle 2011, 63). Polluters cannot control their actual emissions with certainty, only the *probability distribution* of their emissions (ibid.). This implies that the tradable permits have to be denominated in terms of "emissions estimates constructed from observations on input and practices", for example compliance with certain agricultural best management practices (ibid.). This approach has been applied to water quality trading in several parts of the world, including the United States, Australia, Canada, and the Netherlands (Horan and Shortle 2011; Kraemer et al. 2003). Given the prediction errors involved in modelling emission estimates, there is considerable uncertainty over the actual outcome of individual trades; in other words, "the effects of trade on the ambient environmental conditions must be viewed probabilistically rather than deterministically" (Horan and Shortle 2011, 64). This raises the regulator's information requirements for designing a tradable scheme that ensures a given environmental goal is met (ibid.). As IAS introductions via certain pathways are comparable to the water quality problem, some of the findings from non-point-source pollution trading schemes are further explored in Section 3.2.3.

### 3.2.2 Applicability to invasive species regulation

Unlike other polluting substances, emissions of invasive alien species are generally unobservable under current monitoring technologies and therefore cannot be directly traded (Touza et al. 2007, 359). Instead of setting the amount of allowable emissions for the permit holder, IAS permits would have to be denominated in terms of the *probability* of an alien species introduction by a firm. This is analogous to permit trading systems designed for non-point sources of water pollution in which estimated emissions, rather than actual ones, constitute the instrument base (Horan and Lupi 2005, 291).

Horan and Lupi (2005) consider the application of a permit trading system to prevent aquatic invasions via ballast water in the Great Lakes of North America. In their model, the permit system is based on a performance proxy whereby emissions are estimated based on vessel characteristics and observable biosecurity measures undertaken by the shipper. The regulator sets an acceptable level of aggregate risk in the recipient environment and each vessel entering the port is required to hold a number of permits corresponding to the level of risk they add to this aggregate. The shipper cannot control with certainty the biomass of exotic species introduced, given the influence of stochastic variables (such as environmental factors), but the probability of a certain emissions level is conditional on biosecurity inputs and firm characteristics (Horan and Lupi 2005, 292). The probability that an introduction then leads to invasion and ultimately damage depends on the scale of the introduction and characteristics of the host habitat. The model assumes that the probability of an invasion via one firm is independent of introductions by other firms and invasions are treated as a Bernoulli event: an invasion is either successful or not. It is further assumed that the marginal damage of further invasions by the same species is zero (ibid.).

The authors first demonstrate that a first-best permit system would be too cumbersome to implement. The optimal solution would require different permits for each potential invader, since different IAS usually lead to different damage values. Moreover, since in reality the marginal environmental impact of a vessel's efforts to reduce the likelihood of invasion differs for each vessel, trading risk permits on a one-for-one basis would entail efficiency losses (ibid., 294-295). A first-best system would therefore require vessel-specific prices. The authors then consider a second-best system involving only one type of permit based on the probability of introducing *any* alien species and one-for-one trades between vessels. Even under this scenario, since "the complete state space and associated probabilities, for both potential invaders and potential damages from known and unknown potential invaders, cannot be identified ex ante," the efficient biosecurity measures that minimise the expected social cost of invasions cannot be defined before the event (ibid., 295). The authors therefore propose formulating the problem in terms of cost-effectiveness rather than efficiency and focussing on a set of target species for which the probabilities of invasion and associated damage can be discerned. Using data on the costs and reported effectiveness of various ballast water management technologies on precluding introductions of three target species, the authors compare the cost-effectiveness of the second-best permit trading system with that of three uniform technology requirements (ballast exchange, heat treatment, and filtration). While permit-trading always performs better than the command and control alternatives, the simulation results suggest that the cost savings are highly sensitive to the target risk level chosen by the regulator. The highest cost savings from a permit-trading scheme arise at intermediate levels of aggregate risk, which allow vessels to employ a mix of abatement technologies and various effort levels and therefore to exploit cost differences. At more stringent risk levels, however, vessels' abatement responses are limited, hence the gains from permit-trading are small and may even be outweighed by the higher transaction costs involved (ibid., 302).

Horan and Lupi's analysis shows that the information requirements for implementing such an incentive mechanisms are quite high, hence the instrument might not be practicable in certain real-world situations involving invasive species. The regulator would need to know the risk of introduction and invasion when no abatement measures are taken by the firm, the effectiveness of different biosecurity measures and technologies in reducing this risk, and the aggregate costs of biosecurity measures. Furthermore, the regulatory agency must be capable of perfectly monitoring the abatement efforts undertaken by each vessel, in order to check compliance with the risk allowance defined by the permit.

The instrument's effectiveness in preventing invasions ultimately depends on the identification of a permit base that is sufficiently correlated with risk levels and not prohibitively costly to observe.

Notwithstanding these limitations, the ballast water vector appears to lend itself well to the use of a tradable permit scheme, and the instrument could be considered in the context of the international ballast water regime. The International Convention for the Control and Management of Ships' Ballast Water and Sediments requires all commercial vessels engaged in international traffic to exchange a minimum of 95% of ballast water volume mid-ocean. Ballast water exchange was agreed upon as an interim solution, given its limited effectiveness in reducing introductions and the fact that the requirements set forth in the Convention (in terms of water depth and distance from shore) cannot be met on all shipping routes (Gollasch et al. 2007, 588). A more stringent standard would be phased in over a certain period of time, requiring that the concentrations of living organisms in the ballast water discharged be below specified limits (ibid., 587). In practice, the standard is met by requiring ships to install type-approved on-board ballast water treatment systems that are thought to guarantee the concentration threshold. The standard is believed to significantly reduce propagule pressure compared to untreated water or following ballast water exchange, but some scientific controversy remains over its adequacy in reducing invasion risk to an acceptably low level (see, e.g. Albert et al. 2012; Gollasch et al. 2007). Port authorities may carry out inspections to detect violations of the standards, and even sample ballast water to directly determine the concentrations of living organisms discharged.

Essentially, the Ballast Water Convention is a command-and-control instrument that sets uniform standards across vessels, subject to a limited number of exceptions. Arguably, its objectives could also be attained, potentially at lower cost, with the aid of a tradable permit scheme. Instead of mandating the same concentration-based discharge limits for each vessel, a number of discharge permits summing up to the target level of propagule pressure could be distributed among shipping firms. Shippers would thus have more flexibility to allocate the reduction burden among themselves based on differences in abatement costs. There is evidence that vessels have different abatement costs, and a range of treatment technologies are available (see, e.g. King et al. 2012). Vessels could utilise Ballast Water Treatment Systems with different levels of effectiveness in terms of eliminating living organisms, provided that the organism concentration ensured by that technology corresponds to the number of permits held.

Before phasing in the concentration standard, a tradable permits scheme could also apply to ballast water exchange: instead of imposing the 95% volume standard for each vessel, a system of tradable ballast water shares could be adopted. Vessels that can retain ballast water or treat it on-board could then sell their discharge allowances to those for whom it is too costly to exchange 95% of ballast water (Shine et al. 2008, cxxiii). However, further cost information would be needed in order to assess whether such an instrument would indeed be preferable to a uniform standard. For example, the transaction costs involved are likely to be high.

Two stakeholders from the shipping industry consulted in the framework of this project – the European Sea Ports Organisation and the World Shipping Council – stressed that, in their opinion, market-based instruments would not be an appropriate solution to prevent biological invasions via ballast water and biofouling.

Biological pollution is also a type of damage that depends on the location of emissions, hence permits have to be specific to the receptor environment. Basing the permit scheme on ecological features means that it might have to be enacted and administered by several national jurisdictions.

At a theoretical level, tradable permits have also been considered in the context of agriculture. Richards et al. (2010) compare a system of taxes with a tradable permit scheme to prevent the spread of agricultural insect pests. Pests cause harm to the farms on which the invasion occurs, but also to adjacent farms once the insect population grows and migrates. In the absence of other incentives, each farmer controls pests "until the marginal value of damage inflicted on his or her own crops is equal to the marginal cost of control, including future growth on the grower's own land," but does not take into account damage to other growers when the insects begin to spread (Richards et al. 2010, 355). To ensure optimal control, the regulator can apply a grower-specific tax on the population of insects measured on each farm, or set a limit on the insect population at each location and allocate permits which the farmers can trade among themselves.

The authors extend Stavins' (1996) findings on the relative performance of quantity- and price-based instruments when cost and benefit uncertainty are correlated. In the case of invasive insects, both the benefits and costs of abatement are uncertain and a function of the biology of insect movement, which in turn depends largely on weather events (ibid., 357). Hence, the authors show that Stavins' (1996) results hold for the problem of invasive insects and a system of permits would be more efficient than a tax instrument.

The information requirements of their model are high, given that the proposed tax or permit system is location-specific. Information on the likely damage, cost of control, and several ecological parameters such as the insect's population growth and dispersal rate would need to be known in order to determine the tax or total allowable insect numbers. The authors note, however, that most crop growers already monitor insect infestations and that further regulation would likely encourage the development and reduce the cost of advanced monitoring technologies (ibid., 365). Further research would be needed to determine the likely relative influence of taxes and permits on the development of innovative pest management technologies (ibid.).

Tradable permits would be impracticable for a number of pathways. For example, there is little scope for applying the instrument to intentional introductions of species that may escape or serve as transport vectors for other organisms. In theory, we could apply the same reasoning as to ballast water and organise a trading system based on commodity-specific risk levels. The risk levels would be a function of the management practices adopted by firms in order to reduce the risk of a species escaping containment, or of carrying and spreading other IAS. However (in contrast to ballast water treatment where some data on effectiveness is available), we lack quantitative information on how various practices or technologies in horticulture or aquaculture affect the risk of causing an invasion. Essentially, tradable permits would not work in a situation of uncertainty (as opposed to risk), where we cannot even estimate the probabilities that could constitute the permit base.

### 3.2.3 Expected performance

Dependability

In theory, tradable permit schemes will be effective with respect to environmental goals, provided that the permit base is sufficiently correlated with the target set and can be accurately measured, in order for the regulator to verify a firm's compliance with the permit holding. In the context of invasive species, emissions themselves (organisms introduced) cannot be directly traded, so permits would be denominated in terms of an emissions proxy. If what is traded is, essentially, 'units of risk', the scheme's effectiveness depends on the correct assessment of risk levels associated with each commodity or activity, and a correct estimation of how individual risks of introduction contribute to the aggregate risk of an invasion in a given receptor environment. As in the case of non-point source water pollutants, the uncertainty involved in modelling the effect of management practices (or other performance proxies) on an individual source's emissions (species introductions) and, in turn, the contribution of individual emissions on aggregate pollution levels, is compounded by the effects of stochastic factors. The models proposed in the existing literature rely on a number of assumptions concerning the relation between propagule pressure and invasion risk, the effectiveness of various abatement measures, and the role of stochastic factors, which may not necessarily be verified in practice.

For the ballast water vector, risk levels correlated with the treatment practices applied could be used as an 'emissions proxy' representing the permit base. However, there is considerable uncertainty regarding the effectiveness of currently available treatment systems (World Shipping Council, pers. comm.), so they might not be a reliable proxy for actual reductions in non-native introductions.

