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Social Equity and Ecological Sustainability - Can the Two be Achieved Together?*

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Abstract

Two of the greatest challenges facing societies today are the rapid deterioration of the natural environment as well as high levels of economic inequality. Policies addressing these two challenges are often designed independent of each other, neglecting their interconnected nature. Therefore, designing better policies requires a profound knowledge of this potential trade-off. Until now, however, the characteristics of this trade-off have remained unclear, as little empirical research is available.

This paper fills this gap by conceptualizing the trade-off through a macroeconomic model and estimating it empirically. It is the first paper to develop a microeconomically-based model of consumption that includes two transmission channels of inequality on biosphere use: First, the *income-effect* refers to the non-linear, decreasing impact of rising incomes on consumption spending after subsistence needs are fulfilled, which leads to a negative correlation between levels of inequality and pollution levels. Second is the effect of *conspicuous consumption*, which can reverse the tendency towards increased pollution caused by the income-effect.

The empirical application assesses which of these opposing mechanisms prevails. The model is estimated by the Group Fixed Effects estimator, based on an unbalanced panel of 167 countries over 33 years. To account for the multidimensionality of biosphere use it is measured by the disaggregated components of the Ecological Footprint. Results indicate that the income effect prevails over the conspicuous consumption effect, meaning that there is indeed a trade-off between reducing biosphere use and inequality levels. This means for policy makers that measures to reduce inequality need to be accompanied by policies that limit harmful environmental impacts of redistribution. Since three of the Ecological Footprint's sub-indices refer to food consumption, the analysis also yields interesting conclusions on the relationship between inequality and food security.

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Social Equity and Ecological Sustainability - Can the Two be Achieved Together?

1 Introduction

Two of the greatest challenges of our time are the rapid deterioration of the natural environment and rising inequality at the global level. In the political sphere environmental and social questions are often played out against each other, providing reasonable expectation for a trade-off between the political goals of *reducing inequality* and *reducing biosphere use*. This paper conceptually and empirically assesses whether the separate political goals of reducing inequality and biosphere use are complementary in their relationship, if they are mutually exclusive and thus unlikely to be achieved in tandem.

The anthropogenic impact on the environment has historically included the rapid progress of climate change (Mann et al., 2008), the contamination of the sea with microplastics (Wright et al., 2013), soil degradation (Pennock et al., 2015) and a drastic decline of biodiversity in many habitats (Bellard et al., 2012) inter alia. The consequences of climate change alone include changing weather and a rising sea level (Church and White, 2011; Min et al., 2011; Schlenker and Lobell, 2010), irreversible changes to various ecosystems (Allen et al., 2010; Gonzalez et al., 2010; Hoegh-Guldberg and Bruno, 2010), and immense impacts on human life on Earth, many of which have left densely populated areas nearly uninhabitable (Pal and Eltahir, 2015). Rockström et al. (2009) introduced the concept of "planetary boundaries", which acknowledging that the overuse of the biosphere occurs along several dimensions, rendering the focus on one measure, such as CO_2 emissions, as too simplistic.[1]

However, this concept does not take into account increasing levels of world inequality, the second major challenge facing the global society today. Adam Smith condemned inequality by claiming that "No society can surely be flourishing and happy, of which the far greater part of the members are poor and miserable" (Smith, 1776)[p. 96]. Clearly, even early economists predicted that high levels of inequality would produce undesirable effects on a society's welfare through a number of transmission channels. These include, among others, political instability Roe and Siegel (2011), lower social

[1] As the biosphere includes natural resources and sinks, the term *biosphere use* refers to the depletion of natural resources as well as emitting waste products into the atmosphere and the oceans.

mobility (Chetty et al., 2014; Chetty et al., 2017; Corak, 2013) and reduced future income growth, the latter of which often leads to the poverty trap (Lübker, 2002; Bergeijk and Hoeven, 2017), wherein the poor are less optimistic overall and therefore less likely to make personal development investments that could lead them out of poverty (Graham, 2017; Ravallion, 2001).

The need to address the problems of excessive inequality and overuse of the biosphere as two unique issues has been recognized and institutionalized by the United Nation's sustainable development goals (SDG) # 10 ("reduce inequality") and # 13 ("climate action") (Le Blanc, 2015). However, countervalence methods proposed by policy researchers often see the two issues as disparate, with very few works accounting for the nature of their interconnectedness.

Acknowledging this, Raworth (2017) recently expanded upon the concept of planetary boundaries (Rockström et al., 2009), adding a social dimension vector, based upon the SDGs, which includes the requirement for all individuals in a society to live a life of dignity, including health, clean water, food, literacy, and energy. Another strand in the literature suggests that the first best solution is to decouple economic growth from biosphere use by building a "Green Economy" (Kopp et al., 2017). Critics argue, however, that decoupling economic growth from biosphere use to a level that is both ecologically sustainable *and* enables the poor to grow out of poverty is not realistic (Lange et al., 2018; Jackson, 2009).

This trade-off can be explained by non-linearities in the effect of rising incomes on consumption spending: i.e., poorer people allocate a higher proportion of their income towards consumption due to a base subsistence level of consumption required to fulfill basic needs. Lower levels of inequality would be expected to lead to higher levels of biosphere use, *ceteris paribus* (*c.p.*).

However, the opposite effect of inequality on biosphere use also appears plausible. Higher levels of inequality might spur the individuals' sensed need to indicate their position within the income hierarchy by a higher consumption level than they would aspire to in an environment of lower inequality, *c.p.* This mechanism would result in an increased biosphere use with increasing levels of inequality.

The question that this paper addresses is therefore which of these two opposing influences of inequality on biosphere use prevails. To do so, a microeconomically founded model is derived, including two separate transmission channels of inequality on biosphere use: first is the non-linear impact of rising incomes on consumption after subsistence needs have been fulfilled, and the second is conspicuous consumption. The latter might actually cause the impact of redistribution on pollution levels to stay within acceptable boundaries. If a country's biosphere use is given by function $\Omega = f(\Sigma I, \lambda)$ where Ω is a measure of biosphere use, ΣI is income and λ a measure of inequality, the pertinent question is whether the first derivative with respect to λ is above or below zero.

$$\frac{\partial \Omega(I, \lambda)}{\partial \lambda} \overset{?}{\gtreqless} 0 \tag{1}$$

If the term in equation (1) is < 0 then the income effect prevails, and if it is > 0 then the effect of conspicuous consumption prevails. Applying econometric methodology to equation (1) will indicate whether rising equality increases or decreases total biosphere use.

