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## Public economics of hitchhiking species and tourism-based risk to ecosystem services



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### ABSTRACT

This paper is the first to examine the public economics of export-based externalities arising within the provisioning of ecosystem services, with direct application to policies to prevent the spread of hitchhiking invasive species. We find when risk enters through exports, policy makers face a tradeoff between welfare improvements and reducing risk of invasion. Estimates of visitor demand elasticity for ecotourism are low, so price policies are not likely to reduce risk, though they can raise tax revenue. If demand is elastic enough to reduce risk, trade effects can cause loss of income greater than the risk of the invasion. The paper is motivated by the expansion of invasive species' within the United States. We apply our model to the specific example of quagga and zebra mussels invasion into the U.S. Pacific Northwest.

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## 1. Introduction

This paper is the first to examine the public economics of export-based externalities arising within ecosystem services, with direct application to ecotourism and policies to prevent the spread of hitchhiking invasive species. Our approach contrasts the large literature on *import*-based spread of invasive species, which has become the dominant paradigm in research and policy. We show the useful but narrow lessons from this import-risk literature could lead to unintended consequences and be applied to problems they were not meant to address. We consider the welfare effects of correcting an externality on both the import and export sides of trade and show the source of risk matters as much as the risk itself when designing corrective measures for bioeconomic externalities posed by invasive species. We find that, when risk comes from exports, price instruments are not likely to be appropriate tools for reducing risk of invasion.

Olson (2006), Lovell et al. (2006), and Finnoff et al. (2010) review the economics literature on invasive species, including literature on managing trade-based risk. As other authors have pointed out, trade is like any other risky behavior in which humankind partakes. Agents must balance risk of contamination with enhanced opportunities from multiple trade partners. Well informed agents can optimally manage this risk by choosing private or public methods of protection and insurance (Sausgruber, 1990). Work along these lines has focused on externalities introduced through imports, and not addressed the contact with trade partners through exports and trade in domestically provided services. The story in this paper is centered around hitchhiking aquatic invasives, such as zebra and quagga mussels, but the model is applicable to any hitchhiking species and other export-based threats such as domestically owned ships, planes, and automobiles that can become contaminated while visiting other regions and bring unwanted pests home. Following the trade literature (Deardorff, 1985; Melvin, 1989; van Marrewijk et al., 1997; Copeland, 2002; Cullinan, 2005), goods and services consumed by nonresidents are exports, as payments flow from outside the region to local firms and households.<sup>1</sup>

Differentiating between import- and export-related externalities determines the ability of agents to manage the associated risk. Consumption of imports can be taxed in a way that internalizes cost of environmental damages within the regional economy (McAusland and Costello, 2004).<sup>2</sup> Environmental damages cannot be internalized when they come from exports. We show that if taxes reduce risk, they must also lower regional incomes. Taxes affect the terms of trade, and levying a tax causes declines in domestic production, and local income, large enough to offset the welfare gains from correcting the environmental problem. This result is taken for granted when discussing commodity exports, and many exported goods are subsidized. Taxes targeting visitors, however, are common (e.g., hotel taxes, rental cars, out of state fishing licenses, airport fees), consistent with evidence that voters prefer taxing others over themselves regardless of the efficiency of the taxes (Sausgruber and Tyran, 2011). Costello and McAusland (2003) show that tariffs can alter the domestic production mix making a country more or less susceptible to damages, and Tu et al. (2008) show that the resulting effect of tariffs on production mix can influence the probability of invasion by favoring imports more likely to harbor invasive species.

The focus of our paper is on differences between import and export policy perspectives. Our theoretical model purposely follows the previous literature to allow comparability of results and further an ongoing discussion within the literature, though some new features are required for our analysis. Specifically, we follow the public finance literature on environmental regulation and tax interactions. We contribute new second best welfare effects that are necessary for studying trade-based externalities. A large literature exists on potential gains from an environmental tax beyond correcting the externality, known as the ‘double dividend’ hypothesis. Oates (1995) reviews this literature and

<sup>1</sup> Recent findings of a fish virus (*viral hemorrhagic septicemia*) have restricted interstate transport of live bait in the Great Lakes area. Other examples of externalities from exported services and visitor consumption are automobile exhaust (Peretz et al., 2005), diver impact on coral reefs (Hawkins et al., 2005), and pollution tied to sporting events (Collins et al., 2007). While these externalities are well known, little has been said about the welfare effects of policies to correct these externalities.

<sup>2</sup> In a model with taxes and inspections, they find optimal tariffs are non-negative, and equal to zero if and only if inspection is costless and detection is perfect.

discusses the existence of the double dividend.<sup>3</sup> Proost and Van Regemorter (1995) examine the effect government structure has on welfare effects of corrective taxes in an open economy, and Markusen (1975) and Krutilla (1991) look at optimal taxation in partial equilibrium for an open economy. Our work builds directly on Whittier (1999) (hereafter Williams) and Taheripour et al. (2008) (hereafter TKN). Williams uses a general equilibrium model to measure welfare effects of trade policies. In his model, welfare effects are due to changes in rents from trade; he does not consider externalities. TKN derive general equilibrium effects in an open economy with a distortionary income tax and agricultural subsidies and compare welfare effects of a tax on a dirty input versus a tax on the resulting dirty output. TKN find both an input tax and output tax in a dirty agricultural sector can generate welfare gains by reducing distortionary agricultural subsidies and by shifting some of the tax burden to foreign consumers. Like TKN we find welfare effects depend on terms of trade. In light of their result, the ability to pass the entire burden to visitors in our story implies strong support for a double dividend, though we report mixed results. The different conclusions result from assumptions about substitution possibilities for clean factors of substitution and consumption goods. In our setting, *consumers* are either clean or dirty.

The motivation for this paper is the domestic spread of invasive species. It is the first paper to focus on policies directed at human mediated domestic spread despite growing concern among policy makers and ecologists about within-country dispersal. Of *100 of the World's Worst Invasive Alien Species* listed in the Global Invasive Species Database (Lowe et al., 2000), 86 species have been introduced into the United States or are increasing their range within the United States, 7 species are indigenous or non-threatening to other areas of the U.S., and only 7 have not been introduced.<sup>4</sup> These species are introduced near major ports of entry as 'hitchhikers' on international transporters or attached to the trade goods themselves, and following introduction and colonization, hitchhiking on domestic pathways expands species' ranges. A species is deemed invasive, as opposed to nonnative, if it causes economic or ecological damages in the ecosystems where it is newly established. Externalities from hitchhiking species are unique in at least two ways. First, the trade vector, where the externality originates, is itself an integral part of the supply chain that can not be decoupled from the consumption and production of goods. Second, because trade is bidirectional (no vessel returns empty) imports and exports create risk of invasion.

We apply our model to the threat of invasion by zebra and quagga mussels (*Dreissena polymorpha* and *Dreissena rostriformis bugensis*, hereafter collectively referred to as dreissenids) into the Columbia River Basin. Dreissenids are small freshwater mussels that, following an invasion, cover surfaces and clog intake pipes for industries dependent on water, requiring costly installation of mitigation equipment and additional personnel to monitor and control the effects. They are also prolific filter feeders, causing ecosystem-wide effects in the bodies of water they invade. They compete with native mussels (Ricciardi et al., 1998) and have been linked to declines in catches and conditions of sport fish (Ohio Sea Grant, 1996; Nalepa, 1998; Marsden and Chotkowski, 2001; Strayer et al., 2004) and lost recreational opportunities (Vilaplana and Hushack, 1994).

The Columbia River Basin is roughly represented by the United States Pacific Northwest. Its drainage area exceeds 260,000 mile<sup>2</sup>, an area larger than France. It includes portions of seven U.S. states and British Columbia. Coordination of basin management among U.S. states is achieved by federal programs, including the Environmental Protection Agency's Council of Large Aquatic Ecosystems and the Department of Agriculture's Invasive Species Program. Across-agency and international coordination is the jurisdiction of the 100th Meridian Initiative, a long-standing working group of Western States and Canadian Provinces tasked with preventing the spread of zebra and quagga mussels. Programs are

<sup>3</sup> There is a well-established literature on welfare effects of environmental taxes, including Bovenberg and de Mooij (1994), Bovenberg and van der Ploeg (1994), Parry (1995), Goulder (1995), Goulder et al. (1997), Fullerton and Metcalf (2001), and Whittier (2002). Expanding the scope of problems to include export-related externalities, we find taxes can also reduce the gains from trade, thereby reducing overall welfare.