As in the case of tax instruments, improved risk assessments and reliable data on propagule pressure and the effectiveness of various abatement measures could improve the instrument's performance on this criterion.

If it were possible to accurately measure IAS emissions directly (e.g. the concentration of living organisms discharged with ballast water), we could also envisage a system in which emissions themselves are traded.

Efficiency and cost-effectiveness

A system of tradable permits will in principle be cost-effective, but the cost savings depend on the heterogeneity of abatement costs among firms and the availability of alternative abatement measures. Horan and Lupi's (2005) analysis shows that the relative advantage of tradable permits over command and control regulations is highly sensitive to the target set. Moreover, Horan and Lupi show that a first-best system would involve species-specific permits, but it would not be practicable to design and implement such a system.

Furthermore, in the context of water quality trading, Horan and Shortle (2011) show that, in contrast to the 'textbook example' of point-source emissions trading, the regulator cannot design cost-effective emissions markets without information on the abatement costs of individual polluters. This arises from the fact that compliance is judged based on a firm's mean estimated emissions, without regard to the variability of emissions. The water quality goal, on the other hand, depends on emissions variability. The authors show that in this case ecological information would no longer be sufficient to set the appropriate trading ratios between two sources; the regulator will need firm-specific cost information to predict how firms will respond to different trading ratios (Horan and Shortle 2011, 64-65). This would probably hold in the case of IAS, too.

More generally, experience with tradable permits implemented for various types of pollutant shows that most programmes have in practice not achieved all the cost savings predicted by theory (Friedman et al. 2000, 376). Theoretical estimates of cost-savings presume that trading takes place until the economically efficient allocation of emissions control is achieved, but some programmes gave rise to only limited trading, or even no trades at all (ibid.). It is difficult to predict the extent of cost-savings that would result from a tradable permits scheme applied to IAS.

Ease of monitoring and enforcement

As illustrated above, the information requirements for implementing this instrument are likely to be very high. The regulating authority needs to estimate what level of aggregate propagule pressure corresponds to an acceptable risk of invasion, identify an adequate performance proxy correlated with propagule pressure, and assess the (reduction in the) probability of introducing alien species associated with different management practices. Observing management practices in order to monitor compliance with the permit holding might also prove impracticable. In general, tradable permit schemes are appealing partly because they reduce the need for the regulator to identify optimal control technologies or other practices (Friedman et al. 2000, 37), but a system where permits are denominated in terms of performance proxies does not entirely eliminate this burden, since the regulator needs to assess the effectiveness of various practices in reducing invasion risk.

Adaptability to changing knowledge and conditions

Tradable permit schemes are often applauded for their flexibility compared to other instruments since they allow firms the leeway to adapt their strategies (Friedman et al. 2000, 375). However, a system that is complicated to establish might be politically difficult to modify (OTA 1995, 188). This is all the more likely in the case of IAS, where permits would be denominated in terms of risk levels rather than direct emissions.

Innovation

The discussion of innovation in the context of taxes also applies, *mutatis mutandis*, to tradable permits. The instrument should in theory promote innovation, as firms with high marginal costs have an incentive to innovate to reduce their emissions instead of buying permits (OTA 1995, 194), but it is difficult to estimate to what extent this expectation will hold in the context of IAS prevention.

## 3.3. Liability Insurance

### 3.3.1 Principles and information requirements

The role of insurance in the management of environmental risks has been long recognised, both in the theoretical literature and in existing legislation. In line with the polluter-pays principle, environmental liability provisions require agents who carry out activities that result in environmental harm to remedy the damage or to compensate the harmed party to the extent of the damage (OTA 1995, 123). Agents at risk of incurring liability for the consequences of their activities would contract insurance to cover potential costs. Insurance thus "involves a choice to incur a small and certain loss (the premium) now in exchange for not being exposed to a larger, uncertain loss in the future" (Bergkamp 2003, 270-271). Insurance companies are willing to undertake the risk in exchange for an insurance premium since the law of large numbers enables them to manage such risks effectively, by making predictable the claims they would have to pay (OECD 2003, 14). The larger the number of insureds pooled together, the more closely the incurred losses will match the underlying probability of loss (ibid.).

A liability insurance regime pursues the twin goals of compensation for pollution-caused damages and deterrence of activities that may cause pollution in the first place (OECD 2003, 23). The latter function arises from the risk-segregation inherent to insurance: the insurer defines risk pools and sets premiums corresponding to the risk level of the average member of the pool (Bergkamp 2003, 271). If preventive actions result in a reduction of the premium, the insured has an incentive to undertake them (Faure 2001, 15). Very high-risk individuals who would be required to pay an extremely high premium may be unable to contract insurance at all and thus deterred from engaging in the respective activity (Bergkamp 2003, 271). The insurer also engages in 'risk remodelling' by monitoring the insureds' activities and actively aiding the insured to enhance loss prevention (OECD 2003, 45). Insurance is therefore said to function as a form of 'surrogate regulation' (Abraham 1988, 954).

Not all risks are, however, insurable and a number of criteria for assessing insurability have been put forward. According to a review by the OECD (2003), these include:

1) Assessibility

The insurer must possess accurate information on the probability that the insured event will occur and the possible magnitude of associated damage in order to calculate the actuarially fair premium (Faure 2001, 5-6). The expected loss must be quantifiable in monetary terms (Bergkamp 2003, 272). If the uncertainty surrounding these probabilities is excessive, an insurer may be as risk-averse as the insureds because it cannot estimate its likely success in diversifying risk through pooling, nor determine the correct premium (Abraham 1988, 946-947). Some degree of uncertainty is, however, acceptable, and in the absence of reliable statistics, the insurer can take uncertainty into account by charging an additional risk premium (Faure 2001, 7).

2) Randomness

This criterion refers to the actual occurrence of the event, whose timing must be unpredictable and independent of the insured's will (OECD 2003, 16). The insured risks must be statistically independent (Bergkamp 2003, 272). Risks that do not have a sufficiently probabilistic character – i.e. where damage will occur with certainty – are not insurable (ibid.).

3) Mutuality

A risk community made of a large number of persons exposed to a given risk must exist, in order for the risk to be shared and diversified (OECD 2003, 16)

4) Economic feasibility

The insurer must be able to charge a premium proportionate to the insured risk (ibid.).

Liability insurance usually covers accidental discharges and hazards, not so-called gradual pollution, since the latter tends to be either expected or intended by the insured (Abraham 1988, 953). The OECD report further notes that an environmental liability regime should not cover historic pollution, pollution for which a causal link to the responsible party cannot be established, and the cumulative effect of authorized emissions (OECD 2003, 51).

Informational asymmetries between the insurer and the insured give rise to two problems that hinder the effectiveness of insurance: adverse selection and moral hazard. The former refers to a situation where the demand for insurance is higher for higher-risk individuals and the insurer cannot reflect this correlation in the risk premium (Faure 2001, 10). Moral hazard denotes the increase in the probability of loss following the purchase of insurance, since the deterrent effect of being liable to pay compensation in case of an accident is removed from the policy-holder (ibid., 8). While adverse selection and moral hazard can to some extent be circumvented by a variety of monitoring and bonding devices, certain risks will be characterised by 'generalized uncertainty': both the insurer and the insured may have incomplete information about the probability and magnitude of expected losses, and the risk can therefore not be properly evaluated (OECD 2003, 17).

When multiple polluters are involved in the same environmental accident, they can be held jointly and severally liable for the damage. Joint and several liability presents an advantage from the perspective of compensation, but may undermine the deterring function of liability mechanisms and the ability of insurers to properly evaluate the risks posed by their prospective customers (OECD 2003, 24-25).

At EU level, the Environmental Liability Directive[19] establishes a common framework for liability regarding direct and indirect damage to the aquatic environment, biodiversity in Natura 2000 areas, and land contamination posing a risk to human health. The directive covers diffuse pollution in so far as a causal link can be established between the damage and a particular polluter (EEA 2006, 38). It establishes a strict liability regime[20] for an exhaustive list of occupational activities and a system of fault-based liability for all other activities. The directive does not make financing mechanisms such as liability insurance mandatory, but requires member states to encourage the development of such instruments.

### 3.3.2 Applicability to invasive species regulation

A report for the European Commission considering policy options for an EU legislative framework on IAS suggests extending the scope of the Environmental Liability Directive to activities presenting a high risk of introducing invasive species, and applying a general duty of care concerning IAS to all other activities (Shine et al. 2010, 154). Invasive species present, however, specific constraints that render the application of liability instruments less straightforward.

The Environmental Liability Directive explicitly recognises that for a liability mechanism "to be effective, there need to be one or more identifiable polluters, the damage should be concrete and quantifiable, and a causal link should be established between the damage and the identified polluter(s). Liability is therefore not a suitable instrument for dealing with pollution of a widespread, diffuse character, where it is impossible to link the negative environmental effects with acts or failure to act of certain individual actors" (Directive 2004/35/EC, Recital 13). As discussed in the preceding sections, the difficulties – and in certain cases, impossibility – of tracing invasions back to a particular source of introduction render liability laws ineffective. Moreover, given the significant time lags

[19] Council Directive 2004/35/EC on environmental liability with regard to the prevention and remedying of environmental damage
[20] i.e. an agent can be held liable despite having used reasonable care in the conduct of its activities

between introduction and invasion, the potential for 'orphan liability', arising when the polluter is no longer in operation, is high.

A further constraint is that biological invasions via unintentional pathways are often generated by the repetitive actions of several agents. For example, ballast water discharges and regular transport and trade generate propagule pressure which eventually results in successful invasion when the population of an alien species in the receptor environment is sufficiently high and other biotic and abiotic factors favour establishment and spread (as discussed in Chapter 1). It would be problematic to establish causality, and hence liability, for these pathways. Joint and several liability may be a possible solution; for example, all vessels using a port could be held liable in the event of an aquatic invasion.

For cases where the introduction pathways and vectors can be identified with precision, liability provisions would ensure that the introducer is held responsible for the damage caused. Liability would be mainly applicable to intentional introductions, i.e. the introducer would be held responsible for subsequent escapes from containment, such as aquaculture facilities, horticultural nurseries, ornamental and pet retail centres. The most high-risk activities could be determined via risk assessment and brought under the scope of national liability provisions. This may raise, however, disputes over which sectors should be targeted. The specific legal provisions would have to clarify which economic agents, at which point in the import and distribution chain, are to be held liable for eventual damage.

A review of existing IAS policies in the EU found that no member state had fully established liability mechanisms to enforce responsibility, accountability and negligence with regard to invasive species damage (Sonigo et al. 2011, 142). Some IAS-related liability requirements were identified in a few member states, such as provisions in Spain and Lithuania regarding invasive plants cultivated without a permit (ibid.). In Belgium, legislation is in place for the prevention and remediation of damage resulting from the transport of non-indigenous species (Shine et al. 2010, 154).