To the best of our knowledge this is the first paper to systematically develop a microeconomically founded model to address the theoretical implications of inequality on total consumption by simulating the opposing effects of conspicuous consumption and non-linearity of incomes' effect on consumption. To fill that gap, this paper develops a microeconomic model to derive the estimation equation. On the empirical side it applies the innovative Group Fixed Effect (GFE) estimator (Bonhomme and Manresa, 2015). To account for different dimensions of biosphere use while avoiding the problem of arbitrary aggregation (Wiedmann et al., 2015) the dependent variables in our analysis are the sub-indices of the ecological footprint (EF). Results indicate that the income effect prevails over the conspicuous consumption effect, meaning that there is indeed a trade-off between reducing biosphere use and inequality levels. This means for policy makers that measures to reduce inequality need to be accompanied by policies that limit harmful environmental impacts of redistribution. Since three of the EF's sub-indices refer to food consumption, interesting conclusions on the relationship between inequality and food security can be drawn.

This paper is structured as follows: the literature review in subsequent section 2 gives an overview of previous findings on the effect of inequality on consumption. The theory developed in section 3 predicts the two opposing effects of inequality on biosphere use. Section 4 describes the data and estimates the effect of inequality and income on several indicators of biosphere use via the Group Fixed Effects estimator. The results and corresponding policy implications are discussed in section 5. Section 6 concludes.

2 Background: effects of inequality on consumption

2.1 Negative effect of inequality on total consumption: income effect

Subsistence consumption is the minimum consumption level required by a human to live. In a narrow definition this includes only the biological requirements of food, water, shelter, clothing, etc. A broader definition however also includes the societal needs of the individual, i.e. consumption of goods required for active participation in society, such as communication, mobility, etc. While there is lengthy debate as to exactly what these societal needs are the point here is *that* that there is a minimum subsistence consumption requirement needed to sustain a reasonably fulfilling life. Reuter (2000) argues that once these basic needs are fulfilled for an individual, an increase in personal income typically results in relatively lower increases in consumption. This means that the richer people are, the smaller their proportional consumption, relative to their income. Heerink et al. (2001) developed and estimated a cross-country model quantifying the effect of inequality on environmental quality, finding evidence for a negative impact of inequality on the environment due to a Kuznets-like relationship between inequality and pollution. So income has a positive, but *diminishing* marginal effect on household consumption spending.

2.2 Positive effect of inequality on total consumption: conspicuous consumption

The intuition behind the opposing effect is that the *desire* to climb up the social ladder is less pronounced in more equal countries where the *social ladder is shorter*. Friehe and Mechtel (2014) find in their literature review that individuals in general are very status-aware and tend to compare themselves to others. Empirical evidence across multiple societies and cultures appears to support this theory. Carlsson and Qin (2010) found evidence that individuals place value on their relative societal standing in rural China, Caporale et al. (2009) various EU countries, and Solnick et al. (2007) the United States and China.

An important concept when discussing conspicuous consumption is the “Veblen effect” (Veblen, 1899), which is the alleged income signalled to others by the acquisition of goods that fulfill two criteria: a) they are expensive and b) they are visible to others.

This includes goods like luxury cars (Kuhn et al., 2011; Winkelmann, 2012), electronic gadgets such as smart phones and expensive watches (Friehe and Mechtel, 2014), activities such as frequent flying (Friehe and Mechtel, 2014), owning/renting more than one house (Alpizar et al., 2005), and even in some cases insurance (Alpizar et al., 2005) or public goods (Sexton and Sexton, 2014).

In terms of economic modelling this means that individuals include their relative position in the society in the assessment of their own utility (Clark et al., 2008). This explains the Easterlin Paradox – the fact that individuals' increasing incomes lead to an increased perception of happiness while on an aggregate view, an increase of average income does not lead to a society being happier as a whole (Clark et al., 2008). Paskov et al. (2013) find that the more unequal a given country's income distribution is, the higher is the average anxiety concerning social status. Frank et al. (2010) explain this phenomenon with so-called "expenditure cascades", meaning that each income group attempts to adapt the next-higher income group's consumption patterns. The country-wide effects of conspicuous consumption are therefore an increase in total consumption with an increasing level of inequality, *ceteris paribus* (with aggregate income being held constant).

Empirical evidence for these mechanisms has been found in a number of studies. Wilkinson and Pickett (2009, p. 223f) summarize empirical evidence from a number of studies which indicate that in more equal societies people seem to work less hours overall, indicating a smaller interest in making a great effort to climb up the social ladder. According to Bowles and Park (2005), greater inequality is associated with longer work hours, and the observed *Veblen effects* are fairly robust across methodologies and across the ten (European) countries observed.

Little theoretical work is available that conceptualizes the question of whether the conspicuous consumption effect dominates over the income effect. For example, the econometric analysis in Grunewald et al. (2017) provides some empirical evidence, but without a formal, microeconomic foundation.

To expand upon the current understanding of the underlying factors regarding the effects of conspicuous consumption and the income effect on inequality, the following section derives a country's total consumption from a microeconomic foundation, and linking it to the biosphere use generated during the production of all goods consumed. This measure is independent of the physical location of the production process, meaning exports and imports of emissions are accounted for.

3 Economic model

We start with a utility function in which utility U is generated from savings S and from consumption C. The utility derived from consumption consists of two components: the utility generated by actual consumption U_{ac} and the utility derived from the status signal that is sent out to the rest of society by one's consumption pattern. This *conspicuous consumption* (Friehe and Mechtel, 2014) is denoted by U_{cc}. Utility derived from saving is denoted by U_S.