<sup>4</sup> Some introductions were purposeful, with full understanding of their damages coming after populations became established. These figures include introduction into and between Hawaii and U.S. island territories. Included in the seven currently absent are two seaweeds, a seastar, and a comb jelly.

sponsored by local wildlife agencies and financed in part by license revenues. They maintain inspection stations for invasive species and have authority to impose fines.

The Columbia River Basin is an ideal case study for four reasons. First, the basin's location in the Pacific Northwest has protected it from introduction from non-U.S. sources. Dreissenids arrived in the U.S. through shipping channels connecting the East Coast and Europe. There are no dreissenid threats from Asia, so the only realistic vectors of introduction into the Columbia River Basin are of U.S. origin. Second, the Rocky Mountains and the Continental Divide have provided barriers of natural introduction. No body of water in the Columbia River Basin is directly connected to any currently invaded body of water making within-stream dispersal impossible. Introduction must occur through overland transport, of which trailored boats are the most likely vector (Warziniack et al., 2011). Third, policy makers in the Columbia River Basin fear impacts from a dreissenid invasion will be large. It is estimated that invasion of zebra or quagga mussels into the Columbia River Basin will lead to over \$23.6 million in additional direct costs to federal hydropower facilities (Phillips et al., 2005). Both invasion and the policies to prevent invasion are likely to affect recreational fishing and boating in the Columbia River Basin and the industries that support them. Nearly 4 million recreational fishing licenses, permits, and stamps were sold to anglers in the Columbia River Basin in 2007, over 700,000 of which were to non-residents (United States Fish and Wildlife Service (USFWS), 2007). Two million individuals spent \$50 million on licenses, and according to the American Sportfishing Association (2008), added \$3 billion to the local economies. Fourth, there exists data on the suitability of basin waters as dreissenid habitat and on boat movement between these bodies of water and infested regions of the U.S. (Solow, 1991; Drake and Bossenbroek, 2004; Bossenbroek et al., 2009, 2007; Whittier et al., 2008). Bossenbroek et al. (2007) estimate the overland boat traffic potentially infected with dreissenid mussels traveling to the Columbia River Basin in a given year. The mere threat of invasion these boats carry has already caused impacts in the region, and while some risk will probably always remain, policies try to eliminate as much of that threat as possible.

Taxes and quotas imposed on another state's residents, common in controlling international trade, are forbidden by the (Dormant) Commerce Clause of the U.S. Constitution and to a lesser extent the Equal Protection Clause of the U.S. Constitution.<sup>5</sup> Fees issued for wildlife and natural resource management, however, routinely differ between in-state and out-of-state consumers, a practice that has been debated in the courts (Baldwin v. Fish, 1978; Douglas v. Seacoast Products, 1977) and introduced in legislation by the Reaffirmation of State Regulation of Resident and Nonresident Hunting and Fishing Act of 2005. The courts have traditionally upheld a state's right to charge different rates to nonresidents for game licenses and limit access to public lands. The courts do not, however, allow states to discriminate between nonresidents from different states.<sup>6</sup>

In what follows, we develop the analytical model and derive analytical welfare effects of environmental taxes for this class of externality in the fashion of Bovenberg and de Mooij (1994), Fullerton and Metcalf (2001), and Whittier (2002). We implement the method in a regional computable general equilibrium (CGE) model for the Columbia River Basin and calculate lost welfare associated with uncertainty and welfare effects of corrective taxes. A brief discussion concludes.

## 2. General equilibrium model

The model follows the general equilibrium models of Williams and TKN. To Williams' model we add an uncertain environmental externality due to trade, which also differs from TKN in that our externality is tied to the trade vector rather than production. Like both of these papers, we consider an open economy but extend the analysis to  $I$  regionally produced goods, indexed by  $i$ . This extension

<sup>5</sup> See Complete Auto Transit v. Brady (1977) and Conservation Force (2002).

<sup>6</sup> The Commerce Clause is an article of the Constitution that gives Congress the power to regulate commerce among the States. Because the Commerce Clause explicitly gives Congress the right to regulate interstate trade, the courts have defined an implied (or dormant) clause that limits states' power to do so. The Dormant Commerce Clause relies on an inaction by Congress, and a number of regulations are permitted because Congress has written them into law, that is, Congress has acted. This model applies to all areas where Congress has acted or may act in the future, including transportation fees, toll booths, restrictions on transport of freight, hotel taxes, and speed limits.

allows our analytical model to mirror the computational model used in the Columbia River Basin example. The results presented in this section allow us to study impacts that occur in similar CGE models, but are difficult to decipher.

The economy has two types of goods. Goods of type  $X \subset I$  are consumed by residents and foreigners (i.e., exported), and goods of type  $Y \subset I$  are both produced locally and imported. Export and import goods are indexed by lower-case letters,  $x$  and  $y$ .  $X \cap Y = \emptyset$ , and  $X \cup Y = I$ . At least one good  $x' \in X$  is consumed by foreigners within the region. We refer to these goods as tourist goods and those that consume them as visitors.

The country is assumed to be a small country with regard to imports  $m_y(p_y)$  with fixed world prices  $p_y$ . Import demand is determined by the usual Armington assumptions (Armington, 1969). Export demand  $m_x(p_x)$  is elastic and downward sloping, where  $p_x$  is the price paid by resident consumers (De Melo and Tarr, 1992). If a tax  $\tau_x$  is levied on good  $x$ , a balance of trade implies<sup>7</sup>

$$\sum_{y \in Y} p_y m_y(p_y) = \sum_{x \in X} (p_x + \tau_x) m_x(p_x + \tau_x)$$

Total regional output in each sector is represented by  $F_i$ . Each good is produced using a composite of primary value-added inputs, which we will call labor  $L$ , and nonrivalrous ecosystem services  $Q$ , with constant return to scale production functions  $F_i(L_i, Q)$ . With probability  $\gamma$  an invasion occurs that degrades ecosystem quality forcing the firm to adopt a less efficient production technology. Faced with uncertainty about the state of the environment, firms choose labor to maximize expected profits,

$$\pi_i = \hat{p}_i [\gamma F_i(L_i, Q^d) + (1 - \gamma) F_i(L_i, Q^o)] - L_i; \quad i \in I$$

where  $\hat{p}_i$  indicates the domestic price of good  $i$  and the wage rate is numeraire. Superscripts denote degraded ( $d$ ) and original ( $o$ ) states of the environment. Our formulation with expected profit is meant to capture current behavior from anticipation of an invasion. Rapid spread, lag time between introduction and discovery, and time required to install equipment implies threats in areas even without known established dreissenid populations (Solow and Costello, 2004). Firms and government agencies exist in a state of uninvaded anticipation, and many firms are already investing in equipment and technologies assuming an invasion will occur. Risk of invasion causes real loss of resources.

In case of an import tariff the price that locals pay for good  $y$  is  $\hat{p}_y = p_y + \tau_y$ . We assume firms cannot discriminate between consumers, so prices for all  $x \in X$  are the same for locals and visitors, i.e.,  $\hat{p}_x = p_x$ . The government, however, can discriminate. This story applies to a wide range of goods and services, depending on the level of industry aggregation. We have in mind fees for wildlife licenses, local hotel taxes, and airport fees, all of which are indirect taxes on complementary goods and services (e.g., gear, gas, food). The first order conditions for firms require a balance between the expected marginal revenue product of labor and its marginal cost, or the ratio of input to output price to equal the expected marginal product of labor

$$\frac{1}{\hat{p}_i} = \gamma \frac{\partial F_i(L_i, Q^d)}{\partial L} + (1 - \gamma) \frac{\partial F_i(L_i, Q^o)}{\partial L} \quad (1)$$

Defining  $\tilde{F}_i(L_i, \gamma) = \gamma F_i(L_i, Q^d) + (1 - \gamma) F_i(L_i, Q^o)$ , Eq. (1) can be written

$$\frac{1}{\hat{p}_i} = \frac{\partial \tilde{F}_i(L_i, \gamma)}{\partial L}$$

Because invasion caused by any one visitor is likely to lead to widespread damages, we model the probability of invasion as a weak-link public good as in Perrings et al. (2002) and Horan et al. (2002). We assume the habitat is conducive to host the invasive species (Drake and Bossenbroek, 2004) and all

<sup>7</sup> In the short run, trade balance may not hold for small sectors of the economy such as tourism. In the long run, however, trade balance is required in general equilibrium.

visitors' actions are exactly alike in that they carry the same probability of invasion  $q$ . The probability of a successful introduction occurring by any visitor is

$$\gamma(N) = \Pr(Z \geq 1) = 1 - \prod_{n=1}^N (1 - q) = 1 - (1 - q)^N$$

where  $Z$  is the number of times the invasive species invades the ecosystem. The probability increases with the number of visitors  $N$ , and as  $N$  approaches infinity, invasion is virtually certain.