Provided that a liability framework for invasives-related damage is put in place, would the risk of biological invasions be insurable? In most cases, the uncertainty surrounding biological invasions is higher than for other environmental hazards and insurers would not have sufficient data to construct the probability distribution of expected losses. As discussed in Section 1.4, quantifying the expected damage is also extremely challenging, both because the range of possible outcomes cannot always be defined with certainty, and due to the inherent limitations of estimating the monetary value of biodiversity and ecosystem services. At the same time, growing demand for IAS-related coverage would stimulate further development of risk assessment methodologies and the insurance industry would have an incentive to gather data that would be useful beyond the sector, in other areas of IAS regulation. As Katzman (1988, 82) underscores with regard to insurance for chemical releases, "competitive pressures among insurers result in continual improvements in the art of risk analysis.

Unlike government bureaucrats, insurers may lose business if they overestimate risks and set premiums too high.”

Hogarth and Kunreuther (1985) show that the level of uncertainty concerning potential losses affects agents’ willingness to pay for or to offer insurance: for low-probability but potentially large losses, insurers demand a risk premium that makes the rates exceed the expected losses substantially, while the insured are willing to pay a lower premium than suggested by expected utility calculations (Horan et al. 2002, 1304). This implies that an insurance market for low-probability catastrophic events would be unlikely to come into being voluntarily (Katzman 1988, 86), hence insurance should be made mandatory for industries likely to introduce invasive species.

The effectiveness of any legislative requirement for economic operators to insure against the risk of causing invasions will ultimately depend on the response of the insurance sector and the availability of IAS-related cover. With regard to environmental risks in general, an assessment of the market for environmental liability insurance in the EU reports that insurance products for most activities covered by the Environmental Liability Directive are available (Munchmeyer et al. 2009, 52). A main gap reported was coverage for gradual pollution, with insurers citing lack of data and the inability to quantify potential losses among the reasons for not insuring this type of damage (ibid., 58). In the case of insurance for IAS risks, a mandatory requirement would create demand on the part of operators, and it can be expected that the insurance industry would respond by developing appropriate insurance products, provided that the risks in question meet the minimum criteria for insurability.

### 3.3.3 Expected performance

Dependability

A liability regime does not prohibit pollution as such, but merely requires the polluter to provide compensation for the harm caused (OTA 1995, 128). The effectiveness of liability in preventing invasions therefore depends on whether the threat of financial exposure has a sufficiently deterrent effect on the introducer of non-native species. Insurance against IAS-related risks may engender moral hazard, rather than more responsible behaviour on the part of an economic agent. Variable premiums may, however, provide an incentive for agents to minimize their risk in order to benefit from cheaper coverage. Effectiveness will also depend on the extent of ‘risk-remodelling’ that insurers can engage in, by providing incentives and support for the ensured firm to reduce risky behaviour.

Provided that causation can be established, insurance guarantees that funds are available for eradication and ecosystem restoration in the event of invasion. However, the actual damage could exceed the upper limit of the insurance cover and it would not alleviate the problem of irreversible damage to biodiversity.

Ease of monitoring and enforcement

The main obstacles to the enforcement of a liability insurance scheme are likely to be the difficulty of establishing causation in the event of an invasion and the potentially long time lags between a species' introduction and invasion.

The requirement for mandatory insurance would probably be relatively easy to enforce; for example, permits for introducing an alien species or the issuing of a licence to operate (e.g. in the aquaculture or horticulture sector) could be made conditional on the contracting of an insurance cover.

Efficiency and cost-effectiveness

Performance on this criterion is difficult to estimate ex-ante. Cost-effectiveness will ultimately depend on the insurers' ability to estimate the likelihood and magnitude of damage and to set the correct risk-differentiated premiums, and on how agents introducing alien species respond to the risk of incurring liability.

Adaptability to changing knowledge and conditions

To the extent that premiums can be recalculated in light of revised risk assessments and the emergence of new evidence concerning risks, insurance is a flexible instrument compared to other policy tools. On the other hand, it might be more difficult (at least politically) to revise the list of sectors and occupational activities that are subject to a compulsory-insurance requirement.

Innovation

As noted above, the insurance industry has a potentially important role to play in the development of risk assessment and reliable data concerning IAS pathways and specific economic activities. To the extent that risk-segregation, variable premiums, and risk-remodelling function correctly, insurers can also encourage the development of risk-minimising technologies.

## 3.4. Environmental performance bonds

### 3.4.1 Principles and information requirements

An instrument specifically aimed at internalising the uncertain environmental costs that may arise from an activity is the performance bond (also referred to as an 'assurance bond'). Under the scheme, each firm about to undertake an activity with possible adverse effects on the environment is required to post a financial bond equal to the maximum conjectured damage. The bond would be returned to the firm if it demonstrates that damage has not occurred or was lower than anticipated (Constanza and Perrings 1990, 65). Should damage occur, a corresponding amount of the bond is forfeited to cover the costs of rehabilitation or to compensate the injured parties (Kysar 2009, 142). The value of the bond corresponds to "the environmental authority's best estimate of the worst outcome of any given activity, given the state of knowledge at the date the bond was struck or reappraised" (Constanza and Perrings 1990, 66). This would not necessarily be the worst outcome imaginable, but the activity's 'focus loss' as discussed in the preceding chapter: "the least unbelievable of those costs of an activity to which the decision-maker's attention has been drawn for whatever reason" (ibid., 67). The instrument is intended as a complement to liability rules and addresses the latter's shortcomings. In particular, liability alone does not prevent the polluter from escaping financial responsibility via dissolution or bankruptcy (Boyd 2001, 9).

Note that the scheme is to be applied to activities for which reliable data to compute the probability distribution of potential damage does not exist. Where the range and probability of outcomes are known, Constanza and Perrings (1990, 65) underscore that commercial insurance should be available instead.

The actual financial instrument employed could take several forms, including collateral bonds such as cash deposits, certificates of deposit, letters of credit, or security pledges, 'self bonds' consisting of "legally binding promissory obligations from regulated entities", and surety bonds (a "guarantee from a third party to either perform the defaulted obligation or pay funds to the regulating agency") (Kysar 2009, 142-143).

The instrument's main information requirement is knowledge of the worst-case plausible outcome and the possibility of assigning a monetary value to it. The regulator must also be able to assess the damage or absence thereof once the activity has ended or at a date set in the bonding contract. However, the burden of proof is shifted from the regulator onto the promoters of risky activities, as advocated by proponents of the precautionary principle (Kysar 2009, 142). It is the firm's responsibility to provide evidence of the likely damage *ex-ante* and of the actual damage or lack thereof *ex-post*. The bond would also be reduced during the life of the project or other economic activity if the environmental authority's estimate of the worst case outcome is revised downwards (Constanza and Perrings 1990, 65). Under the scheme, firms would therefore have a high economic incentive to improve the accuracy of the damage forecasts and to take actions that minimise the expected damage in order to benefit from a lower bond. The scheme is believed to be "minimally intrusive into the internal operations of the regulated industries", while at the same time ensuring that industries internalise the social cost of their activities and minimise uncertainty about these costs (Constanza and Perrings 1990, 72). As Kysar (2009, 142) underlines, however, the degree to which the burden of proof is actually shifted depends on the specific details of the bonding contract: "what threshold of scientific plausibility for a worst case scenario would the agency need to demonstrate during the initial stage of establishing the bond requirement? Which actor, according to what standard of proof, would need to show that a posted bond could be returned or reduced as information develops suggesting that the threat was less severe than initially feared?"

The liquidity constraints faced by the regulated firm may hinder the instrument's effectiveness. In particular, too large a bond may over-deter activity and over-restrict a firm's capital for production or research if a large fraction of the firm's borrowing capacity has been used to post the bond (Shogren et al. 1993, 116-117). Moreover, the actual damage may still turn out to be higher than the maximum possible loss estimated *ex-ante*, in which case the bond would not be sufficient to restore the site to its prior condition or compensate affected parties (Common and Stagl 2005, 432).

To date, there has been little experience with environmental performance bonds in Europe (EFTEC and IEEP 2010, 39), but the instrument has been applied to a variety of operations in the United States and Australia, including surface coal mining, offshore oil and gas installations, oil shipping, hazardous waste treatment facilities, and nuclear plants (for a review, see Shogren et al. 1993, Boyd 2001). At a theoretical level, the applicability of bonds has been examined in the context of water quality (Weersink and Livernois, 1996), agricultural non-point source pollution (Shogren et al., 1993), hardrock mining (Gerard, 2000), carbon capture and storage projects (Gerard and Wilson 2009), coal mining (Shogren et al., 1993), and nanotechnology (Kysar 2009).

Shogren et al. (1993, 121-122) specify several conditions for bonds to perform well in environmental regulation:

1) The possible outcomes of the regulated activity are known and a value can be placed on the 'focus loss' scenario;

2) The environmental damage should be observable to the regulator, in order to compare it to the costs conjectured ex-ante and avoid moral hazard;

3) The administrative costs are lowest and the regulator can easily identify the guilty party when there are few agents potentially causing damage;

4) There is a limited time horizon, by when the regulator can discern whether the activity has or has not caused damage;

5) The possible outcomes ('states of the world') are known;

6) The activity has no irreversible effects;

7) Given the problem of liquidity constraints, the bonding mechanism is easier to implement when the worst-case outcome has a relatively low value.

These conditions are discussed below with regard to invasive species, after reviewing the few existing studies that specifically examine the applicability of bonds to activities that may cause bioinvasions.

### 3.4.2 Applicability to invasive species regulation

Thomas and Randall (2000) examine the decision of whether to allow introductions of an exotic species as an optimal trade-off between *information* regarding a species' invasive potential and *revocability* of the introduction should the species turn out to be invasive. In most cases, the regulator would have neither perfect information to screen out invasives with certainty *ex-ante*, nor the possibility of full *ex-post* revocation of its decision to allow a harmful introduction (ibid., 334). The model is particularly relevant for intentional introductions of species that may subsequently escape containment. Current permit and risk-assessment protocols focus on reducing uncertainty, but the necessary information tends to be costly to generate and may prove unreliable (ibid.). Thus, many potentially beneficial introductions are prohibited, or the importer does not undertake the optimal level of care post-introduction. The authors show that the posting of an environmental bond equal to the costs of full revocability (i.e. of returning the host environment to its pre-introduction status) would encourage the importer to take the necessary actions for avoiding damage.

Similarly, Fernandez (2011) considers the use of environmental bonds to reduce the threat of invasive species in wetlands leased for aquaculture. The model employed assumes that aquaculturalists have perfect information on the risk of their activities and the costs of efforts to prevent escapes of species onto neighbouring aquaculture farms. It is shown that a bond paid collectively by aquaculturalists leasing portions of a wetland induces optimal prevention efforts. The application of environmental bonds to invasive species associated with aquaculture is also explored in Mathis and Baker (2002).

Padilla and Williams (2004) recommend the use of bonds for trade in aquarium and ornamental species. Regulators could take a step-wise approach and allow limited introductions of exotic species, subject to a performance bond and strict monitoring, followed by incremental increases in trade if the species turns out to be harmless.