Conspicuous consumption is based on an assumed targeted rank R within the income distribution. This targeted rank depends on the country's level of inequality. While everybody would be happy with the average income in a perfectly equal society, with rising inequality individuals seek to signal their location at increasingly higher levels on the income distribution ladder. This targeted income level is signalled to the other members of society by a corresponding targeted ideal level of consumption T. T is assumed to be a linear function of income and inequality: $T = T(\phi\lambda) = \delta\phi\lambda$ where ϕ stands for mean income and $\lambda \in [0, 1]$ for a continuous measure of inequality with 0 standing for perfect equality and 1 for perfect inequality, such as the GINI coefficient. δ is an unknown parameter. The bigger the dispersion of incomes, the bigger the utility derived from conspicuous consumption, so the utility derived from conspicuous consumption U_{cc} is defined as one person's actual consumption level C in relation to T. C below T constitutes a punishment in the utility, and C above T constitutes a reward. The literature on conspicuous consumption exhibits two ways of incorporating the utility-diminishing effect of T into a utility function: either by subtracting it or by dividing through it (Alpizar et al., 2005). In this paper we follow the more common approach of subtraction.

The reasoning behind the income effect is based on the subsistence level of consumption that every member of society needs to achieve in order to fulfill fundamental needs, so consumption is non-linear in incomes. This means that consumption rises less than linearly with increases in income; i.e. the more an individual earns, the less proportional share of his or her income is consumed, leading to higher marginal propensities to spend among those with lower incomes. Following Nigai (2016) this is accomplished by adding μ to the utility function, reresenting the subsistence level of consumption in a given country on which each consumer spends a certain amount, before dividing the remaining income amongst consumption and savings according to his or her preferences. One individual's total consumption $\overline{C}$ is the sum of the subsistence consumption μ and his or her preference-driven consumption C^*.

This yields the following non-homothetic utility function, based upon the Stone-Geary specification (Bergstrand, 1989; Deaton and Muellbauer, 1980).[2]

$$U = (C^* + \mu - T)^\alpha S^\beta \tag{2}$$

Taking logs on both sides yields

$$\ln U = \alpha \ln(C^* + \mu - T) + \beta \ln S \tag{3}$$

To find the first order condition for an individual's consumption decisions we equalize the marginal utility of consumption and saving generated by differentiating with respect to C and S, respectively.

$$\frac{\partial \log U}{\partial C^*} = \frac{\alpha}{C^* + \mu - T} \stackrel{!}{=} \frac{\partial \log U}{\partial S} = \frac{\beta}{S} \tag{4}$$

Imposing the budget constraint $I = C^* + S$ and solving for C^* yields one individual's optimal preference-driven consumption level, depending on μ, I and T:

$$C^* = \frac{\alpha I + \beta T - \beta\mu}{\alpha + \beta} \tag{5}$$

Since $\alpha + \beta = 1$ we can simplify to:

$$C^* = \alpha I + \beta T - \beta\mu \tag{6}$$

Total consumption $\overline{C}$ is given by adding μ to equation (6):

$$\overline{C} = \alpha I + \beta T + \alpha\mu \tag{7}$$

[2]We assume a representative consumer and small, open economies, so prices are exogenously determined and not affected by the consumption decisions made in one country. We further assume the coefficients of the utility function to add up to one: $\alpha + \beta = 1$.

The subsistence level of consumption μ is approximated by $\mu = \sigma\sqrt{I}$, meaning that individuals with higher incomes spend more on subsistence goods (as a decreasing share of income). Each individual's target consumption T is replaced by $\delta\phi\lambda$, the linear function of inequality and mean income.

$$\overline{C} = \alpha I + \beta\delta\phi\lambda + \alpha\sigma\sqrt{I} \tag{8}$$

Subscript i is added to account for individuals. Aggregating over all M members of society, who differ only in their respective income levels I_i, leaves us with the country's total consumption, denoted by Ω.[3]

$$\Omega = \sum_{i=1}^{M} \overline{C} = \sum_{i=1}^{M} \left(\alpha I_i + \beta\delta\phi\lambda + \alpha\sigma\sqrt{I_i}\right) \tag{9}$$

Considering that the sum of all incomes in one country are given by the GDP, we can replace the first sum term:

$$\Omega = \alpha GDP_j + M\beta\delta\phi\lambda + \alpha\sigma\sum_{i=1}^{M}\sqrt{I_i} \tag{10}$$

The remaining sum term can, however, not be simply aggregated to $\sqrt{GDP}$ since the sum of the root is unequal to the root of the sum. In order to solve this term, individual incomes are expressed as a function of the mean income ϕ and inequality λ, which is equivalent to the Lorenz curve.

Since the measure of inequality is a simple number, we must make an assumption on the functional form of the Lorenz curve underlying the distribution of incomes. This functional form is highly debated in the literature. The most cited one has been introduced by KAKWANI and PODDER (1973): $\eta = \pi e^{-\lambda(1-\pi)}$. $\eta(\pi)$ stands for the share of total income that is received by proportion π of the population and λ measures inequality. BASMANN et al. (1990) provide a conclusive literature review on functional forms of Lorenz curves up to then. ROHDE (2009) discusses the most commonly used

[3] While drawing conclusions from models that include a simple aggregation from the micro to the macro level often represents a challenge, it is the most sensible approach in this application, as the idea is to generate an intuition on the qualitative effects on aggregate biosphere use in a cross-country, over-time comparison without considering the additionally associated macroeconomic consequences.

Lorenz curve functions and claims to have developed a new one, given by $\eta = \pi\left(\frac{\lambda-1}{\lambda-\pi}\right)$. Sarabia et al. (2010) prove, however, that this is equivalent to the function introduced by Aggarwal (1984): $\eta = \frac{(1-\lambda)^2\pi}{(1+\lambda)^2-4\lambda\pi}$.