We link number of visitors to visitor spending following the random utility and travel cost literature (e.g., Hausman et al., 1995; Cullinan, 2011; Champ and Boyle, 2003). The number of nonresident visits to the region is a function of price of visitor goods,

$$N = \exp(\beta(p_{x'} + \tau_{x'})) \quad (2)$$

where  $\beta$  is an estimated parameter given in the literature. For this analysis, we assume only trip cost changes, and within trip costs, only the price changes for a fixed bundle of goods,  $b$ , required to enjoy tourist-based activities. Total visitor demand is  $m_{x'} = Nb$ , and demand elasticity is  $\beta(p_{x'} + \tau_{x'})$ .

A representative domestic household is endowed with time  $T$  that it devotes to either labor or leisure  $l$ . In addition to labor income, the household receives government transfers  $G$  and the total of any firm profits  $\Pi = \sum_{i \in I} \pi_i$ , which the household takes as given.

Household income is used to purchase each good in amounts  $c_i$ , pay tariffs on imports, and pay a tax on labor income at rate  $\tau_L$ . Households are assumed to be removed enough from the risk that they only observe it as variations in prices they take as given, so uncertainty does not enter into the household decision problem. The household has constant elasticity of substitution utility function

$$U(c_1, c_2, \dots, c_I, l)$$

and faces budget and time constraints

$$(1 - \tau_L) \sum_i L_i + G + \Pi = \sum_{x \in X} p_x c_x + \sum_{y \in Y} \hat{p}_y c_y$$

$$\sum_i L_i + l = T$$

We assume the utility function is continuous and quasi-concave. Letting  $\lambda$  be the marginal utility of wealth, the first order conditions for the household are

$$U_{c_x} = \lambda p_x; \quad U_{c_y} = \lambda(p_y + \tau_y); \quad U_l = \lambda(1 - \tau_L) \quad (3)$$

Government behavior is closed in the model by assuming a balanced government budget and a fixed income transfer to households in amount  $G$ . The transfer is financed with labor taxes, visitor taxes, and import tariffs.<sup>8</sup> Changes in tax rates on trade goods lead to adjustments in the tax rate on labor. The government budget constraint is

$$G = \sum_i (\tau_L L_i + \tau_i m_i)$$

In equilibrium, the goods market clears when  $F_x = c_x + m_x$  and  $F_y = c_y - m_y$  for all  $x \in X$  and  $y \in Y$ . The labor market clears when  $\sum_i L_i + l = T$ .

<sup>8</sup> A labor tax is used for comparability with other studies. In reality, governments use a combination of tax types. The model could be extended, for example, to include public goods financed through sales taxes.

### 3. Tax policies in general equilibrium

This section analyzes the welfare effects of tax policies aimed at correcting externalities associated with import- and export-related risk. Our general equilibrium model is intentionally similar to those used in the public finance literature on environmental regulation and tax interactions (Goulder, 1995; Oates, 1995; Goulder et al., 1997; Whittier, 1999; Taheripour et al., 2008). These approaches are the most well-developed tools for general equilibrium welfare analysis and the only ones we found capable of addressing the import-export differences that interest us. Within this literature, a tax is used to correct the environmental externality, and the revenue is used to reduce pre-existing taxes (usually on labor). Reductions in other taxes are required to maintain a balanced government budget. They are an additional means of compensating households and have the potential of correcting other distortions in the economy – the so-called ‘double-dividend’ associated with environmental taxes.

We lay the groundwork for our analysis by showing how additional tax revenue is used to compensate households and how any tax affects the pre-existing distortion in the labor market. We then use these results in welfare analysis of import and export taxes. There are two key results in this paper. (1) Welfare effects differ between import and visitor taxes. (2) When risk enters through hitchhiking species and tourist activities, the policy can either reduce the probability of an invasion or raise revenue. It cannot do both. This trade-off between revenue and risk associated with hitchhiking species is new in the invasive species literature.

With neither a labor tax nor threat of invasion, we have the standard open economy equilibrium. The marginal rate of substitution and marginal rate of transformation for any two goods in the local economy equal the ratio of world prices. Assuming the uncompensated labor supply elasticity is positive, the labor tax causes households to withhold labor, and the invasion causes a loss in productivity of local firms. Both reduce production possibilities within the economy. To correct these distortions the government levies taxes on visitors or residents to reduce the probability of invasion and uses the revenues to decrease labor taxes. We treat each instrument separately, assuming risk either comes from visitors or imported goods, not both, and show the consequences differ between taxes. In reality, risk comes from both sources and the optimal policy may be a mix of taxes. This mix is not the focus of this paper.

In either case, corrections in the labor market depend on the size of the reduction in the labor tax and the interaction between labor and trade taxes resulting from changes in the real wage. For a tax on good  $j$

$$\frac{dl}{d\tau_j} = \frac{\partial l}{\partial \tau_j} + \frac{\partial l}{\partial \tau_L} \frac{d\tau_L}{d\tau_j} \quad (4)$$

Totally differentiating the government budget constraint gives

$$dG = \sum_i (\tau_L dL_i + L_i d\tau_L + \tau_i dm_i + m_i d\tau_i) = 0$$

Assuming  $d\tau_i = 0$  for  $i \neq j$ , the above can be rearranged to get

$$\frac{d\tau_L}{d\tau_j} = \frac{\tau_L(\partial l/\partial \tau_j) - \sum_i \tau_i(dm_i/d\tau_j) - m_j}{(T - l) - \tau_L(\partial l/\partial \tau_L)}$$

Substituting into Eq. (4) gives

$$\frac{dl}{d\tau_j} = \frac{\partial l}{\partial \tau_j} (1 + z) - z \frac{m_j + \sum_i \tau_i(dm_i/d\tau_j)}{\tau_L} \quad (5)$$

where  $z$  is the marginal excess burden of labor taxation (Goulder et al., 1997),

$$z = \frac{\tau_L(\partial l/\partial \tau_L)}{(T - l) - \tau_L(\partial l/\partial \tau_L)}$$



If only good  $j$  is taxed, the effect on leisure can be written

$$\frac{dl}{d\tau_j} = \frac{\partial l}{\partial \tau_j}(1+z) - z \frac{m_j(1+\eta_j)}{\tau_L} \quad (6)$$

where  $\eta_j = (dm_j/d\tau_j)/(m_j/\tau_j) < 0$  is the price elasticity of  $j$ .

Eq. (6) contains two well-known effects in the public finance literature. The first term is the tax-interaction effect. Taxes change the relative returns to labor, and can increase or decrease leisure consumption. The total change is amplified by the marginal excess burden of the income tax. The second term is the revenue recycling effect. It is the gain in efficiency from reducing the tax on labor. It equals the marginal excess burden of labor taxation multiplied by the marginal revenue from the tariff. These two effects play key roles in our analysis of trade taxes. We apply this general framework to the specific cases of import and export taxes and expand the analysis to include welfare effects associated with trade policies.

### 3.1. Tax on imports

The traditional approach in invasive species research is to assume the threat of invasion increases with imports, i.e.,  $\gamma'(m_Y)$ ,  $\gamma'(m_Y) > 0$ , and to use an import tariff to reduce the threat. In this setting  $\tau_{y'} > 0$  for some  $y' \in Y$ ,  $\tau_y = 0$  for  $y \neq y'$ , and  $\tau_x = 0$  for all  $x \in X$ . The change in welfare is found by taking the derivative of utility with respect to  $\tau_{y'}$  and dividing by  $\lambda$  to get

$$\frac{1}{\lambda} \frac{dU}{d\tau_{y'}} = \sum_x p_x \frac{dc_x}{d\tau_{y'}} + \sum_y (p_y + \tau_y) \frac{dc_y}{d\tau_{y'}} + (1 - \tau_L) \frac{dl}{d\tau_{y'}}$$

Noting  $d\tilde{F}_i/d\tau_{y'} = (\partial\tilde{F}_i/\partial\gamma)(d\gamma/d\tau_{y'}) + (\partial\tilde{F}_i/\partial L_i)(dL_i/d\tau_{y'})$  and using the goods market clearing conditions,

$$\begin{aligned} \frac{1}{\lambda} \frac{dU}{d\tau_{y'}} &= \sum_x p_x \left( \frac{\partial\tilde{F}_x}{\partial\gamma} \frac{d\gamma}{d\tau_{y'}} + \frac{\partial\tilde{F}_x}{\partial L_x} \frac{dL_x}{d\tau_{y'}} - \frac{dm_x}{d\tau_{y'}} \right) + \sum_y \hat{p}_y \left( \frac{\partial\tilde{F}_y}{\partial\gamma} \frac{d\gamma}{d\tau_{y'}} + \frac{\partial\tilde{F}_y}{\partial L_y} \frac{dL_y}{d\tau_{y'}} + \frac{dm_y}{d\tau_{y'}} \right) \\ &\quad + (1 - \tau_L) \frac{dl}{d\tau_{y'}} \end{aligned}$$