The above studies assume that most of the prerequisites identified in Shogren et al. (1993) hold for the problem at hand. However, the peculiarities of the invasive species problem discussed in the preceding sections would also hamper the applicability of performance bonds. Firstly, for certain introductions it would be difficult to value the maximum expected damage, especially if adverse impacts on biodiversity need to be considered. Moreover, the damage of invasions may be irreversible and there may be a low potential for ecosystem restoration post-invasion. The instrument would have to be applied in conjunction with a clearly defined liability framework, hence it would not circumvent the difficulties of establishing causality and determining the source of invasions. Contrary to mining activities, for example, the invasion process does not always have a fixed time horizon, therefore it would be problematic to determine at which date the final impact of an introduction should be assessed. As a prevention instrument, bonds would only incentivise abatement efforts in so far as abatement measures exist (or could be developed).

Notwithstanding these caveats, the threat of having to forfeit a sizeable bond has the potential to foster more responsible practices on the part of importers. To the extent that damage is reversible, bonds are likely to work well as a cost-recovery mechanism, for example to cover the costs of eradication. Since damage would be lower in the case of early detection, the agent introducing an exotic species has the incentive to monitor and mitigate the damage before it reaches the worst-case scenario associated with the full bond.

Bonds would not be appropriate for species whose risk of invasion is known and extremely high, but rather in situations where the risk cannot be determined and the benefits of allowing the species' introduction are high. As such, the instrument would be most suitable for intentional introductions, for example, in the pet trade sector, where bans may in fact encourage illegal trade. As Perry and Farmer (2004) argue, in many cases it would be better to allow introduction under tightly controlled conditions and prepare for the eventuality of accidental escape by having a fund in place. Bonds could be applied in connection to grey lists of species (i.e. species whose invasive potential is not known and has yet to be assessed).

### 3.4.3 Expected performance

Dependability

Performance bonds cannot guarantee that invasions are prevented, but the threat of forfeiting a large bond is likely to foster responsible practices on the part of introducers. The instrument would ensure that funds are available for eradication and remediation should invasion occur, but this would be of little use in the event of irreversible damage to biodiversity.

Ease of monitoring and enforcement

The instrument shifts the burden of proof away from the regulator and onto the introducer of alien species. Nevertheless, the regulator needs to be able to verify the introducer's claims and to assess the eventual damage. It would be necessary, in a first step, to decide which sectors and activities should be covered by the liability and bonding requirement, which implies accurate risk assessment.

Efficiency and cost-effectiveness

The instrument would be cost-effective since it does not charge firms unless damage arises, but a large bond can tie up significant capital. If damage turns out higher than anticipated, society has to absorb the costs.

Adaptability to changing knowledge and conditions

The instrument would perform well on this criterion, since the size of the bond can be adjusted following revised risk-assessments. It would also serve as a learning tool about the potential risk associated with various activities: allowing controlled introductions or use, rather than imposing bans on species with unknown risks, means that some of the uncertainty can be gradually eliminated.

Dynamic effects and innovation

Since the size of the bond is determined by the worst-case conjectured damage, the instrument should in principle encourage innovative solutions to reduce the risk of invasions, but it is difficult to anticipate to what extent bonds could help minimise prevention costs over time. Since the agent introducing a species has an incentive to detect any eventual escape or introductions of non-target species, we may also expect the instrument to encourage development of more accurate early-detection and monitoring mechanisms. The fact that the burden of proof regarding the expected damage is shifted to the introducer might also provide incentives for improved risk-assessment methodologies.

## 3.5. Conclusions regarding instrument applicability

The following table provides a synthesis regarding the applicability of various economic instruments. The economic sectors or specific introduction vectors for which the instrument appears, *a priori*, to be potentially useful are listed. The key conditions for the applicability of each instrument, as well as some important caveats, are also highlighted.

**Table 3. The applicability of economic instruments to the prevention of invasive species**

| Instrument | Sector / vectors | Key conditions | Limitations |
| --- | --- | --- | --- |
| Tax (tariffs) on commodities introduced, proportionate to invasion risk | Commodities that may turn out invasive themselves (alien plants, species introduced for aquaculture, pet and aquarium species);<br>Commodities that may carry IAS as contaminants or stowaways (e.g. agricultural produce, plants, timber, animal species) | - The goal is to minimise risk, not eliminate it;<br>- Commodity-specific risk levels can be accurately estimated;<br>- Increased prices lead to lower import levels. | - Difficult to identify the tax rate that guarantees a pre-determined target of overall risk reduction;<br>- Potential for such tariffs to be used as 'disguised protectionism'; it might be difficult to prove WTO-compatibility;<br>- Taxing importers would be ineffective if risk arises at subsequent steps of the distribution chain (e.g. negligence of pet owners). |
| Taxes/fees on activities known to introduce alien species that are/may become invasive | Shipping, horticulture / ornamental trade, recreational boating, angling, aquaculture, pet-keeping | - The goal is to minimise risk, not eliminate it;<br>- Risks levels can be accurately estimated;<br>- It is politically and administratively feasible to set up a system of fees modulated according to risk levels;<br>- The tax has a sufficiently deterrent effect. | - Difficult to identify the tax rate that guarantees a pre-determined target of overall risk reduction;<br>- Difficulties of monitoring compliance (e.g. if a tax reduction is contingent on the adoption of some predefined standard or best practice). |

| | | | |
|---|---|---|---|
| Ambient tax (based on changes in the population of alien species in a receptor environment) | Unintentional introductions, especially from shipping (ballast water, biofouling) | - It is possible to determine an acceptable ambient level, known to guarantee a sufficiently low risk of invasion/damage.<br>- The regulator is capable of accurately monitoring the ambient population of alien species in a given environment;<br>- Agents introducing alien species can estimate the effect of their abatement actions on ambient population levels. | - Information asymmetries between the regulator and the introducers;<br>- Ambient levels may reflect past introductions rather than current abatement efforts;<br>- Fairness concerns, since agents may be penalized despite having taken all reasonable efforts to reduce their own discharges of alien species. |
| Tradable permit scheme | Ballast water | - A quantifiable and observable permit base correlated with invasion damage exists (e.g. ballast water treatment systems and other measures corresponding to a specific reduction in risk of invasion);<br>- Heterogeneous abatement costs among polluters;<br>- IAS ‘emission’ permits are specific to a receptor environment;<br>- The units traded represent equivalent risks. | - High information requirements for designing and enforcing the scheme;<br>- A market will not emerge if the abatement options and costs are similar across polluters. |
| Compulsory insurance for activities which may introduce or spread invasive species | Intentional introductions: pet / aquarium trade, horticulture / ornamentals, aquaculture; | - The source of invasions can be identified with precision;<br>- It is possible to quantify and express in monetary terms the expected damage;<br>- A liability framework for IAS introductions is in place;<br>- Insurers have sufficient data to construct the probability distribution of expected losses;<br>- Variable premiums according to risk levels can be set. | - Difficulties in establishing causation;<br>- Variable premiums might not be a sufficient incentive for agents to minimise the risks of invasions;<br>- Danger of moral hazard;<br>- Eventual damage may exceed the upper limit of cover;<br>- Ineffective in the case of irreversible damage to biodiversity and ecosystems. |
| Posting of | Intentional | - The source of an invasion | - Too large a bond may over- |

| | | | |
|---|---|---|---|
| performance bonds by importers of alien species or agents undertaking high-risk activities | introductions: pet / aquarium trade, horticulture / ornamentals, aquaculture; | can be identified with precision;<br>- The worst-case plausible outcome can be defined and expressed in monetary terms;<br>- The lag time between introduction and potential invasion can be estimated;<br>- The size of the bond can be adjusted following revised risk assessments. | deter activity;<br>- The actual damage may turn out higher than the maximum potential loss estimated ex-ante;<br>- Ineffective in the case of irreversible damage to biodiversity and ecosystems. |

## 3.6. Stakeholders' and experts' views on the use of economic instruments in IAS policy

To get a better idea of how economic instruments for the prevention of IAS would be perceived by stakeholders and how they are likely to perform in practice, I conducted a mini-consultation of industry representatives, political stakeholders, and IAS experts in Europe. Two separate questionnaires[21] were sent in early 2013 to two categories of respondents.

The first was sent to representatives of economic sectors associated with IAS introductions, to find out which instruments business stakeholders deem applicable and what the constraints to their application would be from the industry's perspective. The stakeholders were also asked whether they believed limitations on the trade and use of IAS would be acceptable in their sector and what impact bans on the commercialisation of high-risk alien species would have on their business.[22] The survey was sent by email to 33 business stakeholders including: members of the Invasive Alien Species Working Groups established by the European Commission in the context of preparations for the forthcoming EU legislative instrument on IAS, participants in a European Commission stakeholder consultation on IAS held in September 2010, and European and international associations and umbrella organisations in sectors of relevance to IAS (identified via the European Transparency Register and an internet search). The response rate from industry stakeholders was very low, with answers and additional comments received from only six organisations: the International Association of Horticultural Producers (AIPH), the European Sea Ports Organisation, World Shipping Council, Ornamental Fish International (OFI), Angling Trust, and the Sustainable Users Network (representing

[21] See Annex I.
[22] These questions were omitted from the questionnaire sent to businesses associated with unintentional introductions only, namely shipping.

pro-use groups in the UK from a range of sectors, such as pet trade, horticulture, zoos and aquaria, timber trade, etc.).[23]

The second questionnaire was sent to a list of 65 political stakeholders and experts, comprising the members of the IAS Working Groups established by the European Commission (including experts from research organisations, national ministries, and environmental NGOs), members of the Council of Europe Group of Experts on IAS, members of the CBD Inter-Agency Liaison Group on IAS, and three DAISIE contributors with expertise in the economics of IAS. Several respondents suggested additional experts, who were also contacted. These experts and stakeholders were asked to indicate which factors they see as significant impediments to the application of economic instruments with regard to IAS and how each policy instrument considered in this study[24] is, in their opinion, likely to perform against seven evaluation criteria.[25] Responses were provided by 28 of the individuals contacted (10 from ministries and governmental agencies responsible for invasive species/nature conservation, 14 from research institutions, and four from not-for-profit organisations).

The number of responses for both surveys is of course too low for the results to be considered generalisable and representative of stakeholders' views overall, but the results give us an idea of real-world perceptions of economic instruments for IAS prevention and complement the findings from the theoretical literature.

Results

Both sets of actors were asked to indicate, from a predefined list, which factors they see as significant impediments to the application of economic instruments with regard to invasive alien species. There was a near-consensus among respondents that the considerable time lag between the introduction of non-native species, their spread, and resulting damage would render the applicability of economic instruments difficult (27 out of the 33 respondents who answered the question selected this factor). The next two commonly cited impediments were the uncertainty regarding the potential magnitude of the damage caused by invasive species (13 respondents) and uncertainty regarding the causes of biological invasions (12 respondents). The difficulty of setting acceptable risk levels, the low price

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[23] All stakeholders responded in their personal capacity and did not necessarily voice the opinion of their organisation as a whole.

[24] In addition to the instruments discussed in the preceding sections, the questionnaire also included 'labelling and certification schemes'. For reasons of time and space, this type of instrument was no longer considered in the analysis of instruments based on the current literature. I have, nonetheless, retained this instrument in the presentation of survey results.

