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Analysis

Economic drivers of biological invasions: A worldwide, bio-geographic analysis

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ABSTRACT

The introduction of invasive alien species (IAS) is generally acknowledged to depend both on the propagule pressure imposed by openness to international trade and on the health of the receiving ecosystem. Bio-geographic factors however play a crucial role in determining the level of risk associated with trade. We develop an analytical treatment of bioclimatic similarity between trade partners, within a model that links the incidence of invasive species to resource extraction, pollution and to import volumes disaggregated by country and region of origin. The model, estimated with data on invasive species of all taxa in 123 countries, shows that considering the geographical structure of trade flows and the bioclimatic similarity between sources and destinations substantially improves our understanding of the drivers of biological invasions. The results allow us to identify, in a worldwide perspective, the relative risk of biological invasions (in general, and by habitat type) entailed by different commercial partners.

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1. Introduction

Due to their increasing severity, introductions of invasive alien species (IAS) and the resulting ecological and economic damage have received growing attention in recent years. If there is a long history of studies on biological invasions in the natural sciences, with classical works dating back to the 1950s (e.g. Elton, 1958), economics has begun devoting attention to the issue in the last decade, after international scientific and policy-oriented initiatives (such as the Global Invasive Species Programme, sponsored by the United Nations and major international environmental organizations) called for the inclusion of an economic perspective on the driving forces and on the policy options. The corpus of economic analyses is now relatively rich, comprising studies on the valuation of economic costs (e.g. Adams and Lee, 2007; Born et al., 2005; Horsch and Lewis, 2009; McIntosh et al., 2007; Pimentel et al., 2005; Sinden et al., 2011; Turpie and Heydenrych, 2000), on the economic determinants (Costello et al., 2007; Essl et al., 2011; Hlasny and Livingston, 2008; Pyšek et al., 2010a,b; Westphal et al., 2008), on decision-making and policy strategies (Batabyal, 2006; Costello et al., 2007; Eiswerth and Johnson, 2002; Finnoff et al., 2005; Horan and Lupi, 2005; Leung et al., 2005; Liu et al., 2011; Margolis and Shogren, 2012; Margolis et al., 2005; Mehta et al., 2007; Mérel and Carter, 2008; Olson and Roy, 2010; Perrings, 2005; Rout et al., 2011; Sanchirico et al., 2010; Shogren, 2000; Shuang et al., 2011, among others), and on bioeconomic models that examine the influence of specific traits of invading species on their chances of establishing and on the optimal prevention and management options (Finnoff and Tschirhart, 2005; Finnoff et al., 2010; Gutierrez and Regev, 2005; Haight and Polasky, 2010; Marten and Moore, 2011; Rauscher and Barbier, 2010).

A complete survey of the economic literature on biological invasions — a hint on its dimensions being offered by the about 140 Econlit entries between 2000 and today — is beyond the scope of this paper.[2] This work places itself among the studies that seek to

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[2] A valuable synthesis of the state of the art on the ecology, economics and policy of biological invasions, paying particular attention to the international dimension, is the collection in Perrings et al. (2010b).

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deepen our understanding of the economic determinants of the phenomenon — the human pressures that, by creating pathways of introduction and by altering the conditions of receiving ecosystems, facilitate biological invasions. As to the pathways, international trade is recognized as the leading cause of harmful unintentional introductions (e.g. GISP, 2001), which are often those posing the most challenging policy issues.[3] The role of trade flows has been examined in several recent studies: Hlasny and Livingston (2008) examine the relation between imports, immigration and international travel and introduction of non-indigenous insects in the United States. Westphal et al. (2008) conduct the first worldwide study of the impact of international trade (merchandise imports) on biological invasions, refereed to all species, using a regression tree analysis. Costello et al. (2007) investigate how the risk of invasions carried by imports varies by trading partner: they use data on shipping, disaggregated by country of origin, and consider marine species discoveries in the San Francisco Bay between 1853 and 1994. They distinguish imports arriving from the Atlantic/Mediterranean region, West Pacific, and Indian Ocean. Essl et al. (2011) show the existence of a legacy of past economic activities on biological invasions, using alien species introductions recorded in European countries for different taxa before 1900, between 1900 and 1950, and after 1950 and the historical levels of trade and GDP. Pyšek et al. (2010b), again using a regression tree approach, find that national wealth and human population density, analyzed jointly with climate, geography, and land cover, are statistically significant predictors of the number of non-indigenous plants, fungi, and animals in European countries.

Until now the availability of data has forced empirical research either to consider very broad variables (such as aggregate imports reaching a country, regardless of their origin) in order to include a large number of countries, or to aim at a deeper analysis at the cost of confining it to one country or site and/or to a restricted set of organism types. As a result, a consensus has not yet emerged on the relative importance of anthropogenic drivers of invasions.