Using the firm's first order conditions and  $\sum_i dL_i/d\tau_{y'} + dl/d\tau_{y'} = 0$ ,

$$\frac{1}{\lambda} \frac{dU}{d\tau_{y'}} = \sum_i \hat{p}_i \frac{\partial\tilde{F}_i}{\partial\gamma} \frac{d\gamma}{d\tau_{y'}} - \sum_x p_x \frac{dm_x}{d\tau_{y'}} + \sum_y \hat{p}_y \frac{dm_y}{d\tau_{y'}} - \tau_L \frac{dl}{d\tau_{y'}} \quad (7)$$

Differentiating the trade balance equation gives

$$\sum_y \left( p_y \frac{dm_y}{d\tau_{y'}} + m_y \frac{dp_y}{d\tau_{y'}} \right) - \sum_x \left( p_x \frac{dm_x}{d\tau_{y'}} + m_x \frac{dp_x}{d\tau_{y'}} \right) = 0 \quad (8)$$

Subtracting (8) from (7), using Eq. (6), and assuming a small country with respect to imports so  $dp_y = 0$  for all  $y \in Y$ , we can write

$$\frac{1}{\lambda} \frac{dU}{d\tau_{y'}} = \sum_i \hat{p}_i \frac{\partial\tilde{F}_i}{\partial\gamma} \frac{d\gamma}{d\tau_{y'}} + \sum_x m_x \frac{dp_x}{d\tau_{y'}} + m_{y'} \eta_{y'} + z m_{y'} (1 + \eta_{y'}) - (1 + z) \tau_L \frac{dl}{d\tau_{y'}} \quad (9)$$

Eq. (9) is comparable to the welfare effect derived in Williams and is discussed in detail in his paper. The first term represents the primary welfare effect. It is the gains from reducing the probability of invasion. The second and third terms are the primary trade effect. It represents the change in value of exports and reduced demand from imports following the policy. The primary welfare effect and the primary trade effect equal the efficiency effect in the first-best case. Without labor distortions an



optimal tax would account for these two effects. With preexisting distortions, the relative sizes of the revenue recycling effect (fourth term) and the tax-interaction effect (fifth term) determine whether a double dividend exists and whether welfare increases or decreases from the first-best solution. We now consider a visitor tax.

### 3.2. Tax on visitors

If the threat of invasion is from hitchhiking species and visitors,  $\gamma'(m_X)$  and  $\gamma'(m_X) > 0$ . Recognizing the source of risk, the government levies a visitor tax such that  $\tau_{x'} > 0$  for some  $x' \in X$ ,  $\tau_x = 0$  for  $x \neq x'$ , and  $\tau_y = 0$  for all  $y \in Y$ . Revenues from the visitor tax are used to reduce income taxes. Domestic prices are not directly affected by a tax on exports. The only direct effect is on export demand, which is assumed to fall according to  $m'_{x'}(p_{x'}) < 0$ .

The process for deriving welfare effects for the visitor tax is similar to that for the import tax. The major differences are in the balance of trade condition, which is differentiated to yield

$$1 + \sum_x \left( (p_x + \tau_x) \frac{dm_x}{d\tau_{x'}} + m_x \frac{dp_x}{d\tau_{x'}} \right) - \sum_y \left( p_y \frac{dm_y}{d\tau_{x'}} + m_y \frac{dp_y}{d\tau_{x'}} \right) = 0$$

Domestic price changes are due to general equilibrium adjustments rather than direct policy. Without a direct effect on prices,  $\partial l / \partial \tau_{x'} = 0$ , eliminating the tax-interaction effect. The change in welfare from a visitor tax is

$$\frac{1}{\lambda} \frac{dU}{d\tau_{x'}} = \sum_i p_i \frac{\partial \tilde{F}_i}{\partial \gamma} \frac{d\gamma}{d\tau_{x'}} + \sum_x m_x \frac{dp_x}{d\tau_{x'}} + m_{x'} \eta_{x'} + m_{x'} (z(1 + \eta_{x'}) + 1) \quad (10)$$

The first term on the right is the primary welfare effect. The second and third terms are the primary trade effect. The fourth term is the revenue recycling effect. Comparing Eq. (10) to Eq. (9), Eq. (10) has an additional  $m_{x'}$  in the revenue recycling effect and does not have a tax-interaction effect. We examine each effect in turn and compare results between import and visitor tax scenarios.

### 3.3. Comparing tax policies

The primary welfare effect shows the ability of a tax to reduce the threat of invasion. For simplicity we assume both tariffs and visitor taxes are equally effective in reducing the threat. The size of the effect will depend on the elasticity of the good being taxed. If demand for the risky sector is elastic, a tax will effectively reduce the threat and cause expected productivity of labor to rise. Wages and incomes will rise accordingly.

With an import tax, the domestic price for  $y'$  rises causing import demand to fall by  $m_{y'} \eta_{y'}$ . To maintain balanced trade, adjustments must occur in the export markets. As households substitute for other goods, increased demand for at least some  $x \in X$  raises their prices. Increases in the price of export goods cause visitor demand to fall, highlighting a well-known result in general equilibrium models – a tax on imports is an implicit tax on exports (Brenton et al., 1997). Provided visitor demand does not fall too much, part of the burden of the import tax can be passed on to foreign consumers. The sign of the trade effect depends on the parameters of the system. This result is consistent with TKN's model with an import tariff.

A visitor tax reduces demand for  $x'$  by  $m_{x'} \eta_{x'}$ . As demand adjusts,  $p_{x'}$  will fall. Because domestic producers cannot differentiate between resident and nonresident consumers, welfare falls according to the share of nonresident consumption in total demand shown by  $m_{x'}(dp_{x'}/d\tau_{x'})$ . Some substitution possibilities exist, but expenditures on other goods can be no larger than that spent on the bundle preferred in the lower-tax scenario,  $\sum_x m_x(dp_x/d\tau_x) \leq 0$ . With an export tax, the primary trade effect is unambiguously negative.

The revenue recycling effect is fundamentally different between import and visitor taxes. In both cases it depends on the ability to generate revenue and offset the labor tax, and so it depends on the amount of distortion in the labor market, the elasticity of demand for the good being taxed, and the

size of the tax base. Benefits of the revenue recycling effect increase with the size of the distortion in the labor market. Inelastic goods and goods consumed in larger amounts will more effectively raise revenue, but taxes on highly elastic goods lead to a decline in tax revenues, in which case maintaining a balanced government budget requires raising the labor tax. It is important to note that we are assuming adjustments to a pre-existing tax (in our example, raising license fees or visitor taxes). Introducing a new tax cannot decrease tax revenues through the revenue recycling effect. An export tax also raises  $m_{x'}$  in tax revenue from people living outside of the region; the revenue recycling effect also includes pure income benefits that exist regardless of pre-existing distortions.

The tax-interaction effect only appears with an import tax. We assume a visitor tax only raises prices for nonresidents and has no direct effect on the labor-leisure choice of the resident household. For a visitor tax, the existence of a double dividend depends entirely on the revenue recycling effect. Under an import tax, higher prices on the import good reduce real wages. The effect is usually negative unless the import good is highly complementary with leisure (Atkinson and Stiglitz, 1972). In such cases the tariff could increase labor supply, raising welfare. In our example,  $x'$  is recreational boating, which is likely to be more complementary than other goods with leisure, suggesting a welfare-reducing tax-interaction effect.

The sum of all effects hinges on a key economic behavioral parameter, the elasticity of nonresident demand, and its relationship with a key parameter at the intersection of the economic and ecological processes, the probability of invasion. If demand is highly inelastic, welfare effects of an import tax depend on the relative sizes of the revenue recycling effect and the tax-interaction effect. The primary welfare effect and the primary trade effect are likely to be small. The welfare effects of an export tax depend on the size of the revenue recycling effect. This implies net welfare effects with inelastic demand are ambiguous with an import tax but most likely positive with a visitor tax. Neither tax, however, effectively reduces the probability of invasion. Welfare gains are through secondary effects on prices and revenue generated by the tax on trade.

If demand is highly elastic, all effects must be considered carefully to determine the net change in welfare with either tax. The primary welfare effect is likely to be large and positive, but the trade effect and the revenue recycling effect could be large and negative. Our key result is that, the more effectively the policy reduces risk, the more likely it reduces incomes and tax revenues. The relationship between elasticity of demand and ability to raise revenues through higher prices is a fundamental economic principle, regardless of setting.