[25] The exact question was: "In your opinion, how would each policy instrument listed in the first column of the following table perform against the seven evaluation criteria? Please fill in the matrix below using the following symbols:
- - The instrument is likely to perform **very poorly** on this criterion
- The instrument is likely to perform **poorly** on this criterion
0 The instrument would be **neutral** to this criterion
+ The instrument is likely to perform **well** on this criterion
++ The instrument is likely to perform **very well** on this criterion"

elasticity of demand for (potentially) invasive species or commodities that may result in unintentional introductions of exotic species, the high informational requirements of such instruments, and high costs of administering them were only regarded as serious obstacles by 5 to 7 respondents. Only 3 respondents believed that the potential for firms to abate this type of pollution is too low (note that none of the business representatives selected this factor).

When asked how the polluter-pays principle should be enshrined in invasive species policy, a majority of respondents (25) indicated that cost-recovery mechanisms should be introduced in order to contribute to financing prevention, early warning, rapid response and management measures. Twenty respondents believed the sectors that may intentionally or unintentionally introduce alien species in the environment should be held collectively responsible for any damage such species may cause if released or allowed to spread into the environment, while 17 stated the individual users should be held responsible, if identifiable.[26]

The industry representatives were also asked to choose among a set of economic instruments up to three that they deemed most effective to foster responsible practices and create the right incentives for operators in their sector to reduce the risks of introducing invasive alien species. Both respondents from the shipping sector – the European Sea Ports Organisation and the World Shipping Council – believed that none of the suggested instruments would be appropriate to address unintentional introductions via shipping. They both stressed the importance of ratifying and implementing the Ballast Water Convention. OFI similarly noted that the listed economic instruments were "merely theoretical solutions" and unlikely to be effective. AIPH believed that tariffs on commodities which may cause invasions, proportionate to invasion risk, and compulsory insurance could play a role in the horticultural sector. The Sustainable Users Network also expressed a preference for tariffs, and also indicated labelling and certification, as well as tradable permit schemes as potentially effective. The Angling Trust selected labelling and certification and the posting of assurance bonds.

Political stakeholders and other experts were presented with an evaluation matrix of seven instruments and seven criteria and asked to indicate how each instrument is likely to perform, in their opinion, against each criterion if applied to invasive species prevention.[27] A clear shortcoming is that the question was framed in a very general way, without specifying to which pathways or taxa the instrument would be applied, hence (as several respondents also underlined) the scores should be seen as a very general, intuitive estimation of instrument performance. One of the experts underscored that the instruments would have to be considered in light of an impact assessment and of the trade-off between preventive policies and other measures such as eradication and control.

[26] The same question was also posed by the European Commission in its 2012 public consultation on IAS. There, the majority of respondents (approx. 65%) stated that individual users should be held responsible, and approx 33% suggested the use of cost-recovery mechanisms. See http://ec.europa.eu/environment/nature/invasivealien/docs/results_consultation.pdf , accessed 7 August 2013.

[27] The performance scale was 'very poorly', poorly', 'the instrument would be neutral with regard to this criterion', 'well', 'very well'.

Respondents' evaluations varied widely and it is difficult to aggregate the scores in a meaningful way. The full dataset of responses (28), broken down per instrument, can be found in Annex III. The following table shows, for each instrument-criterion dyad, the score assigned by the largest number of respondents (i.e. the mode). In a second table, I have merged (in the original dataset) the categories 'very poorly'/ 'poorly' and 'very well'/'well' and then recalculated the mode, in order to show which instruments were deemed to have a positive, negative, or neutral performance by the largest number of experts. As already noted, the number of responses is too low for the results to be considered representative, but the matrix provides a rough indication of expert opinion on the matter.

Interestingly, regarding effectiveness in attaining the goal set, all instruments were rated positively by most respondents.

As shown in Table 5, tradable permit schemes are the instrument judged to perform poorly or very poorly by most experts, with regard to all criteria except effectiveness and dynamic effects. This is not surprising given that this instrument would be the most innovative among the ones considered in this study, as well as the hardest to design in terms of preventing invasions. To some extent, respondents' scepticism regarding this instrument might also reflect a limitation of the questionnaire, since it was not fully specified how such a system would be implemented, only that risk would constitute the permit base. Three experts further stressed in additional comments that tradable permits would not be appropriate to tackle this problem. One respondent noted that in this case such an instrument "would be so complex as to be completely impractical".

Regarding the rest of the instruments considered, when no distinction is made between good and very good performance, and between very poor and poor performance, there is not much variation among instruments in terms of the most frequently assigned score: all of the six instruments receive a positive evaluation on most criteria.

One respondent added that none of these tools are likely to be effective in isolation, but ought to be considered in the context of a policy-mix.

**Table 4: Experts' Evaluation of Policy Instruments Applicable to IAS (1)**

| INSTRUMENT | EVALUATION CRITERIA | | | | | | |
|---|---|---|---|---|---|---|---|
| | Effectiveness with respect to environmental goals | Political/ administrative feasibility (e.g. compatibility with existing institutions, public / stakeholder acceptance) | Ease of monitoring and enforcement | Cost-effectiveness | Flexibility/ adaptability to changing knowledge and conditions | Equitable distribution of costs and benefits | Dynamic effects and innovation (e.g. development of new ballast water treatment technologies) |
| A tax on the purchase price of alien species that are/may become invasive | ++ | + | + | + | + | + | 0 |
| Tariffs on commodities which may cause invasions, proportionate to invasion risk | + | - | + | + | + | + | + |
| Taxes/fees on activities known to unintentionally introduce alien species that are/may become invasive | + | - | + | + | + | + | + |
| Compulsory insurance requirements on activities which may introduce or spread invasive species | + | + | + | + | + | + | + |
| Tradable permit schemes where permits are denominated in terms of the risk of an invasive alien species introduction | + | + | - | + | - | 0 | 0 |
| The posting of assurance bonds by importers of new species or agents undertaking high-risk activities | + | 0 | 0 | + | ++ | + | + |
| Labelling and certification schemes | + | + | + | + | + | 0 | + |

*Legend:* The instrument is likely to perform: **- - very poorly**, **- poorly**, **+ well**, **++ very well** on this criterion. **0** The instrument would be **neutral** to this criterion.

**Table 5: Experts' Evaluation of Policy Instruments Applicable to IAS (2)**

| INSTRUMENT | EVALUATION CRITERIA | | | | | | |
|---|---|---|---|---|---|---|---|
| | Effectiveness with respect to environmental goals | Political/ administrative feasibility (e.g. compatibility with existing institutions, public / stakeholder acceptance) | Ease of monitoring and enforcement | Cost-effectiveness | Flexibility/ adaptability to changing knowledge and conditions | Equitable distribution of costs and benefits | Dynamic effects and innovation (e.g. development of new ballast water treatment technologies) |
| A tax on the purchase price of alien species that are/may become invasive | + | + | + | + | + | + | 0 |
| Tariffs on commodities which may cause invasions, proportionate to invasion risk | + | + | + | + | + | + | + |
| Taxes/fees on activities known to unintentionally introduce alien species that are/may become invasive | + | + | + | + | + | + | + |
| Compulsory insurance requirements on activities which may introduce or spread invasive species | + | + | + | + | + | + | + |
| Tradable permit schemes where permits are denominated in terms of the risk of an invasive alien species introduction | + | - | - | - | - | - | 0 |
| The posting of assurance bonds by importers of new species or agents undertaking high-risk activities | + | - | + | + | + | + | + |
| Labelling and certification schemes | + | + | + | + | + | + | + |

*Legend:* The instrument is likely to perform: **- poorly or very poorly**, **+ well or very well** on this criterion, **0** The instrument would be **neutral** to this criterion.

## Conclusions

Since biological invasions are the external effects of trade and other economic activities, a number of scholars and policy documents have suggested that they could be addressed with the same economic toolbox conventionally applied to other environmental externalities. This thesis has endeavoured to examine more closely the peculiarities of invasive species compared to other pollutions and whether these distinguishing features preclude their internalisation via economic instruments. The potential applicability and likely performance of price-based instruments, tradable permit schemes, liability insurance, and environmental performance bonds was explored.

The uncertainty involved in estimating a species' invasiveness prior to introduction into a new range, the considerable time-lags between introduction and successful invasion, the problems of establishing causation once an invasion occurs, and the difficulty of assessing invasion damage in monetary terms (*ex-ante*, but even *ex-post*) render the application of economic instruments less straightforward than in the case of other externalities.

Contrary to other emissions where the level of damage associated with a given flow or stock of the pollutant can be known with certainty, IAS management decisions are usually formulated in terms of risk: what prevention measures are necessary to reduce the likelihood and value of damage to an acceptable level? Economic instruments will not be of interest where the target risk level is set to zero. However, there is scope for applying such instruments when the goal is to minimise risk rather than eliminate it, for example, in the case of intentionally introduced species with economic benefits and for unintentional introductions that cannot be detected and excluded at the border. Here, economic incentives would be aimed at making the agents responsible for the introduction or spread of potentially invasive species internalise the expected costs of invasions in their decision-making, in order to undertake the optimal prevention efforts.

The few existing theoretical explorations of market-based instruments and IAS suggest that there is scope for their application in this field, but subject to the availability of information on key parameters. A risk-based tax on imported commodities or on activities that may introduce IAS presupposes that risk levels can be accurately estimated. In practice, it will usually be difficult to determine what level of propagule pressure guarantees a sufficiently low risk of invasion, and what tax rate would reduce propagule pressure to the desired level. Taxes might therefore not be sufficiently effective as an incentive measure. Nevertheless, they could be a useful cost-recovery or revenue-raising tool.

Tradable permits could be of interest for minimising invasions via ballast water discharges. As long as it is not possible to observe IAS introductions directly, the instrument's effectiveness in preventing invasions is contingent on the identification of a permit base that is correlated with risk levels and not prohibitively costly to observe. The information requirements and burden on the regulating authority in terms of monitoring and enforcement will be relatively high. In the absence of information on the specific details of a given tradable permits scheme (e.g. the number of polluters that would come under its scope, the heterogeneity of abatement measures and costs among polluters, the transaction costs involved), it is difficult to predict how cost-effective such an instrument would be. Most of the experts who responded to the survey conducted within this project were sceptical about the utility of this instrument with regard to IAS.

Liability insurance and performance bonds would be applicable to intentional pathways, such as the pet and aquarium trade, horticulture and ornamental plants trade, and aquaculture, in connection with permit requirements or the granting of a licence to operate. Such instruments are of interest only in so far as the source of invasions can be identified with precision and a liability framework for the introduction of non-native species is in place. In certain cases characterised by radical uncertainty, the risk of invasion may turn out uninsurable, since insurers would not have sufficient data to determine the value and probability distribution of expected losses. On the other hand, a mandatory requirement for introducers of alien species to contract insurance could stimulate improved risk assessments and data-gathering. Further research would have to consult the insurance sector regarding their preparedness to provide cover for IAS-related risks and the factors or policy measures that could enhance insurability of such risks. As a prevention tool, insurance would only be effective in so far as variable premiums and monitoring by the insurer can provide incentives for agents to minimise the invasion risk associated with their activities. Performance bonds are suitable for addressing the uncertainty characterising biological invasions and would be a useful tool to recover the costs of potential damage from the responsible party, should an invasion occur. The threat of forfeiting the bond is likely to incentivise introducers to adopt practices that minimise the risk of invasion. These two instruments seem to be, *a priori*, easier to design and enforce than an invasives tax or tradable permit system.