We develop a model taking into account a few further elements that crucially characterize biological invasion dynamics, and then we test it on data pertaining to all taxa on a global geographical scale. Specifically, we try to answer the following questions: (i) What is the importance of openness to trade and ecosystem health in determining invasibility? (ii) How does the spatial pattern of trade flows (the weight of inter-regional, long distance trade) affect the invasion risk? (iii) How does bioclimatic similarity affect the relative risk entailed by different trading partners, and how does such risk vary for different habitats?

Our conceptual framework is based on three prior hypotheses: first, international trade (and merchandise imports in particular) is a crucial pathway of invasions. Second, invasions are more likely to occur where ecosystems are relatively more disturbed by economic activities. Third, the process of introduction and establishment of IAS has a spatially differentiated structure in which key roles are played by (a) the similarity between bioclimatic conditions of the origin and destination site and (b) the extent to which the two ecosystems have evolved in separation. The first notion is generally accepted in previous analyses of the economic determinants of invasions (Hlasny and Livingston, 2008; Levine and D'Antonio, 2003; Perrings et al., 2002, among others). The second, known as the disturbance hypothesis, has been dealt with mainly by biologists (e.g. Cohen and Carlton, 1998; Cumming, 2002; Enserink, 1999; Pyšek et al., 2010a; Tilman, 2004), with few exceptions (e.g. Dalmazzone, 2000; Westphal et al., 2008), through empirical studies. The third one, although recognized as a crucial factor by biologists (e.g. Bomford et al., 2009; Pheloung et al., 1999; Shigesada and Kawasaki, 1997; Williamson, 1996) and by some previous economic studies (e.g. Costello et al., 2007), has been the object of very little specific theoretical or empirical inquiry within the economic theory of biological invasions. Springborn et al. (2011) is the only economic study, to our knowledge, that explicitly introduces a metric for climate matching (borrowed from Bomford et al., 2009 and based on climatologic modeling softwares) in a study assessing the risk of introductions of non-indigenous species with international trade. We aim at contributing to the development of this area of inquiry by proposing an alternative modeling approach, based on both climate and bio-geographic information.

2. Modelling Biological Invasions

Biological invasion theory generally identifies at least three nested stages leading to ecological damage: the transport and introduction of non-indigenous species in a new environment, their establishment in the destination habitat, and their spread to become pests and generate harmful effects for native species and human activities. Transport and introduction are mostly due to the international movement of commodities. Establishment and spread depend on local conditions — the health of the receiving ecosystems, its supply of resources — and on the capacity of the non-native organism to adapt to the new environment. The latter in turn depends on the bioclimatic similarity between the origin and destination sites as well as on the species-specific susceptibility to environmental and climatic conditions.

Biological invasions are a complex phenomenon. To disentangle causalities and relationships within such complexity, studies by natural scientists tend to concentrate on specific taxa and/or receptor sites. Economic analyses, in the attempt to identify general relationships, tend to design more aggregate models in which, however, phenomena affecting different species and different habitats may cancel out or blur the picture. The challenge we take with this research is to design an economic analysis of the determinants of biological invasions characterized by a high generality (worldwide rather than single receptor country or site, and considering all taxa), and at the same time taking into account the specificity of different habitats and of the bioclimatic conditions of the countries of origin and destination of IAS.

We analyze the phenomenon of biological invasions in a multi-scale perspective. Natural scientists tend to consider, through empirical ad hoc observations, a restricted range of species at a locally determined geographical scale — generally a specific ecosystem. Economic studies usually investigate the dynamics of one or more species within, to and from one country. We retain countries as the economic unit of analysis, but develop a model that considers economies and ecosystems at a country level as nested in regions of supranational dimension, geographically determined according to the World Bank classification (South Asia, East Asia and Pacific, Europe and Central Asia, Middle East and North Africa, Sub-Saharan Africa, North America, Latin America and Caribbean, Oceania).

The number of invasive alien species recorded by the IUCN Global Invasive Species Database (GISD) as responsible for serious ecological and economic disruption in a single receptor country i (IAS_i) is used as a proxy of the intensity of threat at the national level.[4]

We aim at testing whether import flows work as a pathway according to the level of bioclimatic similarity among country i (destination) and j (origin). In our model, bioclimatic similarity increases the chances

[3] Intentional releases, at least in principle, should be straightforward to monitor and regulate, although in practice developing adequate legislation has also proved difficult (Hulme et al., 2008).

[4] Differently from previous studies that use the number of alien species to measure the level of biological invasions (e.g. Costello et al., 2007; Pyšek et al., 2010b; Essl et al., 2011, to name a few) we do not focus on all introductions and discoveries of non-indigenous species, but only on those that led to significant ecological and economic impact. As Molnar et al. (2008:486) put it, "the number of alien species in a habitat does not indicate the level of threat posed to native biota or the damage already done. Many species establish in a new habitat with few disruptions, whereas others alter entire ecosystems or put native species at risk of extinction." Using only the alien species associated with actual serious impacts partially mitigates this limitation — and is the best indicator for which worldwide data exist. More refined analyses, including threat scoring systems based on documented adverse impacts of each non-indigenous species, will be due as soon as more detailed databases become available.

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