#### 4. Columbia River Basin as an example

We first discuss the effects of a visitor tax aimed at preventing a dreissenid invasion into the Columbia River Basin, then compare these results with a tax on imports that achieves similar reductions in risk. The application implements the analytical model and provides numerical results that are the net of the indeterminate analytical results. For the computational model, we use nested constant elasticity of substitution functions for production  $F_i$  and utility  $U(c_i, l)$ . In  $F_i$ , primary inputs are aggregated into one valued-added input in the lower nest, then combined with intermediate inputs in the upper nest. In  $U(c_i, l)$ , the upper nest represents the household's choice between consumption and leisure, and the second nest determines the bundle of goods consumed. The constant returns to scale assumption for production allows us to model changes in environmental quality as additional costs to produce a given level of output when the environment is degraded. These functions are typical in the literature; detail on their use and calibration are given in De Melo and Tarr (1992), Rutherford (2002), Sancho (2009), and Warziniack et al. (2011). The model is written in GAMS and solved using the PATH solver. GAMS code and computational detail is provided on the project's website (url to be provided after final review and included as online appendix with the journal), or provided upon request. Our numerical results are intended to comment on the relative size of welfare effects between policies and sources of risk for a given set of assumptions. They are not intended to serve as point estimates of specific policy impacts. We acknowledge the impact measurements are sensitive to choices of parameter values and assumptions, and should be treated accordingly (Shoven and Whalley, 1984).

In the Columbia River Basin context, nonresident refers to all consumers living outside of the basin, and trade is defined as all economic exchange with U.S. residents living outside the basin and

consumers living outside of the U.S. Visitors enter the Columbia River Basin to consume fishing and boating experiences, which we aggregate into one industry called ‘recreational boating’ that provides fishing licenses, hotels, restaurant dining, gas, etc. Implementable policies are constrained by lack of information on behavior of nonresidents that fish without boats and boaters that do not fish. This precludes the ability to separate boaters and anglers in our analysis. There is no current license requirement for nonresident boating that could be taxed in a policy targeting boaters and anglers separately. We proceed by assuming a constant ratio between boaters and anglers, but acknowledge the limitations imposed by this assumption.

Bossenbroek et al. (2007) describes boater movement throughout the country and gives the number of boats traveling to or within the Columbia River Basin in relation to other regions in the U.S. Updating the 2006 work to account for post-2007 invasion in other regions of the Western U.S., Bossenbroek (unpublished data) finds the current probability of a successful invasion  $\gamma(N)$  into the Columbia River Basin to be as high as 75 percent over the next 20 years.<sup>9</sup> The predicted relative number of boats  $N$  is 2138. This corresponds to a per boat probability of invasion of 0.065 percent.

Large industrial sectors of the Columbia River Basin will be affected by a dreissenid invasion, particularly industries such as power and agriculture that depend on the services of large federal dams. We model nine production sectors in our CGE,  $I = \{\text{state and municipal power generation, federal power generation, independent power production, municipal water, irrigated agriculture, non-irrigated agriculture, fish hatcheries, recreational fishing, and a catchall miscellaneous sector}\}$ . Of these, we expect significant efficiency losses in production for all power generation, municipal water, irrigated agriculture, and fish hatcheries.<sup>10</sup> With the exception of recreational boating, the Columbia River Basin is assumed to be a ‘small country’ in trade, and standard Armington assumptions (Armington, 1969) are used to define demand functions for imports and exports,  $m_i$  for  $i \neq x'$ . We assume regulators cannot discriminate between boaters from dreissenid regions and other out-of-state boaters, so all nonresident boaters are taxed. This provides an upper bound on the outcomes of the policy (all probabilities of invasion decline) and consequences of the tax (all nonresidents pay the tax) as regionally specific taxes could be targeted and have the same outcome yet distort the choices of fewer boaters. Hicksian equivalent variations are used to measure welfare changes.

#### 4.1. Tax on visitors

Without preventative efforts, threat of a zebra mussel invasion causes an expected annual \$3.2 million welfare loss across all households. This serves as our base for policy comparisons. Net changes in welfare to residents from a visitor tax depend on the elasticity of demand for nonresident boating and the relative magnitudes of the revenue recycling effect, the primary welfare effect, and the primary trade effect.

Fig. 1 shows the change in welfare to residents following a visitor tax for estimates of  $\beta$  found in the literature: 0.057 (Hausman et al., 1995), 0.710 (Cullinan, 2011), and 5.000 (a large number, not found in the literature but used for comparison). Total welfare change is shown in Panel a; the primary welfare effect, primary trade effect, and revenue recycling effect are shown in Panels b–d.

As the tax rate on nonresident boating increases, the number of visitors decreases, and the probability of invasion decreases. Tax revenues are used to reduce household labor taxes, providing the primary means of compensating resident households. Demand elasticities implied by estimates of  $\beta$  are extremely low, leading to welfare gains in all but the most extreme scenario considered. For  $\beta = 5$  and tax rates above 175 percent, tourists stop visiting the basin completely. Damages from the invasion are eliminated through the primary welfare effect, but reduced trade causes over \$6.5 million in

<sup>9</sup> The first of an increasing number of dreissenid mussel populations was discovered in the western United States in 2007, at least 1600 km west of previously known established populations. Initial invasions into the West were most likely a result of boater movements across the continent (Bossenbroek et al., 2009), but new beachheads of invasion exist in Colorado, specifically Pueblo Reservoir and Lake Granby, and the Colorado River watershed. Established populations in Lakes Mead and Powell have already led to downstream spread to the California Aqueduct and multiple reservoirs in California.

<sup>10</sup> Direct costs to industry are described in the supplemental material and in Warziniack et al. (2011).

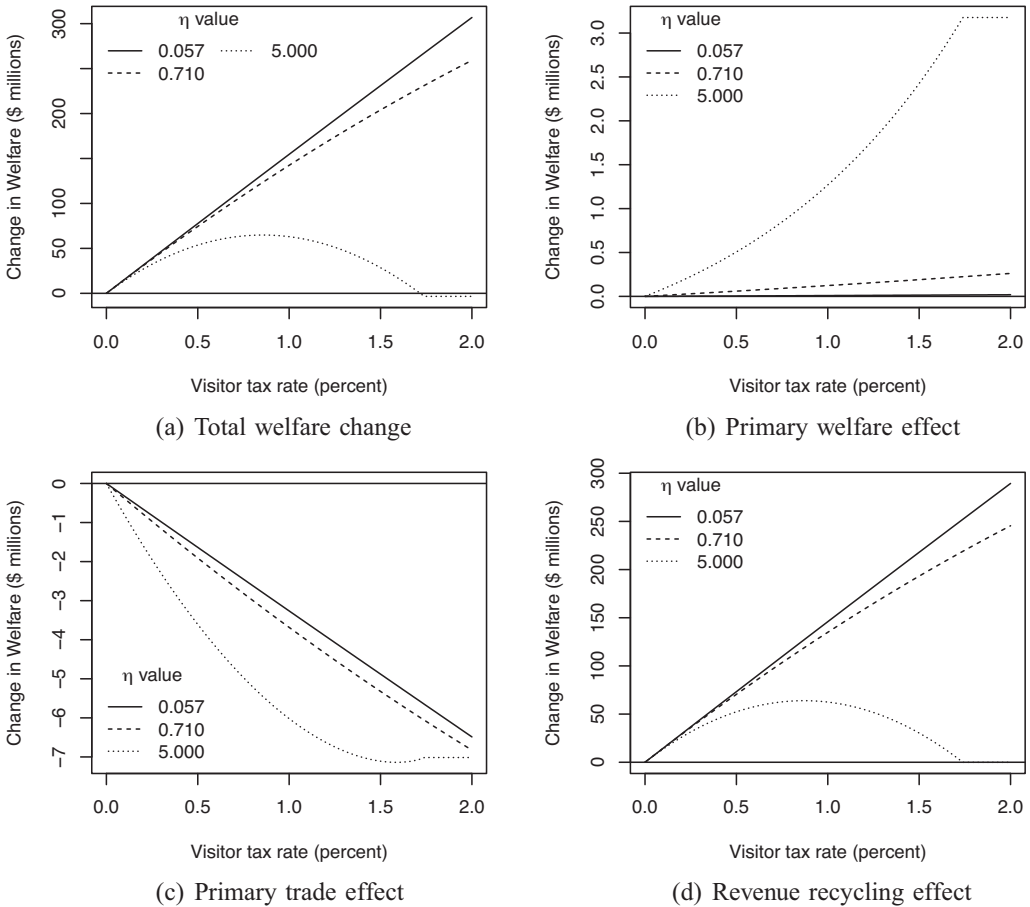


Fig. 1. (a–d) Welfare effects of tax on exports.

losses through the primary trade effect. While illustrative, this scenario is not realistic through price-based policies. It is possible, however, through quantity-based policies. Shutting down the fishery to nonresident boaters has been recommended by some reactionary residents. Welfare losses of such an action would be double the market impact from a dreissenid invasion.<sup>11</sup> This provides an upper bound on non-market impacts of a dreissenid invasion required to justify shutting down the fishery.