This study also attempted to gather stakeholders' perspectives on the applicability of economic instruments to IAS, but the response rate from the relevant economic sectors has been low. Three out of the six industry representatives who responded stressed that such tools would not be appropriate to prevent introductions via the shipping, respectively aquarium trade sector. The political stakeholders and experts who participated in the survey were in general more favourable to the idea of implementing such instruments. For example, all of the instruments considered were deemed to perform well or very well, *a priori*, with respect to the criterion of dependability by a majority of respondents. On the other hand, tradable permits were judged likely to perform poorly or very poorly on other criteria.

No economic instrument would be suitable to address every possible pathway. Moreover, economic instruments would not eliminate the need for more conventional biosecurity measures, on the contrary. For example, all of the examined instruments need to be supported by risk assessments, border inspections, and other measures for monitoring and detecting introductions via the different pathways. Future research should consider in more detail how the various economic instruments could complement or conflict with existing policies and institutions, as well as which instruments should be used in combination in order to improve performance on the various criteria. Moreover, a more precise evaluation of instrument applicability and performance would have to zoom in more closely on each specific economic sector.

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# Annex I: Survey questions

**Economic Instruments for the Prevention of Biological Invasions**

Questionnaire for economic operators and business associations

**Preamble**

Invasive alien species (IAS) are species whose introduction and/or spread, outside their natural past or present distribution, threatens biological diversity. They may cause serious damage, disrupting the local ecology, impacting on human health and producing serious economic effects. Associated costs are estimated to be at least EUR 12.5 billion per year in the EU[28]. Most invasions can be linked to the intended or unintended consequences of economic activities. For example, pet, aquarium, aquaculture and horticulture trade are key pathways associated with intentional species introduction, while transportation ships are a main cause of unintentional introductions. At the same time, invasive alien species can severely impact on a wide range of economic sectors. For example, biological invasions can reduce yields from agriculture, forestry and fisheries, obstruct transportation by blocking waterways, or reduce the recreational value of certain landscapes. The Convention on Biological Diversity has acknowledged the importance of involving business in policies aimed at combatting biological invasions.

As part of my Master's thesis on the application of economic instruments for the prevention of biological invasions, I am conducting a survey of industry representatives and political stakeholders.

Thank you for answering the questions below and returning the questionnaire to lbaroni@ulb.ac.be by 15 March 2013.

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**Respondent Details**

Company/Organisation: ……………………….................................

Respondent's name: …………………………………………………

Position: ……………………………………………………………..

Date: ………………………………………………………………

**Questionnaire**

[28] Kettunen, M., Genovesi, P., Gollasch, S., Pagad, S., Starfinger, U. ten Brink, P. and Shine, C. (2008) *Technical support to EU strategy on invasive species (IAS) - Assessment of the impacts of IAS in Europe and the EU*, Institute for European Environmental Policy (IEEP), Brussels, Belgium.

**1.** Do you consider the (risk of) introduction of invasive alien species to be a problem to which your sector contributes to a large extent? □ Yes □ No

**2.** In your organisation's opinion, which of the following options would be an appropriate policy response to the problem of biological invasions? *Please tick only one box.*

□ More stringent and specific legislation regulating the trade and use of invasive alien species, or of commodities that present a high risk of unintentionally introducing invasive alien species

□ Voluntary approaches (e.g. codes of conduct) promoting responsible practice among economic agents with regard to IAS

□ A combination of new legislation and voluntary approaches

□ No further action is needed to tackle the problem

**3.** Major damage has resulted from intentional introductions of invasive alien species as a commodity for release or use in containment and also from accidental escapes of introduced species. Measures to minimise such risks include more effective regulation of the trade and use of potentially invasive species such as limitations or bans thereto. Do you consider that such limitations on the trade and use of invasive alien species would be acceptable in your sector?

□ Yes □ No □ I don't know

**4.** If the commercialisation of non-native species presenting a high risk of becoming invasive were to be entirely prohibited, the negative impact on your business or (in the case of associations) your member companies would likely be:

□ Nil □ Low □ Medium □ High □ Very high □ Such a ban would have a positive impact

□ I don't know

**5.** a) The Polluter Pays Principle demands that the party responsible for producing pollution be made responsible for paying the costs of associated damage. In your view, how should this principle be enshrined in invasive species policy? *You have the possibility to check more than one response.*

□ Hold the **individual users** (if identifiable) of alien species responsible for any damage such species may cause if released or allowed to spread into the environment

□ Hold the **sectors** that may intentionally or unintentionally introduce alien species in the environment **collectively responsible** for any damage such species may cause if released or allowed to spread into the environment

□ Introduce **cost-recovery mechanisms** (e.g. by subjecting permit applications and risk-assessments to a fee) to contribute to financing prevention, early warning and rapid response and management measures

b) (For associations) Is this view shared by a majority of your members?

□ Yes □ No □ I don't know

**6.** Economic instruments such as taxes and permit-trading schemes have so far not been applied in the field of invasive species policy. However, some theoretical explorations and their application to analogous problems suggest that they may be a useful approach for the prevention of biological invasions. Among the policy instruments listed below, please choose **up to three** that you think would be most effective to foster responsible practices and create the right incentives for operators in your sector to reduce the risks of introducing invasive alien species.

□ Labelling and certification schemes for native species

□ A tax on the purchase price of alien species that are/may become invasive

□ Tariffs on commodities which may cause invasions, proportionate to invasion risk

□ Taxes/fees on activities known to unintentionally introduce alien species that are/may become invasive

□ Compulsory insurance requirements on activities which may introduce or spread invasive species

□ The posting of assurance bonds by importers of new species or agents undertaking high-risk activities, set at a rate equivalent to the conjectured damage if the species were to become invasive

□ Tradable permit schemes where permits are denominated in terms of the likelihood of an invasive alien species introduction (e.g. vessels entering a port would be provided with 'risk permits' for potential invaders and allowed to trade the permits among themselves. The level of risk generated by each vessel must not exceed the vessel's permit holdings.)

**7.** Among the factors listed below, which ones do you see as significant impediments to the application of economic instruments with regard to invasive alien species in your sector? *You may select several items.*

□ It is too difficult to set the targets (i.e. acceptable risk levels).

□ There is considerable uncertainty regarding the potential severity of the damage caused by invasive species.

□ The causes or sources of biological invasions cannot be identified with precision.

□ There is often a considerable time lag between the introduction of non-native species, their spread, and resulting damage.

□ The potential for firms to abate this type of pollution (i.e. to reduce the risk of introducing non-native, potentially invasive species) is too low.

□ The price elasticity of demand for (potentially) invasive species or commodities that may result in unintentional introductions of exotic species is low.

□ The informational requirements of such instruments are too high (for example, 'emissions' of invasive species and/or risk levels cannot be readily measured).

□ The costs of administering such instruments would be too high.

**8.** Other comments:

______________________________________________________________________________

______________________________________________________________________________

## Economic Instruments for the Prevention of Biological Invasions

Experts' Questionnaire

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**Preamble**

Invasive alien species (IAS) are species whose introduction and/or spread, outside their natural past or present distribution, threatens biological diversity. They may cause serious damage, disrupting the local ecology, affecting human health and producing economic losses. Associated costs are estimated to be at least EUR 12.5 billion per year in Europe, according to the available documented information[29]. Most biological invasions can be linked to the intended or unintended consequences of economic activities. For example, pet, aquarium, aquaculture and horticultural trade are key pathways associated with intentional species introductions, while transportation ships are a main cause of unintentional introductions. At the same time, invasive alien species can affect a wide range of economic sectors. For example, biological invasions can reduce yields from agriculture, forestry and fisheries, obstruct transportation by blocking waterways, or reduce the recreational value of certain landscapes.

As part of my Master's thesis on the application of economic instruments for the prevention of biological invasions, I am conducting a survey of experts, industry representatives, and political stakeholders.

Thank you for answering the questions below and returning the questionnaire to l.baroni@ulb.ac.be

Any further comments or information in addition to the closed questions below are also very welcome!

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**Respondent Details**

Organisation/Institution: ……………………….................................

Respondent's name: …………………………………………………

Position: ………………………………………………………………..

Date: …………………………………………………………………

[29] Kettunen, M., Genovesi, P., Gollasch, S., Pagad, S., Starfinger, U. ten Brink, P. and Shine, C. (2008) *Technical support to EU strategy on invasive species (IAS) - Assessment of the impacts of IAS in Europe and the EU*, Institute for European Environmental Policy (IEEP), Brussels, Belgium.

**Questionnaire**

**1.** In your opinion, which of the following options would be an appropriate policy response to the problem of biological invasions? *Please tick only one box.*

□ More stringent and specific legislation regulating the trade and use of invasive alien species, or of commodities that present a high risk of unintentionally introducing invasive alien species

□ Voluntary approaches (e.g. codes of conduct) promoting responsible practice among economic agents with regard to IAS

□ A combination of new legislation and voluntary approaches

□ No further action is needed to tackle the problem

**2.** The Polluter Pays Principle demands that the party responsible for producing pollution be made responsible for paying the costs of associated damage. In your view, how should this principle be enshrined in invasive species policy? *You may select several items.*

□ Hold the **individual users** (if identifiable) of alien species responsible for any damage such species may cause if released or allowed to spread into the environment

□ Hold the **sectors** that may intentionally or unintentionally introduce alien species in the environment **collectively responsible** for any damage such species may cause if released or allowed to spread into the environment

□ Introduce **cost-recovery mechanisms** (e.g. by subjecting permit applications and risk-assessments to a fee) to contribute to financing prevention, early warning and rapid response and management measures

**3.** Economic instruments such as taxes and permit-trading schemes have so far not been applied in the field of invasive species policy. However, some theoretical explorations and their application to analogous problems suggest that they may be a useful approach for the prevention of biological invasions. Among the factors listed below, which ones do you see as significant impediments to the application of economic instruments with regard to invasive alien species? *You may select several items.*

□ It is too difficult to set the targets (i.e. acceptable risk levels).

□ There is considerable uncertainty regarding the potential severity of the damage caused by invasive species.

□ The causes or sources of biological invasions cannot be identified with precision.

□ There is often a considerable time lag between the introduction of non-native species, their spread, and resulting damage.

□ The potential for firms to abate this type of pollution (i.e. to reduce the risk of introducing non-native, potentially invasive species) is too low.

□ The price elasticity of demand for (potentially) invasive species or commodities that may result in unintentional introductions of exotic species is low.

□ The informational requirements of such instruments are too high (for example, 'emissions' of invasive species and/or risk levels cannot be readily measured).

□ The costs of administering such instruments would be too high.

