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Methodological and Ideological Options

# Modeling the links between biodiversity, ecosystem services and human wellbeing in the context of climate change: Results from an econometric analysis of the European forest ecosystems

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ABSTRACT

This paper constitutes a first attempt to model the relationship between climate change, biodiversity, and ecosystem services, with a specific emphasis on European forests. Firstly, we construct a composite biodiversity indicator that integrates quantitative and qualitative changes of biodiversity projected to 2050 for the EU-17 under future IPCC scenarios. Secondly, this indicator is integrated into two simultaneous equation models to capture the marginal impacts of changes in biodiversity on the value of ecosystem goods and services (EGS) due to climate change.

Our estimation results confirm the role of biodiversity as a nature-based policy solution for climate change mitigation, shedding light on the policy actions that generate co-benefits by enhancing ecosystems' capacity to mitigate climate change impacts, while conserving biodiversity and sustaining the flows of EGS for human livelihoods. Especially, nature-based mitigation policies are more cost-effective and better at coping with the ethic and inequality issues associated with distributional impacts of the policy actions, compared to the pure technical solutions to improving energy efficiency and reducing emissions. However, the strength of biodiversity as a nature-based policy option for climate change mitigation depends on both the nature of the EGS and the geographical area under consideration.



## 1. Introduction

Current model projections have consistently indicated that biodiversity would continue to decline over the 21st century, under different socioeconomic scenarios with trajectories of key indirect drivers of ecological changes, such as human population growth and greenhouse gas emissions (Leadley et al., 2010; Pereira et al., 2010). This in turn will impose threats to the benefits of future humanity and result in a change in our production and consumption patterns in the long run (Martens et al., 2003), as biodiversity underpins a variety of ecosystem goods and services (EGS) that are vital to human well-being. Biodiversity by definition encompasses the variety of life on earth from genes to species, through to the broad scale of ecosystems across time and space (Loreau et al., 2001). It is important in terms of determining the health of ecosystem, ensuring the stability and productivity of ecosystem, as well as contributing directly or indirectly to human wellbeing (MEA, 2005). In this regard, the term "biodiversity" is used broadly as an assumed foundation for ecosystem processes, rather than simply the changing number of species on a species list (Loreau et al., 2001). The relationship between biodiversity and ecosystem functioning or primary productivity has been of long-standing interest to ecologists (Cameron, 2002; Kinzig et al., 2001; Loreau et al., 2001, 2002). Over the past years, the subject has been researched in various ways via experimental field research, the formulation of mechanistic theories and quantitative field observation, most of which have led to a common conclusion that a large variety of species has a positive influence on the productivity and stability of ecosystems, as greater biodiversity can cope with various circumstances in a given habitat and thus lead to the more efficient use of available natural resources (Loreau et al., 2001; Martens et al., 2003). Nonetheless, quantifying the link between biodiversity and ecosystem goods and services remains a major scientific challenge to date (Pereira et al., 2010), because there does not exist a general ecological relationship between ecosystem function and diversity owing to species-specific effects and important tropic links (Paine, 2002; Willims et al., 2002). Certainly, biodiversity loss will negatively affect ecosystem functioning by changing the composition and distribution of species (Bloger, 2001; Giller and O'Donovan, 2002; Loreau et al.,

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2001; Schmid et al., 2000), which may have far-reaching socioeconomic consequences in the future, through the provision of ecosystem services to human society (Martens et al., 2003).

In order to quantify the loss of biodiversity, scientists rely on the use of biodiversity indicators to measure and monitor the different dimensions of biodiversity and to predict the future trends of biodiversity and ecosystems. At a global scale, there are roughly 40 potential measures being developed for the Convention on Biological Diversity (CBD) and about 26 indicators being considered in the Streaming Biodiversity Indicators in Europe 2010 process (Mace and Baillie, 2007). Each of these indicators has been developed to reflect a specific attribute and/or issue of concern. Nevertheless, for the purpose of public and business decisions and effective communication with broader audience, there is a general need of creating a single, simple or composite biodiversity measure that can both encompass essential biological information and incorporate socio-economic impacts. Moreover, such kind of indicator may also have broader application in the socio-economic research in terms of explicitly quantifying and evaluating the effect of biodiversity loss on human welfare. In fact, the economics literature has shown many attempts to both conceptualize and value biodiversity, exploring the use of stated- and revealed-preference valuation methods, both of which intend to estimate the marginal impact of biodiversity loss on utility (Kontoleon et al., 2007; Nunes and van den Bergh, 2001). These methods have been largely used to estimate the nonmarket values of biodiversity. On the other hand, biodiversity also has considerable market value through the supply of important inputs for economic production. Thus, when estimating (at the margin) the economic value of biodiversity, this exercise should encompass biodiversity's impact, on, or biodiversity's contribution to the ecosystems capacity to provide goods and services, including provisioning, cultural, regulating and supporting services[1] (see Chiabai et al., 2011; Ding et al., 2010). Nonetheless, numerical analysis of the links between biodiversity and human wellbeing remains exceptional in the literature. In this regard, only two studies have attracted our particular attention, both of which exploring the use of different biodiversity indicators, i.e. species richness and threatened flora and fauna indexes in modeling the effect of biodiversity loss in the value of ecosystem services or ecosystem productivity. The first refers to a recent study conducted by Costanza et al. (2007), who numerically demonstrated a positive relationship between species richness and net primary production (NPP) for the US, followed by Ojea et al. (2010), who employed the use of meta-analysis to greatly extend the regional forest ecosystem valuation studies to a global scale. These indicators partially explain (not sufficiently enough) the causality between biodiversity loss and changes in ecosystem services and human welfare, but some other important information may be lost as most of the individual biodiversity indicators deal with only one biodiversity attribute or a specific policy target.