In all other scenarios, the revenue recycling effect dominates the other effects, indicating the importance of local governments' ability to capture tax revenues. Without the ability to offset other taxes, corrective measures reduce welfare below the base case with an invasion and no policy, shown by the relative sizes of the primary welfare and trade effects. We decompose these effects into the three parts. For the sake of reference, we call the scenario with corrective taxes and full welfare impacts the baseline scenario. When, for example, we refer to the probability of invasion in the baseline scenario, we mean the probability of invasion that results from the corrective tax, similarly for the baseline level of exports, baseline tax level, and baseline consumption of leisure.

<sup>11</sup> Welfare losses from shutting down the fishery would be the same as those under a tax that stops all tourists from visiting the region, i.e., \$6.5 million.

*4.1.1. Primary welfare effect: taxing nonresident consumption decreases the probability of invasion, causing overall welfare to rise*

The primary goal of our policy is to correct the externality by decreasing the probability of invasion. We measure the primary welfare effect by pegging probabilities of invasion to those achieved in the baseline level and running the model without imposing a tax. The results are shown in Panel b of Fig. 1. Higher elasticities lead to larger reductions in nonresident visitors in the baseline scenario, and larger reductions in the probability of invasion. Only the outrageously large value for  $\beta$ , however, leads to meaningful reductions in risk. The Hausman et al. (1995) estimate tracks near zero for all tax levels. For real world reduction in invasive species risk, price instruments are not likely to be effective. Taxable expenditures directly tied to recreational boating are a small part of total expenditures on the activity, and recreational activities contain high non-use values that cannot be taxed at all.

*4.1.2. Primary trade effect: taxing nonresident consumption causes demand for locally owned factors to fall, reducing overall welfare*

Nonresident demand brings money into the Columbia River Basin. Policies aimed at reducing non-resident demand may reduce regional incomes. We measure the size of this effect by setting the levels of exports equal to the baseline levels and setting the probability of invasion and the tax rate equal to zero. Results are shown in Panel c of Fig. 1. Low values of  $\beta$  lead to a low primary trade effect, though it is larger than the primary welfare effects for the same value of  $\beta$ . A 100 percent tax rate reduces the number of boaters by about 8 percent when  $\beta = 0.710$ . It takes an 87 percent tax to reduce visiting boaters by 50 percent with  $\beta = 5$ . For  $\beta = 0.71$  and  $\beta = 5$ , an 87 percent tax leads to primary welfare effects equal to \$0.106 million and \$1.04 million and primary trade effects equal to −\$3.2 million and −\$5.5 million. Considering just the primary welfare and trade effects, corrective taxes lead to welfare losses that exceed the losses of an invasion.

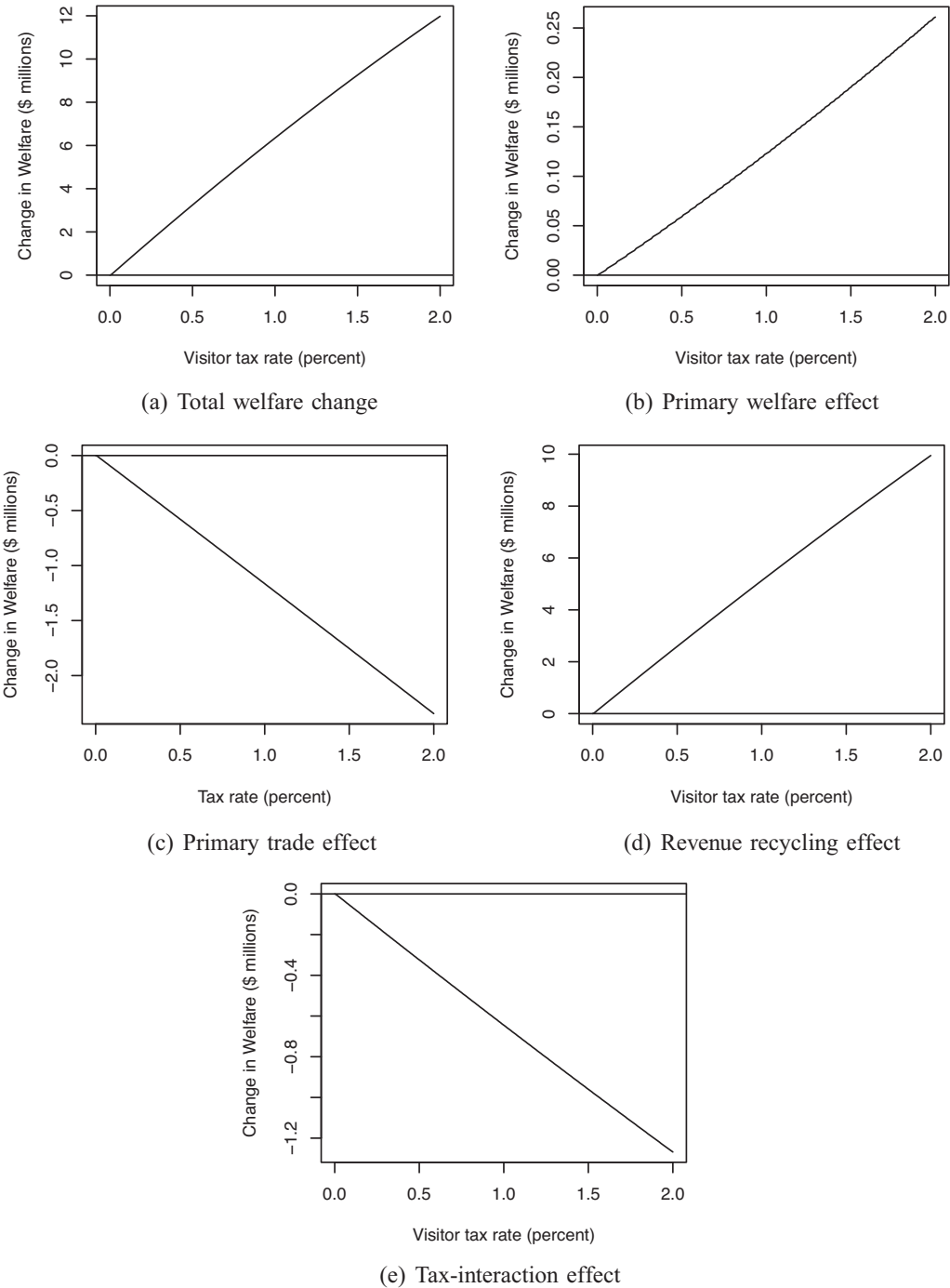
*4.1.3. Revenue recycling effect: reduced labor taxes cause income to go up, increasing overall welfare*

The revenue recycling effect is shown in Panel d of Fig. 1. We measure the size of the revenue recycling effect by setting the probability of invasion and tax rate on exports to zero and the labor tax equal to the baseline level. The revenue recycling effect leads to large welfare gains and is the dominant effect in our case study. Only for the  $\beta = 5$  is there a noticeable curve in Panel d. The effect depends on governments' ability to collect revenue and use it to offset other taxes. We have assumed the location receiving the tax revenues is the same as that facing the externality. This may not always be the case, especially in rural areas that provide environmental amenities but lack infrastructure to support tourist spending. In that case, the revenue recycling effect will be smaller.

In summary, examining Fig. 1, taxing nonresident consumption leads to welfare gains for Columbia River Basin households provided governments can capture the tax receipts and use it to reduce taxes on residents. For very low elasticities, welfare changes are large due to the ability to raise tax revenues and correct the preexisting distortion in the labor market. The ability to correct the externality has little to do with achieving welfare gains. If demand, for some reason, is highly elastic, the number of visitors may fall enough to cause declines in welfare via the primary trade effect. It is not possible to both reduce risk significantly and increase welfare.

