Chapter 2

Modeling the Ecological Footprint of Nations via Evolutionary Computation and Machine Learning Models

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ABSTRACT

The per capita Ecological Footprint (EF) is one of the most-widely recognized measures of environmental sustainability. It seeks to quantify the Earth's biological capacity required to support human activity. This study uses gene expression programming and Self-organizing Maps (SOM) to predict, classify and cluster the EF of 140 nations. A Bayesian approach was used to formally test the research hypotheses. By formulating the linear regression in a probabilistic framework, a Bayesian linear regression model is derived, and a specific simulation method, i.e., Markov Chain Monte Carlo (MCMC), is utilized to estimate the model parameters. Bayesian MCMC methods allow a richer and more complete representation of complex EF data. It also provides a computationally attractive and straightforward method to develop a full and complete description of the inherent uncertainty in parameters, quantiles and performance metrics.

INTRODUCTION

The EF approach was developed by Wackernagel and Rees (1996). It is measured as the total area of productive land and water required to continuously produce all resources consumed and to assimilate all wastes generated by a defined population in a specific location. Since its development, the EF has become "the most widely-used measure of environmental sustainability" (Binningsbo et al. 2007, p. 337). The usefulness of the EF is that it

aggregates typically complex resource use patterns into a single number (Constanza, 2000). According to Dauvergne (2005), the EF is an innovative way to compare the ecological impact of nations across the globe. The validity of the per capita EF is also empirically grounded as it was found to be significantly correlated with key environmental impacts, such as national emissions of ozone depleting substances (Prescott-Allen, 2001) and nuclear power generation (WRI, 2000)

The EF includes six different resources: crop land and pasture land for production of food and goods, built-up land to support infrastructure, forest for the production of wood products, fish for food production, and carbon assimilating capacity for carbon dioxide emissions from fossil fuels. Both land and bio-capacity are measured in global hectares (gha). A global hectare represents a hectare of land with world average bio-productivity. It is estimated that the EF of the global population is at least 30% larger than the Earth's bio-capacity (McDonald & Patterson, 2004). In 2003, the global per capita EF was 2.2 gha, while the global bio-capacity was 1.8 gha/cap. The EF of nations ranged from 0.5 gha/cap in Bangladesh to around 10 gha/cap in the U.S. (White, 2007). These figures can be used as a benchmark for assessing the sustainability of nations. Nations with EF at or below 1.8 gha/cap have a global impact that could be replicated by other nations without threatening long-term sustainability.

Although the EF approach has been applied at various levels, including global (e.g., Rice, 2007), national (e.g., van Vuuren & Smeets, 2000), municipal/institutional (e.g., Barrett and Scott, 2003), and individual levels (e.g., Crompton et al., 2002), no previous studies have attempted to use neuro-computational techniques to predict and classify the EF of nations. In this research we aim to fill this research gap by predicting and classifying the EF of 140 nations through the use of intelligent modeling techniques. More specifically, the purpose of this research is twofold:

- To determine the major factors that affect the EF of nations
- To benchmark the performance of machine learning and evolutionary computational models against traditional statistical techniques.

This paper is organized as follows. The next section summarizes the EF literature and develops the research hypotheses. The methodology used to conduct the analysis follows. The subsequent section presents empirical results of the analysis. Next, the paper sets out some implications of the analysis. The final section of the paper deals with the research limitations and explores avenues for future research.

LITERATURE REVIEW AND HYPOTHESES DEVELOPMENT

Drawing on research from North America, Australasia, and Europe, there is a wealth of evidence that suggest that a wide variety of factors influence EF. These can be characterized as affluence as measured by Gross Domestic Product (GDP), World System Position (WSP), export dependence as measured by the percentage of exports to total GDP, service intensity, domestic income inequality, urbanization, and human capital. Previous research found GDP to be a robust predictor of per capita EF. For example, York et al. (2003) found that population and affluence account for 95% of the variance of total national EF. Jorgenson (2005) found GDP is positively correlated with per capita EF. Venetoulis (2001) examined carbon points for cities in Los Angeles County, California. The results of this study indicate a positive relationship between EF and per capita income. At the individual level data, Ryu and Brody (2004) found that high household incomes have significantly larger EF. Some authors postulate that EF initially rises with GDP growth, and then falls as per capita income continues to rise (e.g.,

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