In this context, the present paper constitutes a first attempt to model, and empirically estimate, the relationship between climate change, biodiversity and EGS, by constructing a news composite biodiversity indicator that integrates essential information of species changes (e.g. change in species richness and abundance) and ecosystem changes (e.g. change in the area of particular biomes). This indicator is expected to be a simple, but comprehensive, measure to map quantitative and qualitative changes of biodiversity projected to 2050 for seventeen European countries under future climate-change scenarios. Furthermore, this indicator is integrated into a set of constructed simultaneous equation systems to allow formally estimating the marginal impacts of changes in biodiversity on the value of ecosystem goods and services due to climate change. Data availability with regards to both biological species and economic values of the ecosystem services leads us to focus on the forest ecosystems in Europe.

The organization of the paper is as follows. Section 2 introduces the concept of climate-change scenarios and describes the source of data used in the research. Section 3 presents the empirical and innovative approach that is characterized by the creation of a composite biodiversity indicator. Section 4 presents and discusses the theoretical model, which is characterized by the use of simultaneous equations. Section 5 presents and compares the empirical results for both model specifications, i.e. a European-aggregated, and a European-regional model specification, respectively. Section 6 discusses the impact of the estimation results on the design and implementations of the EU environmental policies. Section 7 concludes.

## 2. Data Description

### 2.1. Future Climate Change Scenarios

For a comprehensive interpretation of climate change scenarios and the respective socio-economic and biological impacts, it is an essential first step to understand the underlying assumptions of the scenarios under consideration. Scenarios do not predict the future, but rather paint pictures of possible futures and explore the various outcomes that might result if certain basic assumptions are changed. In order to explore the possible future patterns of biodiversity in Europe, the scenarios are developed based on the recent efforts of the Intergovernmental Panel on Climate Change (IPCC) (2000), which explore the global and regional dynamics that may result from changes at a political, economic, demographic, technological and/or social level. The distinction between classes of scenarios is broadly structured by defining them ex ante along two dimensions. The first dimension relates to the extent of economic convergence, and of social and cultural interactions across regions; the second has to do with the balance between economic objectives and environmental and equality objectives. This process therefore leads to the creation of four climate change scenarios, namely A1, A2, B1 and B2. Hereafter, we call them IPCC storylines throughout the paper.

Table 1 below summarizes the political, economic, demographic, technological and social assumptions made in each of the IPCC storyline and analyzes their potential impacts on the future patterns of global biodiversity.

As we can see, scenario A1 and A2 are both economic-oriented scenarios, but with differentiated focuses on global and regional economic development, respectively. In particular, scenario A2 represents a world differentiated into a series of consolidated economic regions characterized by low economic, social, and cultural interactions, uneven economic growth and with the income gap between industrialized and developing countries that does not narrow. Alternatively, the B-type scenarios depict a world, where economic objectives and environmental and equity objectives are more balanced. In particular, scenario B1 shows that environmental and social consciousness can be combined in a more sustainable manner at global scale, offering a more favorable perspective for biodiversity than the A-type scenarios. Moreover, technological development is expected to shift towards renewable energy and higher productivity and consequently reduce the pressure on natural ecosystems from decreased pollution and land conversion. Finally, biodiversity will also benefit from lower pressure of global population growth and improved ecological capital. Similar to scenario B1, the B2 scenario is environmentally oriented with a focus on local environmental and social sustainability. In this scenario, average education level and degrees of organization within communities are high and energy and material efficiency can be achieved. All these social and technological achievements can reduce the pressure on natural ecosystem.

[1] As defined by the Millennium Ecosystem Assessment (MEA) (2005), provisioning services are the goods obtained from ecosystems and they include food, fiber, fresh water, and genetic resources. Regulating services include benefits obtained from the regulation of ecosystem processes, including air quality regulation, climate regulation, water regulation, erosion regulation, pollination and natural hazard regulation. Cultural services are the nonmaterial benefits that people obtain from the ecosystem through esthetic experience, reflection, recreation and spiritual enrichment. Supporting services refer to an ecosystem's life supporting function, which will ultimately influence the provision of other three types of ecosystem goods and services.