## *4.2. Tax on imports*

To illustrate the alternative workings of an import tax we consider a tax on imports that leads to an equivalent reduction in the probability of invasion, shown in Fig. 2. The total effect (Panel a) is composed of the primary welfare effect (Panel b), primary trade effect (Panel c), revenue recycling effect (Panel d), and tax-interaction effect (Panel e). The analysis assumes  $\beta = 0.710$  and solves for tax rates on boating imports that give the same probabilities of invasion calculated with a visitor tax. We assume number of boaters is proportional to the change in boating imports, that is,  $N = (QIMP_b / QIMP_{b,0}) N_0$  where  $QIMP_b$  is the amount of boating imports and zero (0) subscripts denote benchmark values. We emphasize that comparisons relating to rates between import and visitor taxes are not possible. The appropriate comparison is with regard to welfare impacts for similar reductions in risk. This is what we mean by the equivalence of a given import and a given visitor tax. Tax



**Fig. 2.** (a–e) Welfare effects of tax on imports.

rates on the x-axis of Fig. 2 are for relevant visitor taxes, not import taxes. As our approach normalizes impacts around the primary welfare effect (because the probabilities of invasion are equal), we focus the comparison on the primary trade effect, revenue recycling effect, and tax-interaction effect.

The revenue recycling effect is once again an important part of raising overall welfare. The import tax needed to create the same probabilities of invasion is smaller than the visitor tax equivalent, so the revenue recycling effect is smaller than in the visitor tax scenarios. Likewise, the primary trade effect is less than one third its size under an export tax. Economy-wide prices change little with a tax on residents fishing outside of the Columbia. Export demand also changes little. We approximate the tax-interaction effect by setting the tax rate and probability of invasion equal to zero and setting leisure demanded equal to the baseline level for import taxes. The tax-interaction effect is small with regard to the revenue recycling effect, but it is large compared to the primary welfare effect. If the government's ability to lower other taxes is limited, leading to a small revenue recycling effect, welfare losses from price distortions in the economy could cause total welfare to decline even though the risk of invasion falls.

To put these impact numbers in perspective, we use our model to calculate the market impact of the most recent Biological Opinion (NOAA, 2008) aimed at salmon recovery in the Columbia River Basin. Market impacts from the Biological Opinion assume compliance causes a 4 percent increase in the cost of federal hydropower. We find market-based welfare losses of \$8.8 million, or 2.75 times the expected impact from a dreissenid invasion, associated with the policy.<sup>12</sup>

Two caveats are worth noting. First, we do not address the welfare of nonresidents of the Columbia River Basin. Taxing nonresidents is likely to cause welfare losses to frequent visitors. Second, levying a tax on visitors to the Columbia River Basin will decrease the number of trips into the basin, but we cannot be sure these visitors will stay home. The problem may shift elsewhere, raising the threat of invasion into other pristine bodies of water. Warziniack et al. (2011) show the potential for invasion in other nearby western basins to serve as a 'stepping stones' for eventual invasion into the Columbia. Accounting for these sources of risk, invasion into the Columbia, under present policies, is nearly certain. Furthermore, policies that reduce nonresident boater traffic into the Columbia may actually increase risk if eastern boaters launch in other highly susceptible bodies of water and if there is a large amount of traffic between these bodies of water and the Columbia. We have assumed that the collective mechanism (river basin) dominates the decentralized (state by state) mechanism. We do not address issues of environmental or fiscal federalism (Kunce and Shogren, 2005).

Other policy options not considered include the installation of monitor stations and cleaning facilities at boat launch sites. This would have the effect of imposing additional costs on all boaters, reducing their numbers, in exchange for a reduced probability of introduction per boat. Lower probability of invasion would reduce the wage distortion resulting from the firms' uncertainty, leading to large-scale benefits. We do not have data on boater reactions to cleaning stations, though this is a worthwhile extension for policy comparisons and comprehensive cost–benefit analysis.

## 5. Conclusion

Herein we examine the welfare economics of an export-based externality - in our case, a biological invasion from species hitchhiking on visitors' boats. Similar to the well-studied case of a Pigouvian tax on import-based externalities, we also find a perverse result: a tax on exports can reduce welfare. The reason why, however, differs from the traditional import-based double dividend literature. Now, no tax-interaction effect exists to muddy up the Pigouvian waters, rather we have a fundamental tradeoff created by the relative elasticity of visitor demand to local fishing grounds. If visitor demand is sufficiently elastic, an import-based Pigouvian tax sends them elsewhere, which causes the incomes of locals to fall to levels lower than the "do-nothing" alternative.

<sup>12</sup> Estimates on the non-market to market costs of climate change, for example, give ratios between 1–1.5 and 4–1 (Pearce et al., 1996), and nonmarket value of in-stream uses of water are reported to be 1.5 times the market value (Loomis et al., 2000).



We showed this tradeoff using an example of a dreissenid invasion into the Pacific Northwest's Columbia River Basin. Most estimates indicate inelastic demand for nonresident boating, and taxes aimed at reducing the probability of invasion increase welfare, though they do not actually reduce the probability of invasion. Welfare improvements depend entirely on governments' ability to collect taxes and use them to reduce other taxes in the economy. Without this ability, welfare falls in all scenarios, regardless of visitors' elasticity of demand.

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## Appendix A. Supplementary Data

Supplementary data associated with this article can be found, in the online version, at doi:<http://dx.doi.org/10.1016/j.reseneeco.2013.02.002>.

## References

- American Sportfishing Association, 2008]. Sportfishing in America.
- Armington, P., 1969. A theory of demand for products distinguished by place of production. IMF Staff Papers.
- Atkinson, Anthony B., Stiglitz, Joseph E., 1972]. The structure of indirect taxation and economic efficiency. *Journal of Public Economics*.
- Baldwin v. Fish and Game Commission of Montana, 1978]. 436 U.S. 371.
- Bossenbroek, Jonathan M., Finnoff, David, Shogren, Jason F., Warziniack, Travis W., 2009]. Advances in ecological and economical analysis of invasive species: dreissenid mussels as a case study. In: Keller, Lodge, Lewis, Shogren (Eds.), *Bioeconomics of Invasive Species: Integrating Ecology, Economics and Management*. Oxford University Press.
- Bossenbroek, Jonathan M., Johnson, L.E., Peters, B., Lodge, David M., 2007]. Forecasting the expansion of zebra mussels in the United States. *Conservation Biology* 21, 800–810.
- Bovenberg, A. Lans, de Mooij, Ruud A., 1994]. Environmental levies and distortionary taxation. *American Economic Review* 84, 1085–1089.
- Bovenberg, A. Lans, van der Ploeg, F., 1994]. Green policies and public finance in a small open economy. *Scandinavian Journal of Economics* 96, 343–363.
- Brenton, Paul, Scott, Henry, Sinclair, P.J.N., 1997]. *International Trade: A European text*. Oxford University Press.
- Champ, P.A., Boyle, K.J., 2003]. *A Primer on Nonmarket Valuation*, vol. 3. Springer.
- Collins, Andrea, Flynn, Andrew, Munday, Max, Roberts, Annette, 2007]. Assessing the environmental consequences of major sporting events: the 2003/04 FA Cup Final. *Urban Studies* 44, 457–476.
- Complete Auto Transit v. Brady, 1977]. 430 U.S. 274.
- Conservation Force, Inc. v. Manning, 2002]. 301 F.3d 985, 993 (9th Cir.).
- Copeland, Brian R., 2002]. Benefits and costs of trade and investment liberalization in services: implications from trade theory. In: Curtis, John M., Ciuriak, Dan (Eds.), *Trade Policy Research 2002*. Department of Foreign Affairs and International Trade, Ottawa, pp. 107–218.
- Costello, Christopher, McAusland, Carol, 2003]. Protectionism, trade, and measures of damage from exotic species introduction. *American Journal of Agricultural Economics* 85, 964–975.
- Cullinan, J., 2011]. A spatial microsimulation approach to estimating the total number and economic value of site visits in travel cost modelling. *Environmental and Resource Economics* 50, 27–47.
- Deardorff, Alan V., 1985]. Comparative advantage in international trade and investment in services. In: Stern, Robert M. (Ed.), *Trade and Investment in Services: Canada/US Perspectives*. Ontario Economic Council, pp. 39–82.
- De Melo, J., Tarr, D., 1992]. *A General Equilibrium Analysis of US Foreign Trade Policy*. MIT Press, Cambridge.
- Deardorff, Alan V., 2005]. How robust is comparative advantage? *Review of International Economics* 13, 1004–1016.
- Douglas v. Seacoast Products, Inc., 1977]. 431 U.S. 265.
- Drake, John, Bossenbroek, Jonathan M., 2004]. The potential distribution of zebra mussels (*Dreissena polymorpha*) in the U.S.A. *BioScience* 54, 931–941.
- Finnoff, David, McIntosh, Chris, Shogren, Jason F., Sims, Charles, Warziniack, Travis, 2010]. Invasive species and endogenous risk. *Annual Review of Resource Economics* 2, 77–100.
- Fullerton, Don, Metcalf, Gilbert E., 2001]. Environmental controls, scarcity rents, and pre-existing distortions. *Journal of Public Economics* 80, 249–267.
- Goulder, Lawrence H., 1995]. Environmental taxation and the 'double dividend': a reader's guide. *International Tax and Public Finance* 2, 157–183.
- Goulder, Lawrence H., Parry, Ian W.H., Burtraw, Dallas, 1997]. Revenue-raising versus other approaches to environmental protection: the critical significance of preexisting tax distortions. *The RAND Journal of Economics* 28, 708–731.
- Hausman, J.A., Leonard, G.K., McFadden, D., 1995]. A utility-consistent, combined discrete choice and count data model assessing recreational use losses due to natural resource damage. *Journal of Public Economics* 56, 1–30.