For the application at hand, the selection of the functional form is driven by practical considerations since it does not include an estimation of a Lorenz curve. Instead, we are exclusively interested in qualitative insights at this point. The requirements that the chosen function needs to satisfy are the standard theoretical requirements for Lorenz curves. These are positive first and second derivatives for $\pi \in [0;1]$, as well as an inclusion of the points $(0,0)$ and $(1,1)$ (Rohde, 2009). We decide upon a modified version of H_0^3 from Basmann et al. (1990) which is the most convenient to integrate after taking the square root.

$$I_i = \phi\pi^{1+a\lambda^2} \tag{11}$$

with ϕ being mean income and π standing for a counter that moves through all individuals, scaled to a range within $[0;1]$. a is an unknown parameter which is ≥ 1. Substituting into the last term of equation (10) yields

$$\sum_{i=1}^{M} \sqrt{I_i} = \sum_{i=1}^{M} \sqrt{\phi\pi^{1+a\lambda^2}} \tag{12}$$

Writing in integrals gives

$$\sum_{i=1}^{M} \sqrt{I_i} = \int_0^1 \left(\phi\pi^{1+a\lambda^2}\right)^{\frac{1}{2}} \mathrm{d}\pi \tag{13}$$

where the discrete population space is mapped onto the continuum [0;1]. Replacing the integral by its primitive yields

$$\sum_{i=1}^{M} \sqrt{I_i} = \left(\frac{2\pi\sqrt{\phi}\sqrt{\pi^{a\lambda^2+1}}}{a\lambda^2+3} + C\right)\Bigg|_0^1 \tag{14}$$

Solving the integral by inserting the boundaries for π into the equation (14) yields

$$\sum_{i=1}^{M} \sqrt{I_i} = \frac{2\sqrt{\phi}}{a\lambda^2 + 3} \tag{15}$$

This is in line with economic intuition because with increasing levels of inequality, indicated by λ approaching unity from the left, the area under the Lorenz curve is expected to shrink. Plugging equation (15) back into equation (10) yields

$$\begin{aligned} \Omega &= \alpha GDP + M\beta\delta\phi\lambda + \alpha\sigma\frac{2\sqrt{\phi}}{a\lambda^2 + 3} \\ &= \alpha GDP + M\beta\delta\phi\lambda + \alpha\sqrt{\phi}\sigma\frac{2}{a\lambda^2 + 3} \\ &= \alpha GDP + \beta\delta GDP\lambda + \alpha\sqrt{\phi}\sigma\frac{2}{a\lambda^2 + 3} \end{aligned} \tag{16}$$

Since the measure of inequality λ enters equation (16) both as a linearly increasing factor and as a nominator, it follows that inequality can either increase or decrease total consumption Ω, depending on the values of the coefficients α, β, δ, and σ. The target of the following empirical analysis is to generate insights on the net effect from empirical data.

4 Empirical analysis

4.1 The ecological footprint - a debated measure of biosphere use

Jorgenson (2003) argues that the use of natural resources from the production of goods can be proxied by the level of consumption of these goods. The indicators that accurately measure the environmental consequences of a country's consumption need to a) capture different dimensions of biosphere use, and b) take into account that most countries are part of the global economy, which means that many of the products consumed have been imported and many of the goods produced are being exported. A set of indicators that fulfill both requirements are the components of the EF.

As defined by the Global Footprint Network, 2017: "The Ecological Footprint is derived by tracking how much biological productive area it takes to absorb a population's carbon dioxide emissions and to generate all the resources it consumes." Other than most indicators used for human impact on environmental deterioration, this one-dimensional indicator identifies limits by defining a relationship between human demand and earth's regenerative capacity, thereby referring to the world's carrying capacity (Best et al., 2018; Galli et al., 2016).

The supply side in the concept is defined by the biocapacity of the planet, which is the ability of autotrophic organisms to produce resources via photosynthesis. This output can then either be consumed by humans or used to absorb their waste (Galli, 2015). Five land use types (cropland, grazing land, fishing grounds, forest land, and built up land) are considered to compensate for six demand categories (as forest land is used for timber production and absorption of carbon dioxide emission) (Lin et al., 2016). To get comparable units the EF is calculated in *global hectares* which represent the average global bio productivity of an area (Borucke et al., 2013).[4] The EF calculates hypothetical rather than actual land use; therefore, due to trade, the EF can exceed the biocapacity of a region (Van Den Bergh and Verbruggen, 1999).

As many aspects of sustainability cannot be taken into account, such as demand on ecosystem services that cannot be regenerated, different land use types (sustainable or unsustainable) and different types of waste (other than carbon dioxide emission), human demand is underestimated and the environment's regenerative capacity is overestimated (Best et al., 2018; Fiala, 2008; Galli, 2015). Therefore the EF can be understood as a bottom-line indicator of human demand on ecosystems and ecological sustainability (Al-Mulali et al., 2015; Van Den Bergh and Verbruggen, 1999).

The concept of the EF has also received critical assessments. See Van Vuuren and Bouwman (2005) for a summary on the discussion on the appropriateness of the use of the EF as a proxy for biosphere use. The first issue is that aggregating the sub-indices into one composite indicator would require a choice for weights which is strongly criticized in the literature as being arbitrary (Wiedmann et al., 2015). Another problem of aggregation is that missing values of the sub-indices are entered as zeros when constructing the aggregate index. A second frequent critique of the EF and its common application is the transformation into the variable land. To circumvent both problems this application relies on the EF's disaggregated sub-indices. Since the sub-indices are not added up to a combined weight, the relative importance between the sub-indices is

[4] Full details on the calculation methodology and the data sources used for the EF can be found in (Lin et al., 2016).

not of primary concern. And given that the transformation from the measured variables into land is a linear transformation, the relative effects between countries and over time are identified correctly. Proponents of the EF (White, 2007) argue that the benefits outweigh the shortcomings: by following the full life cycle of a product, the EF accounts for both direct and indirect impacts of consumption on the natural environment, which makes this approach superior to alternative measures suggested in the literature.