**4.** In your opinion, how would each policy instrument listed in the first column of the following table perform against the seven evaluation criteria? Please fill in the matrix below using the following symbols:

- - The instrument is likely to perform **very poorly** on this criterion
- The instrument is likely to perform **poorly** on this criterion
0 The instrument would be **neutral** to this criterion
+ The instrument is likely to perform **well** on this criterion
++ The instrument is likely to perform **very well** on this criterion

5. Other comments: ____________________________________________________

| INSTRUMENT | EVALUATION CRITERIA | | | | | | |
|---|---|---|---|---|---|---|---|
| | Effectiveness with respect to environmental goals | Political/ administrative feasibility (e.g. compatibility with existing institutions, public / stakeholder acceptance) | Ease of monitoring and enforcement | Cost-effectiveness | Flexibility/ adaptability to changing knowledge and conditions | Equitable distribution of costs and benefits | Dynamic effects and innovation (e.g. development of new ballast water treatment technologies) |
| A tax on the purchase price of alien species that are/may become invasive | | | | | | | |
| Tariffs on commodities which may cause invasions, proportionate to invasion risk | | | | | | | |
| Taxes/fees on activities known to unintentionally introduce alien species that are/may become invasive | | | | | | | |
| Compulsory insurance requirements on activities which may introduce or spread invasive species | | | | | | | |
| Tradable permit schemes where permits are denominated in terms of the risk of an invasive alien species introduction | | | | | | | |
| The posting of assurance bonds by importers of new species or agents undertaking high-risk activities | | | | | | | |
| Labelling and certification schemes | | | | | | | |

# Annex II: List of survey respondents

- Tim Adriaens, Researcher, Instituut voor Natuur- en Bosonderzoek (INBO)
- Etienne Branquart, Premier Attaché, Cellule interdépartementale sur les Espèces invasives, Service Public de Wallonie
- Jim Collins, Coordinator, Sustainable Users Network UK
- George Franke, Secretary Committee for Environment, International Association of Horticultural Producers (AIPH)
- Piero Genovesi, Senior Scientist, ISPRA and Chair IUCN SSC Invasive Species Specialist Group
- Ema Gojdičová, National IAS expert , State Nature Conservancy of the Slovak Republic
- Stephan Gollasch, Senior Scientist, GoConsult
- Jaakko Heikkilä, Senior Researcher, MTT Economic Research, Agrifood Research Finland
- Marc Kenis, Head of Forestry and Ornamental Pest Research, CABI Switzerland
- Gabor Lovei, Senior Scientist, Aarhus University
- Staci McLennan, Wildlife Policy Officer, Eurogroup for Animals
- Antonis Michail, Policy Advisor on Environment, European Sea Ports Organisation
- François Moutou, Head Epidemiology Unit, Laboratory for Animal Health, ANSES
- Wolfgang Nentwig, Head of Division, Institute of Ecology and Evolution, University of Bern
- Jonathan Newman, Head, Aquatic Plant Management Group, NERC Centre for Ecology and Hydrology
- Johanna Niemivuo-Lahti, Senior Environmental Adviser, Ministry of Agriculture and Forestry, Finland
- Wout Opdekamp, Coordinator LIFE+ Kleine Nete, Natuurpunt
- Mark Owen, Head of Freshwater, Angling Trust
- Iveta Ozolina, Deputy Director, Ministry of Agriculture, Latvia, Department of Agriculture
- Ewa Pisarczyk, Chief Specialist, Ministry of Environment, General Directorate for Environmental Protection, Poland
- Jan Plesnik, Adviser to the Director, Nature Conservation Agency of the Czech republic
- Alex Ploeg, Secretary General, Ornamental Fish International
- Wolfgang Rabitsch, Senior Scientist, Environment Agency Austria
- Lisa Schembri Gambin, Senior Environment Protection Officer, Ecosystems Management Unit, Malta Environment and Planning Authority
- Wojciech Solarz, Assistant Professor, Institute of Nature Conservation, Polish Academy of Sciences, Kraków, Poland
- Ronaldo Sousa, Professor, University of Minho, Portugal

- Catherine Souty-Grosset, Researcher CNRS, University Poitiers
- Branka Tavzes, Undersecretary, Ministry of Agriculture and the Environment, Slovenia
- Alistair Taylor, EU Biodiversity Policy Officer, Royal Society for Protection of Birds / BirdLife Europe
- Teodora Trichkova, Research Scientist, Institute of Biodiversity and Ecosystem Research, Bulgarian Academy of Sciences
- Hans Van Gossum, Policy Advisor Invasive Alien Species, Agency for Nature and Forest – Flanders
- Sabine Wallens and Maud Istasse, Biodiversity Experts, Federal Public Services, Health, Food Chain Safety and Environment – DG Environment, Belgium
- Bryan Wood-Thomas, Vice-President, World Shipping Council
- Argyro Zenetos, Research Director, Hellenic Centre for Marine Research

# Annex III: Experts' Responses to the Evaluation Matrix

**Tax on the purchase price of alien species that are/may become invasive**

| Respondent | Effectiveness | Political feasibility | Ease of monitoring and enforcement | Cost-effectiveness | Flexibility | Equitable distribution of costs & benefits | Dynamic effects and innovation |
|---|---|---|---|---|---|---|---|
| **1** | 2 | 1 | 2 | 2 | 2 | 1 | 0 |
| **2** | 2 | 2 | 2 | 1 | -1 | -1 | 1 |
| **3** | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **4** | -1 | 1 | 2 | 0 | 0 | -1 | 0 |
| **5** | 0 | 1 | 0 | 1 | 1 | 0 | 1 |
| **6** | 1 | -1 | -1 | 0 | 1 | 1 | -1 |
| **7** | 0 | 2 | 1 | 1 | 0 | 0 | 0 |
| **8** | 1 | 1 | 0 | 1 | 1 | 1 | 1 |
| **9** | -2 | -1 | 0 | -2 | 1 | -2 | 0 |
| **10** | 2 | -2 | 1 | 0 | -1 | -1 | 1 |
| **11** | 0 | -1 | 1 | 1 | -1 | 0 | 0 |
| **12** | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| **13** | -2 | -1 | 1 | -2 | 1 | -1 | 0 |
| **14** | 1 | | | 1 | -1 | 1 | 1 |
| **15** | 0 | 1 | 1 | 1 | 1 | 2 | 2 |
| **16** | 2 | -1 | 0 | 2 | 0 | 1 | 0 |
| **17** | 1 | -1 | 1 | 1 | 1 | 1 | 0 |
| **18** | 2 | -1 | 1 | 1 | 1 | 2 | 0 |
| **19** | 2 | 0 | 1 | 1 | 2 | 1 | 2 |
| **20** | 0 | 2 | 2 | 2 | 2 | -1 | |
| **21** | 0 | 1 | -1 | -1 | 1 | 1 | 1 |
| **22** | 2 | -1 | -2 | 1 | 1 | 1 | 0 |
| **23** | 1 | 1 | 1 | 1 | 1 | 0 | 1 |
| **24** | 2 | 1 | 1 | 0 | 1 | 0 | 1 |
| **25** | | | | | | | |
| **26** | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| **27** | 2 | -1 | 2 | 2 | 2 | 1 | -1 |
| **28** | 1 | 0 | 1 | 1 | 0 | 1 | 0 |

*Legend:* The instrument is likely to perform: **- 2 (very poorly)**, **-1 (poorly)**, **1 (well)**, **2 (very well)** on this criterion, **0**:The instrument would be **neutral** to this criterion.

**Tariffs on commodities which may cause invasions, proportionate to invasion risk**

| Respondent | Effectiveness | Political feasibility | Ease of monitoring and enforcement | Cost-effectiveness | Flexibility | Equitable distribution of costs & benefits | Dynamic effects and innovation |
|---|---|---|---|---|---|---|---|
| **1** | 2 | 2 | -1 | 0 | 1 | 1 | 0 |
| **2** | 2 | 2 | 2 | 1 | -1 | -1 | 1 |
| **3** | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| **4** | 0 | -1 | -1 | 0 | -1 | -1 | 0 |
| **5** | 2 | 1 | 2 | 2 | 2 | 2 | 1 |
| **6** | 1 | -1 | 0 | 0 | 0 | 1 | 1 |
| **7** | 0 | 2 | 1 | 1 | 0 | 0 | 0 |
| **8** | 1 | 1 | 0 | 1 | 1 | 1 | 1 |
| **9** | 2 | 1 | 2 | 2 | 2 | 2 | 2 |
| **10** | 2 | -1 | 1 | 0 | -1 | -1 | 1 |
| **11** | 1 | 0 | 1 | 1 | 0 | 1 | 1 |
| **12** | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| **13** | | | | | | | |
| **14** | 1 | | | 1 | 1 | 1 | 1 |
| **15** | 1 | 1 | 1 | 1 | 1 | 2 | 2 |
| **16** | 2 | -1 | 1 | 2 | 0 | 1 | 0 |
| **17** | 1 | -1 | 1 | 1 | 1 | 1 | 0 |
| **18** | 1 | -1 | 1 | -1 | 1 | -1 | 0 |
| **19** | 2 | 0 | 1 | 1 | 2 | 1 | 2 |
| **20** | 0 | 2 | 1 | 0 | 0 | -1 | -2 |
| **21** | 1 | 1 | 0 | 1 | -1 | 1 | 1 |
| **22** | 2 | 1 | -1 | 1 | 2 | 1 | 1 |
| **23** | 1 | 1 | 1 | 1 | 1 | 0 | 1 |
| **24** | 0 | 1 | -1 | 0 | 1 | -1 | 0 |
| **25** | | | | | | | |
| **26** | 2 | -1 | -2 | 2 | 1 | 2 | 0 |
| **27** | 1 | 0 | 0 | 0 | 1 | -1 | 1 |
| **28** | 2 | -1 | 1 | 1 | 0 | 1 | 0 |

*Legend:* The instrument is likely to perform: **- 2 (very poorly)**, **-1 (poorly)**, **1 (well)**, **2 (very well)** on this criterion, **0**:The instrument would be **neutral** to this criterion.

**Taxes on activities known to unintentionally introduce alien species that are/may become invasive**

| Respondent | Effectiveness | Political feasibility | Ease of monitoring and enforcement | Cost-effectiveness | Flexibility | Equitable distribution of costs & benefits | Dynamic effects and innovation |
|---|---|---|---|---|---|---|---|
| **1** | 2 | -1 | -1 | 0 | 1 | 1 | 0 |
| **2** | 2 | 2 | 2 | 1 | -1 | -1 | 1 |
| **3** | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| **4** | 0 | -1 | -1 | 0 | -1 | -1 | 0 |
| **5** | 1 | -1 | 1 | 2 | 1 | 1 | 2 |
| **6** | -2 | -2 | 0 | -1 | 0 | -1 | -1 |
| **7** | 2 | 1 | 1 | 0 | 1 | 1 | 2 |
| **8** | 1 | 1 | 0 | 1 | 1 | 1 | 1 |
| **9** | 2 | 1 | 0 | 2 | 2 | 2 | 2 |
| **10** | 2 | -1 | 1 | 0 | -1 | -1 | 0 |
| **11** | 1 | 0 | 1 | 1 | 0 | 1 | 1 |
| **12** | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| **13** | -1 | -1 | -1 | -1 | -1 | -1 | 0 |
| **14** | 2 | | | 1 | -1 | 1 | 1 |
| **15** | 1 | 1 | 1 | 1 | 1 | 2 | 2 |
| **16** | 1 | -1 | 0 | 1 | 0 | 1 | 0 |
| **17** | 1 | -1 | 1 | 1 | 1 | 1 | 0 |
| **18** | 2 | 1 | 1 | 1 | 1 | 1 | 1 |
| **19** | 2 | 0 | 1 | 1 | 2 | 1 | 2 |
| **20** | -1 | 0 | -1 | 0 | -1 | -1 | -1 |
| **21** | 1 | 2 | 1 | -1 | 1 | 1 | 0 |
| **22** | 2 | -1 | -2 | 1 | 2 | 1 | 1 |
| **23** | 1 | 1 | 1 | 2 | 1 | 0 | 1 |
| **24** | 0 | 1 | -2 | -1 | 0 | -1 | 0 |
| **25** | | | | | | | |
| **26** | 1 | 1 | -2 | 2 | -2 | 2 | 1 |
| **27** | 2 | -1 | 1 | 1 | 0 | 1 | -1 |
| **28** | 1 | -1 | 1 | 1 | 0 | 1 | 0 |

*Legend:* The instrument is likely to perform: **- 2 (very poorly)**, **-1 (poorly)**, **1 (well)**, **2 (very well)** on this criterion, **0**:The instrument would be **neutral** to this criterion.