- Hawkins, Julie, Roberts, Callum M., Kooistra, David, Buchan, Ken, White, Susan, 2005]. Sustainability of scuba diving tourism on coral reefs of Saba. *Coastal Management* 33, 373–387.
- Horan, Richard D., Perrings, Charles, Lupi, Frank, Bulte, Erwin H., 2002]. Biological pollution prevention strategies under ignorance: the case of invasive species. *American Journal of Agricultural Economics* 84, 1303–1310.
- Krutilla, Kerry, 1991]. Environmental regulation in an open economy. *Journal of Environmental Economics and Management* 20, 127–142.
- Kunce, Mitch, Shogren, Jason F., 2005]. On interjurisdictional competition and environmental federalism. *Journal of Environmental Economics and Management* 50, 212–224.
- Loomis, John, Kent, Paula, Strange, Liz, Fausch, Kurt, Covich, Alan, 2000]. Measuring the total economic value of restoring ecosystem services in an impaired river basin: results from a contingent valuation survey. *Ecological Economics* 33, 103–117.
- Lovell, S.J., Stone, S.F., Fernandez, L., 2006]. The economic impacts of aquatic invasive species: a review of the literature. *Agricultural and Resource Economics Review* 35, 195–208.
- Lowe, S., Browne, M., Boudjelas, S., De Poorter, M., 2000. 100 of the world's worst invasive alien species: a selection from the global invasive species database. Technical report, The Invasive Species Specialist Group, a specialist group of the Species Survival Commission of the World Conservation Union.
- Markusen, J., 1975]. International externalities and optimal tax structures. *Journal of International Economics* 5, 259–284.
- Marsden, E.J., Chotkowski, M.A., 2001]. Lake trout spawning on artificial reefs and the effect of zebra mussels: fatal attraction? *Journal of Great Lakes Research* 27, 33–43.
- McAusland, Carol, Costello, Christopher, 2004]. Avoiding invasives: trade-related policies for controlling unintentional exotic species introductions. *Journal of Environmental Economics and Management* 48, 954–977.
- Melvin, James R., 1989]. Trade in producer services: a Heckscher–Olin approach. *The Journal of Political Economy* 97, 1180–1196.
- Nalepa, Tom, 1998]. Dramatic changes in benthic macroinvertebrate populations in southern lake Michigan. *ANS Update*, 4.
- NOAA, 2008. Supplemental comprehensive analysis of the Federal Columbia river power system and mainstream effects of the upper snake and other tributary actions. Technical report, National Oceanic and Atmospheric Administration Fisheries.
- Oates, Wallace E., 1995]. Green taxes: can we protect the environment and improve the tax system at the same time? *Southern Economic Journal* 61, 914–922.
- Ohio Sea Grant, 1996]. Sea Grant Zebra Mussel Update: A 1995 Report of Research (Part 1 of 2).
- Olson, Lars J., 2006]. The economics of terrestrial invasive species: a review of the literature. *Agricultural and Resource Economics Review* 35, 178–194.
- Parry, Ian W.H., 1995]. Pollution taxes and revenue recycling. *Journal of Environmental Economics and Management* 29, S64–S77.
- Pearce, D.W., Cline, W.R., Achanta, A.N., Frankhauser, S., Pachaur, R.K., Tol, R.S.J., Vellinga, P., 1996]. The social costs of climate change: greenhouse damage and the benefits of control. In: Bruce, J.P., Lee, H., Haites, E.F. (Eds.), *Economic and Social Dimensions of Climate Change*. Cambridge University Press, New York, pp. 179–224.
- Peretz, Jean H., Tonn, Bruce E., Reed, Gregory D., Robles, Luis Alonso Diaz, 2005]. Using scenarios to assess the impact of air pollution in the Great Smoky Mountains National Park. *Public Works Management and Policy* 10, 170–185.
- Perrings, C., Williamson, M., Barbier, E.B., Delfino, D., Dalmazzone, S., Shogren, J., Simmons, P., Watkinson, A., 2002]. Biological invasion risks and the public good: an economic perspective. *Conservation Ecology*, 6.
- Phillips, S., Darland, T., Sytsma, M., 2005. Potential economic impacts of zebra mussels on the hydropower facilities in the Columbia River Basin. Technical report.
- Proost, S., Van Regemorter, D., 1995]. The double dividend and the role of inequality aversion and macroeconomic regimes. *International Tax and Public Finance* 2, 207–219.
- Ricciardi, A., Neves, R.J., Rasmussen, J.B., 1998]. Impending extinctions of North American freshwater mussels (unionoida) following zebra mussel (*Dreissena polymorpha*) invasion. *Journal of Animal Ecology* 67, 613–619.
- Rutherford, T.F., 2002]. Lecture Notes on Constant Elasticity Functions. University of Colorado.
- Sancho, F., 2009]. Calibration of CES functions for real-world multisectoral modeling. *Economic Systems Research* 21, 45–58.
- Sausgruber, R., Tyran, J.R., 2011]. Are we taxing ourselves? How deliberation and experience shape voting on taxes. *Journal of Public Economics* 95, 164–176.
- Shogren, Jason F., 1990]. The impact of self-protection and self-insurance on individual response to risk. *Journal of Risk and Uncertainty* 3, 191–204.
- Shoven, J.B., Whalley, J., 1984]. Applied general-equilibrium models of taxation and international trade: an introduction and survey. *Journal of Economic Literature*, 1007–1051.
- Solow, A.R., Costello, C.J., 2004]. Estimating the rate of species introductions from the discovery record. *Ecology* 85, 1822–1825.
- Strayer, David L., 1991]. Projected distributions of the zebra mussel. *Canadian Journal of Fisheries and Aquatic Sciences* 48, 1389–1395.
- Strayer, David L., Hattala, Kathryn A., Kahnle, Andrew W., 2004]. Effects of an invasive bivalve (*Dreissena polymorpha*) on fish in the Hudson River estuary. *Canadian Journal of Fisheries and Aquatic Sciences* 61, 924–941.
- Taheripour, Farzad, Khanna, Madhu, Nelson, Carl H., 2008]. Welfare impacts of alternative public policies for agricultural pollution control in an open economy: a general equilibrium framework. *American Journal of Agricultural Economics* 90, 701–718.
- Tu, Anh Thuy, Beghin, John, Gozlan, Estelle, 2008]. Tariff escalation and invasive species damages. *Ecological Economics* 67, 619–629.
- United States Fish and Wildlife Service (USFWS), 2007. National fishing license report, grant 9500.
- van Marrewijk, Charles, Stibora, Joachim, de Vaal, Albert, Viaene, Jean Marie, 1997]. Producer services, comparative advantage, and international trade partners. *Journal of International Economics* 42, 195–220.
- Vilaplana, J.V., Hushack, L.J., 1994. Recreation and the zebra mussel in Lake Erie, Ohio. Technical report, technical summary no. OHSU-TS-023, Ohio Sea Grant Program, Columbus, Ohio.
- Warziniack, T.W., Finnoff, David, Bossenbroek, Jonathan M., Shogren, Jason F., Lodge, David M., 2011]. Stepping stones for biological invasion: a bioeconomic model of transferable risk. *Environmental and Resource Economics* 50, 605–627.

- Whittier, Thomas R., Ringold, Paul L., Herlihy, Alan T., Pierson, Suzanne M., 2008]. A calcium-based invasion risk assessment for zebra and quagga mussels (*Dreissena* spp.). *Frontiers in Ecology and the Environment* 6, 180–184.
- Williams III, Robertson C., 1999]. Revisiting the cost of protectionism: the role of tax distortions in the labor market. *Journal of International Economics* 47, 429–447.
- Williams III, Robertson C., 2002]. Environmental tax interactions when pollution affects health or productivity. *Journal of Environmental Economics and Management* 44, 261–270.