The EF has been employed as an indicator of biosphere use in various publications. Jorgenson (2003) establishes the link between per-capital consumption levels and the EF. This paper also includes within-country inequality as an explanatory variable for the EF. However, the analysis is made on a cross-country level, ignoring unobserved, country-specific effects. Dietz et al. (2007) find in another cross-country analysis with data from the early 21st century that population size and wealth are positively related to anthropogenic environmental degradation, measured as the EF. White (2007) connects the literature on the EF and inequality on a methodological level by calculating two measures of inequality in biosphere use and analyses the effect of EF-inequality of the different components to total EF-inequality. Van Vuuren and Bouwman (2005) find that in the past the main determinants of EF were consumption spending, agricultural yield levels, and population size. A simulation approach shows that in the prediction of future EFs the assumptions on the development of crop yields are the most important in generating precise estimates. On a very local scale, Liu and Lei (2018) found the key determinants of EF levels in the Beijing metropolitan area: Population, GDP, sales of consumer goods, trade, and energy consumption. More examples for analyses based on the EF are provided in the literature review by White (2007).

4.2 Data

We use an unbalanced panel dataset which contains at least 3 periods of observations per country on the EF and its sub-indices. The dataset contains observations for 167 countries for the years between 1980 to 2012. In the following the different data sources are explained.

The Global Footprint Network provides data on the EF. It calculates, based on roughly 15,000 data points per country per year, the Footprints of 232 countries for the years 1961 to 2012 (Global Footprint Network, 2016). As elaborated above, the EF has received criticism for a variety of reasons, most prominently the aggregation issues. We circumvent this challenge by employing primarily the EF's disaggregated sub-indices – carbon emissions, built-up areas, fishing area, cropland, grazing land, and forest land – to understand how much of these resources each country accounts for.

For the GINI measures we use the Standardized World Income Inequality Database (SWIID) by SOLT, 2016. The SWIID contains observations for 192 countries over the years 1960 to 2016 (SOLT, 2016). For this analysis, we use *gini_disp*: "Estimate of Gini index of inequality in equalized (square root scale) household disposable (post-tax, post-transfer) income, using Luxembourg Income Study data as the standard" (SOLT, 2017, p.1).

GDP per capita and the control variables agriculture, service, manufacturing, construction as well as urban population are taken from the World Development Indicator Database (THE WORLD BANK, 2017). We use GDP per capita based on constant 2010 US Dollars. For the agriculture, service, manufacturing, and construction sectors we use the shares of value-added as percentage of total GDP. We also add the variable *urban*, which is defined as the percentage of the total population that lives in cities (THE WORLD BANK, 2017).

Summary statistics of the dependant variables are presented in table (1) and the exogenous variables in table (2).

Table 1: Summary statistics of dependent variables

VARIABLES	N	mean	sd	min	max
$\ln EF\_Carbon$	3843	-0.240	1.415	-4.554	2.668
$\ln EF\_Fish$	3844	-2.782	1.800	-9.928	3.819
$\ln EF\_Crop$	3879	-0.629	0.630	-3.932	1.389
$\ln EF\_Grazing$	3836	-1.699	1.187	-7.592	1.495
$\ln EF\_Forest$	3825	-1.268	1.140	-13.59	1.214
$\ln EF\_built-up$	3708	-2.955	1.003	-8.994	2.518

Table 2: Summary statistics of explanatory variables

VARIABLES	N	mean	sd	min	max
$\ln GDP$	3812	8.36	1.53	5.21	11.63
$\ln GINI$	3880	3.63	0.23	2.99	4.11
Agri	3369	15.38	13.65	0.0354	66.03
Serv	3365	54.68	14.11	2.428	91.48
Manu	3258	16.17	7.654	0.237	47.34
Urban	3880	54.17	23.38	4.988	100

4.3 Estimation

Various methods have been used in the past to evaluate the relationship between ecological indicators and inequality. Recent literature suggests that the grouped fixed effects estimator (GFE) is the most appropriate approach to address the relationship between inequality and environmental degradation, as it takes into account variation over time in unobserved heterogeneity (Bonhomme and Manresa, 2015; Grunewald et al., 2017).This is in contrast to the fixed effects estimator which assumes that all countries have the same patterns in unobserved heterogeneity over time (Bonhomme and Manresa, 2015). The fixed effects estimator addresses unobserved heterogeneity by adding time fixed effects for countries: $a_{it} = a_i + \lambda_t$ for country i at time t. However, this would lead to an elimination of most of the variation of the GINI data, as the intertemporal variation in the GINI coefficient is small compared to the cross country variation (Grunewald et al., 2017).

Unlike the fixed effects estimator, the grouped fixed effects estimator assumes that countries can be divided into groups with similar time patterns in their unobserved characteristics. Given time-varying unobserved heterogeneity, grouped fixed effects are more appropriate to account for endogeneity (Bonhomme and Manresa, 2015). Therefore, this method better addresses the variation in the GINI coefficient. To account for between-country variation over time, the grouped fixed effects estimator clusters countries into groups that follow a similar pattern in the unobserved variables over time. These groups are then restricted to have the same pattern over time but vary between each other. The group specific time effect is $\alpha_{g_i t}$ with g being the group that country i

belongs to, with the same time profile t (Bonhomme and Manresa, 2015).

These groups are estimated using a clustering method that is incorporated in the GFE method. Groups are determined within the model and not set by the researcher.[5] These groups incorporate countries which exhibit similar time profiles in their covariates. One important aspect of this approach is that the number of groups is relatively small (Bonhomme and Manresa, 2015).