## Compulsory insurance on activities which may introduce/spread IAS

| Respondent | Effectiveness | Political feasibility | Ease of monitoring and enforcement | Cost-effectiveness | Flexibility | Equitable distribution of costs & benefits | Dynamic effects and innovation |
|---|---|---|---|---|---|---|---|
| **1** | 2 | -1 | -1 | 0 | 1 | -1 | 1 |
| **2** | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| **3** | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| **4** | 0 | -1 | -1 | 0 | -1 | 0 | 0 |
| **5** | -2 | 1 | -1 | 1 | 1 | 0 | -1 |
| **6** | -1 | -1 | -1 | 1 | -1 | 0 | 1 |
| **7** | 2 | 1 | 1 | -1 | 1 | 1 | 2 |
| **8** | 1 | 1 | 0 | 1 | 1 | 1 | 1 |
| **9** | 1 | 1 | 0 | 2 | 2 | 1 | 1 |
| **10** | 1 | -1 | 1 | 0 | -2 | 0 | 0 |
| **11** | 1 | 1 | 1 | 1 | 0 | 1 | 1 |
| **12** | 0 | 0 | -1 | 1 | 0 | -1 | 0 |
| **13** | 1 | 1 | -1 | 1 | 1 | 1 | 0 |
| **14** | 1 | | | 1 | -1 | 1 | 1 |
| **15** | 2 | 0 | 0 | 1 | 1 | 1 | 2 |
| **16** | 1 | -1 | 0 | 0 | 1 | 0 | 1 |
| **17** | 1 | -1 | 1 | | 1 | 1 | 0 |
| **18** | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| **19** | 2 | 1 | 1 | 1 | 2 | 1 | 2 |
| **20** | 0 | 0 | -1 | 0 | 0 | 0 | 0 |
| **21** | 0 | 2 | 1 | 0 | -1 | 0 | -1 |
| **22** | 1 | -1 | -2 | 1 | 1 | 1 | 1 |
| **23** | 2 | 1 | 1 | 2 | 1 | 1 | 1 |
| **24** | 0 | 1 | 1 | 0 | -1 | -1 | -1 |
| **25** | | | | | | | |
| **26** | -1 | -1 | -2 | -2 | -1 | -2 | -2 |
| **27** | 2 | -1 | 1 | 1 | 0 | 1 | 1 |
| **28** | 1 | 1 | 1 | 0 | -1 | 2 | 1 |

*Legend:* The instrument is likely to perform: **- 2 (very poorly)**, **-1 (poorly)**, **1 (well)**, **2 (very well)** on this criterion, **0**:The instrument would be **neutral** to this criterion.

## Risk-based tradable permits

| Respondent | Effectiveness | Political feasibility | Ease of monitoring and enforcement | Cost-effectiveness | Flexibility | Equitable distribution of costs & benefits | Dynamic effects and innovation |
|---|---|---|---|---|---|---|---|
| **1** | 2 | 1 | 2 | 1 | 2 | -1 | 2 |
| **2** | 2 | 2 | 2 | 1 | -1 | -1 | 1 |
| **3** | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **4** | -2 | -2 | -2 | -2 | -2 | -2 | -2 |
| **5** | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| **6** | 0 | -2 | -2 | -1 | -1 | 0 | -1 |
| **7** | 1 | 1 | 2 | -1 | 2 | 2 | 1 |
| **8** | 1 | 1 | 0 | 1 | 1 | 1 | 1 |
| **9** | -2 | -2 | -2 | -2 | -2 | -2 | 0 |
| **10** | 0 | | | 0 | -1 | | |
| **11** | | | | | | | |
| **12** | -1 | -1 | -1 | -1 | 0 | -1 | 0 |
| **13** | -1 | -1 | -1 | -1 | -1 | -1 | 0 |
| **14** | 1 | | | 1 | -1 | 1 | 1 |
| **15** | 1 | 0 | 0 | 0 | 0 | 1 | 2 |
| **16** | 1 | -1 | 0 | -1 | 0 | -1 | 0 |
| **17** | -2 | 0 | -1 | | -1 | 0 | 0 |
| **18** | -1 | -2 | -1 | -1 | -1 | -1 | 0 |
| **19** | 1 | 0 | 1 | 1 | 2 | 1 | 2 |
| **20** | -2 | -2 | -2 | -2 | -2 | -2 | -2 |
| **21** | 1 | 1 | 1 | 1 | 0 | 1 | 0 |
| **22** | 1 | -1 | -2 | 1 | 1 | 1 | 1 |
| **23** | -1 | 0 | 1 | -1 | -1 | 0 | -2 |
| **24** | -1 | 1 | 1 | -1 | 0 | -1 | -1 |
| **25** | | | | | | | |
| **26** | 1 | 0 | -1 | 1 | -1 | 0 | 0 |
| **27** | | | | | | | |
| **28** | 2 | -1 | -1 | 2 | 1 | 2 | 2 |

*Legend:* The instrument is likely to perform: **- 2 (very poorly)**, **-1 (poorly)**, **1 (well)**, **2 (very well)** on this criterion, **0**:The instrument would be **neutral** to this criterion.

**Posting of assurance bonds by importers of new species or agents undertaking high risk activities**

| Respondent | Effectiveness | Political feasibility | Ease of monitoring and enforcement | Cost-effectiveness | Flexibility | Equitable distribution of costs & benefits | Dynamic effects and innovation |
|---|---|---|---|---|---|---|---|
| **1** | 1 | -2 | -2 | -1 | -2 | -2 | -2 |
| **2** | 2 | 2 | 2 | 1 | -1 | -1 | 1 |
| **3** | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **4** | | | | | | | |
| **5** | 2 | 1 | 0 | 1 | 2 | 1 | 1 |
| **6** | 1 | -1 | 0 | 0 | 0 | 1 | 1 |
| **7** | 1 | -1 | 1 | -2 | 2 | 2 | 0 |
| **8** | 0 | 0 | 0 | 1 | 0 | 1 | 0 |
| **9** | 1 | 1 | 0 | 2 | 2 | 1 | 1 |
| **10** | 1 | | | 0 | -1 | | |
| **11** | 1 | 1 | 1 | 0 | | 1 | 0 |
| **12** | | | | | | | |
| **13** | | | | | | | |
| **14** | 1 | | | 1 | 1 | 1 | 1 |
| **15** | 1 | 0 | 0 | 2 | 2 | 2 | 2 |
| **16** | 1 | -1 | -1 | -1 | 0 | 0 | 1 |
| **17** | -2 | 0 | -1 | | -1 | -1 | 0 |
| **18** | 1 | -2 | 1 | -1 | 1 | -1 | 1 |
| **19** | 1 | 0 | 1 | 1 | 2 | 1 | 2 |
| **20** | 0 | -2 | 0 | -2 | 0 | 0 | 0 |
| **21** | -1 | 0 | -1 | -1 | 0 | 0 | 0 |
| **22** | 2 | -2 | -1 | 1 | 2 | 1 | 1 |
| **23** | 1 | 2 | 1 | 1 | 1 | 0 | 1 |
| **24** | -1 | 0 | -1 | -1 | -1 | -2 | -2 |
| **25** | | | | | | | |
| **26** | 2 | 1 | -2 | 2 | 1 | 2 | 1 |
| **27** | 2 | 0 | 1 | 2 | 2 | 2 | 1 |
| **28** | 0 | -1 | 1 | 0 | -1 | -1 | -1 |

*Legend:* The instrument is likely to perform: **- 2 (very poorly)**, **-1 (poorly)**, **1 (well)**, **2 (very well)** on this criterion, **0**:The instrument would be **neutral** to this criterion.

**Labelling and certification schemes**

| Respondent | Effectiveness | Political feasibility | Ease of monitoring and enforcement | Cost-effectiveness | Flexibility | Equitable distribution of costs & benefits | Dynamic effects and innovation |
|---|---|---|---|---|---|---|---|
| **1** | 2 | 2 | 2 | 2 | 2 | 2 | 0 |
| **2** | -1 | 1 | 1 | -1 | -1 | -1 | 1 |
| **3** | 1 | 0 | 1 | 1 | 1 | 0 | 1 |
| **4** | 1 | 1 | 2 | 0 | 0 | 0 | 0 |
| **5** | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| **6** | 1 | 1 | 1 | 2 | 1 | 1 | -2 |
| **7** | 0 | 0 | 2 | 2 | 1 | 0 | 0 |
| **8** | 0 | 1 | -1 | -1 | 0 | 1 | 1 |
| **9** | 2 | 2 | 0 | 2 | 2 | 0 | 1 |
| **10** | 2 | 2 | 2 | 2 | 2 | 0 | 1 |
| **11** | 1 | 2 | 0 | 1 | 0 | 0 | 0 |
| **12** | | | | | | | |
| **13** | 1 | -1 | -1 | -1 | 1 | -1 | 1 |
| **14** | | | | | | | 1 |
| **15** | 2 | 1 | 1 | 2 | 1 | 2 | 0 |
| **16** | 2 | 1 | 1 | 1 | 1 | 1 | 1 |
| **17** | 0 | | | | 1 | 1 | 0 |
| **18** | 2 | 2 | 2 | 1 | 1 | 2 | 1 |
| **19** | 1 | 0 | 1 | 1 | 2 | 1 | 2 |
| **20** | 0 | 2 | -2 | 0 | 0 | -2 | 0 |
| **21** | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **22** | 1 | 1 | 2 | 1 | 1 | 1 | 0 |
| **23** | -1 | 0 | 1 | -1 | -1 | 0 | -2 |
| **24** | 2 | -1 | 2 | 1 | -1 | 0 | 1 |
| **25** | | | | | | | |
| **26** | 1 | -1 | 2 | 1 | -2 | -1 | 0 |
| **27** | 2 | 1 | 1 | 1 | 2 | 1 | -1 |
| **28** | 0 | 1 | 1 | -1 | -1 | -1 | -1 |

*Legend:* The instrument is likely to perform: **- 2 (very poorly)**, **-1 (poorly)**, **1 (well)**, **2 (very well)** on this criterion, **0**:The instrument would be **neutral** to this criterion.