For the econometric estimation equation, (16) is re-parametrized to a simpler representation and denoted in logs:

$$\ln \Omega_{it} = \chi \ln GDP + \eta \ln GDP \ln \lambda + \tau \ln \lambda \tag{17}$$

The term is augmented by country-subscripts i, time-subscripts t, the group fixed effects $\alpha_{g_i t}$, and an error term u_{it}. As discussed in the literature on the environmental Kuznets curve (see Dinda (2004), Romero-Ávila (2008), and Stern (2004) for reviews of recent literature), non-linear effects of $\ln GDP$ on the environmental use are plausible which we allow for by adding $\ln GDP^2$, following Grunewald et al. (2017). Additionally, we add the squares of inequality, $\ln \lambda^2$, which is a novelty in this context, and allows us to drop the assumption of a linear relationship between $\ln GINI$ and $\ln \Omega$. Following Grunewald et al. (2017), we also control for the agricultural, service, and manual sectors as shares of GDP, as well as the population share living in urban areas, all included in vector γX_{it}:

$$\begin{aligned} \ln \Omega_{it} = &\alpha_{g_i t} + \beta_1 \ln GDP_{it} + \beta_1 \ln GDP_{it}^2 + \beta_3 \ln \lambda_{it} + \beta_4 \ln \lambda_{it}^2 \\ &+ \beta_5 \ln GDP_{it} * \ln \lambda_{it} + \gamma X_{it} + u_{it} \end{aligned} \tag{18}$$

Following the argumentation above total consumption $\ln \Omega_{it}$ is replaced by a proxy of the biosphere use of one country, which includes total emissions resulting from goods produced, denoted by $\ln EF_{it}$. Ω_{it} in the theoretical model includes all goods and services consumed in country i at time t, including the ones produced domestically and abroad. Similarly, the EF and its sub-indices include all units of biosphere consumption resulting

[5]To estimate the group membership the sum-of-squares of residuals is minimized. We use algorithm number 2 which is stated to be the most efficient. The variable neighbourhood search uses two search methods to find the local optimum and the global optimum (Bonhomme and Manresa, 2015).
We use the following settings for the clustering: $neigh_{max} = 10$, $inter_{max} = 10$ and $N_S = 10$.

from all goods consumed in country i, independent of where they were produced. As all global emissions are captured by this variable, we refrain from accounting for the production side separately to avoid double counting. Employing the EF is superior to other approaches in the recent literature because it incorporates all resources/sinks used over the whole life cycle of a good, unlike for example the CO_2 emissions produced in one country which do not account for 'imported emissions', i.e. emissions that were generated in country A while producing a good which is eventually consumed by the society in country B. The indicator of inequality, λ, is replaced by the measure of inequality, the $GINI$ index.

$$\begin{aligned} \ln EF_{it} =& \alpha_{g_i t} + \beta_1 \ln GDP_{it} + \beta_1 \ln GDP_{it}^2 + \beta_3 \ln GINI_{it} + \beta_4 \ln GINI_{it}^2 \\ &+ \beta_5 \ln GDP_{it} * \ln GINI_{it} + \gamma X_{it} + u_{it} \end{aligned} \tag{19}$$

4.4 Results

Estimation results are presented in table (3). Each column displays the coefficients for one of the EF's components. The signs and orders of magnitude of statistically significant coefficients are robust to the estimation method (OLS vs. FE and GFE) and the inclusion/exclusion of control variables. Table (3) reports the results of the GFE estimator.

The estimated coefficients for carbon emissions that are statistically significant exhibit the same signs and are similar in magnitude to the results of Grunewald et al. (2017), verifying our adaptation of the statistical procedure and results. Additionally, the inclusion of the $\ln GINI^2$ variable allows for non-linear effects at no costs in terms of consistency.

To ease the interpretation of the regression results figure (1) displays the estimation results of the depending variables, the sub-indices of the EF, as a three-dimensional function of the two variables of interest, $\ln GINI$ and $\ln GDP$, in the form of heatmaps.

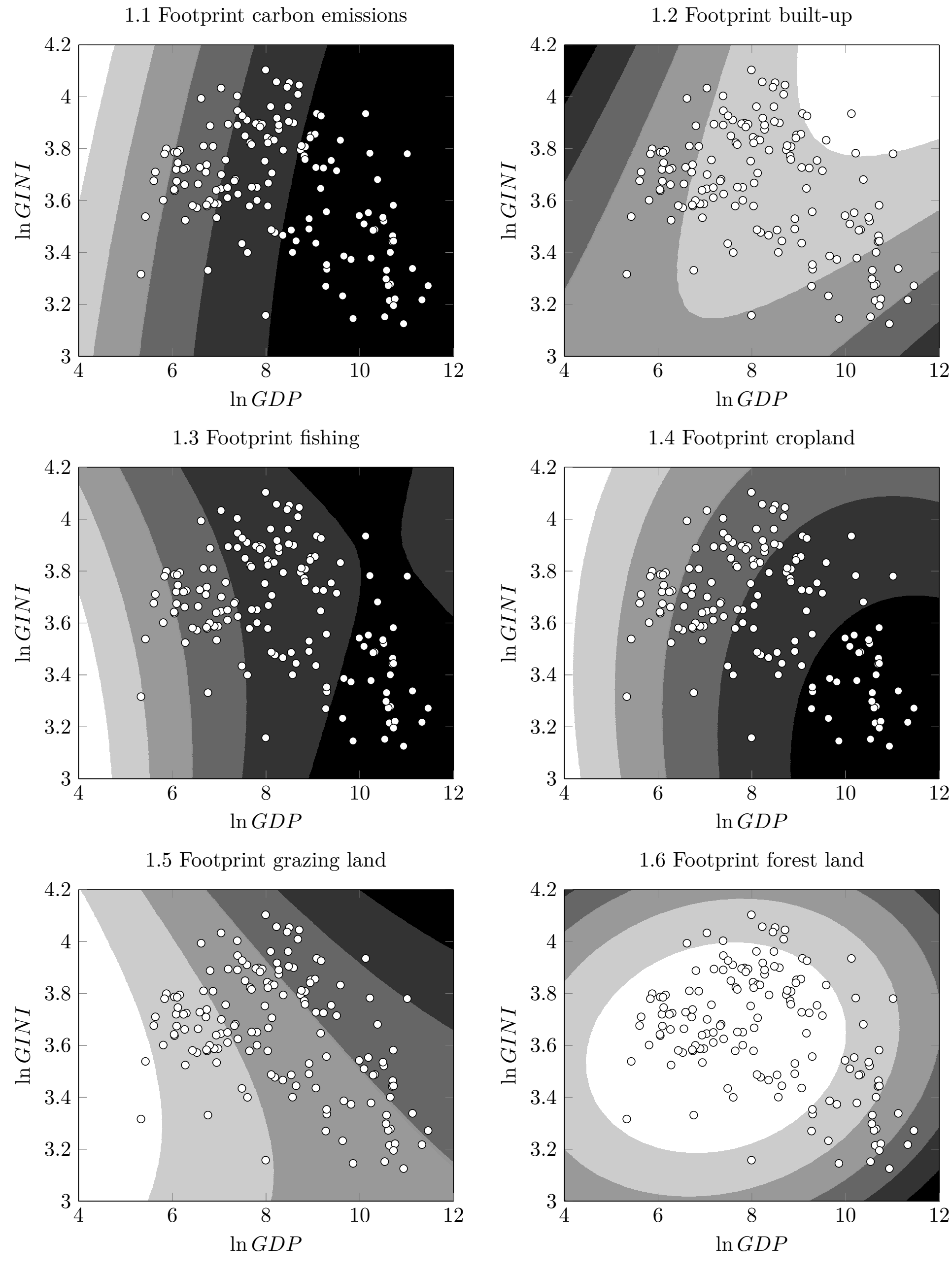
Table 3: Regression results

	Carbon	built-up	Fish	Crop	Grazing	Forest
Intercept	-10.60	-2.69	-21.31	-15.20**	12.35	39.20**
	(10.32)	(13.40)	(36.58)	(7.54)	(24.26)	(19.54)
$\ln GDP$	1.73***	1.06	5.46**	1.29***	-0.04	-0.51
	(0.66)	(1.52)	(2.40)	(0.45)	(1.66)	(1.16)
$\ln GDP^2$	-0.11***	0.06	-0.15**	-0.04***	-0.02	0.07**
	(0.02)	(0.05)	(0.06)	(0.01)	(0.04)	(0.04)
$\ln GINI$	1.17	-2.82	-5.40	4.91	-10.17	-22.48**
	(4.57)	(7.18)	(16.15)	(3.50)	(11.06)	(8.93)
$\ln GINI^2$	-0.57	1.01	1.51	-0.66	1.36	3.27***
	(0.55)	(1.03)	(1.91)	(0.42)	(1.34)	(1.05)
$\ln GDP * \ln GINI$	0.25*	-0.61**	-0.60	-0.10	0.21	-0.14
	(0.13)	(0.25)	(0.51)	(0.09)	(0.32)	(0.24)
Agri	-0.01*	0.01	0.05	0.01***	0.01	0.02**
	(0.01)	(0.01)	(0.02)	(0.00)	(0.01)	(0.01)
Manu	0.03***	0.03**	-0.02	0.01**	-0.03**	-0.01
	(0.01)	(0.01)	(0.02)	(0.00)	(0.01)	(0.01)
Serv	0.00	-0.01	0.04	0.00	-0.01	0.02**
	(0.00)	(0.01)	(0.01)	(0.00)	(0.01)	(0.01)
Urban	-0.00	0.02**	-0.01	-0.00	0.02***	0.00
	(0.00)	(0.01)	(0.01)	(0.00)	(0.01)	(0.00)
N. Groups	4	3	2	3	3	2
BIC	5267.08	8301.77	11938.99	2866.48	9570.74	9581.25
Adj. R^2	0.88	0.39	0.38	0.71	0.31	0.21
Obs	3214	3114	3228	3251	3213	3198

Standard errors in parentheses. *, **, and *** indicate levels of statistical significance of 0.1, 0.05, 0.01, respectively. The optimal number of groups was selected by model selection criterion BIC and is displayed for each sub index at the bottom of the respective column.

As a robustness check all estimations were also exercised with OLS and FE, and without control variables. Statistically significant coefficients exhibit the same signs and similar orders of magnitude. Results can be found in the appendix.

Figure 1: Effects of $\ln GINI$ and $\ln GDP$ on sub-indices of the EF.



The shading indicates the size of the EF of the respective measure: black indicates a high footprint, white a low one. The dots represent the distribution of $\ln GINI$ and $\ln GDP$ of all countries in our sample in year 2001.

5 Discussion of results and policy implications

The main interest of this analysis is to determine the effect, if any, of inequality on the different aspects of biosphere use which is the focal point of our discussion. We cluster the results into three groups. First are indicators of environmental degradation, such as carbon emissions, and the built-up areas. The second group encompasses land masses dedicated to the production of different types of food. And the third group are indicators of environmental goods such as the land area covered by forests. It needs to be kept in mind that imports and exports are accounted for, which allows for a straightforward interpretation from the demand-side perspective.[6]

5.1 Effects of ln$\boldsymbol{GINI}$ and ln$\boldsymbol{GDP}$ on land area

Figure 1.1 indicates that there is indeed a trade-off between the political goals of reducing both inequality and carbon emissions: lowering inequality is associated with an increase of carbon emissions, *c.p.* An increase in the level of inequality in a country leads, *c.p.*, to a decrease in its biosphere use. Thus more virtual land is required to compensate carbon emissions in more equal countries, *c.p.* This means that the income consumption effect unambiguously prevails over the conspicuous consumption effect. The positive correlation between GDP and carbon emissions, *c.p.*, shows that countries with higher income levels tend to exploit more biocapacity than their poorer counterparts. From a policy perspective, this implies that there is indeed a trade-off between the political goal of reducing inequality and reducing environmental pollution: policies that reduce inequality are likely to increase biosphere use and vice versa.

The footprint stemming from built-up areas (figure 1.2) is highest both for countries with low inequality and a high GDP, as well as countries with high inequality and a low GDP, *c.p.* This means that in low-income countries the conspicuous consumption effect dominates over the income effect. In these countries the income effect is comparably small because a moderate level of redistribution would not suffice for the poor to expand

[6] It must not be forgotten that this paper only assesses one measure of inequality – the GINI coefficient – and a number of measures for biosphere use. As the works of ROCKSTRÖM et al. (2009) and STEFFEN et al. (2011) show, this is a simplification, as indeed one could argue that humanity is nearing the edge of our planetary boundaries. More extensive analysis is required to understand the relationship between inequality and other dimensions of anthropogenic environmental changes, such as biodiversity or acidification of oceans.

their housing to a large degree. In richer countries the income effect prevails: a reduction of inequality would increase the total land area covered by streets and buildings, *c.p.*, because more people could afford housing.

The effects on the agricultural sector diverge. Figures 1.3, 1.4, and 1.5 display the effects of $\ln GINI$ and $\ln GDP$ on the area required for producing different types of food consumed. Each of these three sub-indices of the EF stands for one category within food: fish, crops and meat. The latter is produced on land dedicated to grazing animals. While an increase in inequality leads to a reduction in the area required to produce crops consumed in a specific country, *c.p.*, it increases the land required for fish and meat production (grazing land). This means that increasing inequality leads to an increase in the consumption of fish and meat, *c.p.*, while the consumption of crops decreases with an increasing level of inequality. The latter can be associated with staple foods for which the income effect prevails. The opposite is true for meat and fish consumption where the conspicuous consumption effect prevails. This has interesting implications from a food security perspective, as this implies that in more unequal societies less basic foodstuffs, i.e. grains, rice, wheat, and other basic food staples are consumed while more luxury food products (fish and meat) are consumed, presumably by the more affluent members of society. The corresponding policy implications will be discussed below. Within the range of the sample's values for GDP, an increasing GDP has a positive marginal effect on the land required to produce all three types of foodstuffs, *c.p.*, which indicates that richer societies consume comparably more food in general.[7]

The estimation that denotes the area covered by forest is visualized in figure 1.6. Since the EF represents an environmental good, the estimated effects can be interpreted as Kuznets curves along the two dimensions, *c.p.*: starting from a very low GDP, in which a comparably large land area is covered by forest, industrialization leads to deforestation. Further increases in incomes are then associated with increasing efforts to protect the environment, increasing the forest area again, *c.p.* The effect of inequality follows a similar pattern: the effect of inequality on the demand for environmental goods, such as the land area covered by forests, is initially negative, *c.p.*: with increasing inequality, less forest is preserved. This can be explained by the fact that forests are public goods, which are more likely to receive funding in more egalitarian societies. We can argue that

[7]While the estimations for the fishing and cropland areas predict a turning point at the upper bound of the distribution of incomes, the area that would actually be affected is out of the sample range, so we understand the effects of the GDP on fish and crop consumption as a monotonous relation.

increases in inequality are likely associated with the emergence of an elite group who will transform these public goods into a source of personal revenue. So, regarding the effects of inequality on public forest area and other such natural goods, no definitive answer can be given: whether a policy designed to decrease inequality will result in an increase in forest land, or an increase in forest degradation, depends wholly on the specific situation within that country.

5.2 Policy implications

The overall results indicate that increasing inequality leads to a decrease in biosphere use as measured by carbon emissions. Countries with higher income levels also tend to exploit more biocapacity in almost all dimensions. The effect of inequality and income on environmental goods, as measured by forest land, is ambiguous, depending on the specific context. In terms of food, richer countries generally consume more, and fish and meat appear to be luxury goods that are consumed conspicuously.

In the observation period there was a trade-off between the political goals of reducing both inequality and biosphere use. For policy makers, this means that when implementing measures to reduce inequality, accompanying measures must be considered that take into account potential environmental impacts that may occur.

The second results relevant for policy makers regard the implications of changes in inequality for the agriculture related sub-indices of the EF: any measure that reduces inequality is likely to generate the positive effect of improving food security.

6 Conclusions

This paper introduces a microeconomic model to conceptualize opposing effects of inequality on biosphere use. The recently developed group fixed effects estimator is applied to a panel dataset to estimate the model. Results indicate that there are indeed trade-offs between reducing both biosphere use and inequality levels. The key message to policy makers is that reductions in one of the two undesired developments – increasing levels of pollution and inequality – need to be accompanied by measures that limit adverse effects in the respective other dimension.

The results of this paper can be used to calculate the optimal level of redistribution and tax on biosphere use to maximise welfare under constraints of sustainability and equity aspects.

One interesting follow-up question based on the results of this analysis would be to carry out the empirical analysis on a more disaggregated level to understand the effects found at the macro level more thoroughly on the level of smaller units such as household decision making. The level of aggregation could also be increased to the global level to link the costs of increasing global equity to the natural environment without considering the boarders of the nation state.

To summarize our findings, this paper concludes that policy makers should be aware that any policy targeting the SDG of reducing inequality is likely to have a harmful impact on the SDG of reducing the anthropogenic impact on nature, unless thoughtfully accounted for by countervailing measures to reduce the environmental impact that naturally follows reductions in inequality.

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8 Appendix

Table 4: Robustness check: without control variables

	Carbon	built-up	Fish	Crop	Grazing	Forest
Intercept	1.01	1.47	-37.97	-12.13*	14.84**	42.95***
	(12.01)	(16.74)	(35.82)	(6.90)	(21.82)	(16.22)
$\ln GDP$	1.95***	2.38	6.72**	0.70	-0.79**	-1.60***
	(0.72)	(1.75)	(2.99)	(0.44)	(1.37)	(1.09)
$\ln GDP^2$	-0.13***	0.00	-0.14**	-0.03**	-0.03***	0.10***
	(0.02)	(0.04)	(0.07)	(0.01)	(0.04)	(0.03)
$\ln GINI$	-6.28	-7.12	2.56	3.75	-8.48**	-21.57***
	(5.28)	(7.65)	(15.68)	(3.12)	(9.96)	(7.13)
$\ln GINI^2$	0.42	1.60	0.91	-0.64*	0.73*	2.95***
	(0.61)	(1.05)	(1.92)	(0.38)	(1.21)	(0.84)
$\ln GDP * \ln GINI$	0.29*	-0.67*	-1.05*	0.00	0.51***	0.07
	(0.15)	(0.36)	(0.62)	(0.09)	(0.28)	(0.21)
N. Groups	4	2	2	3	4	3
BIC	6728.84	9871.34	14239.03	3422.29	11422.89	11422.89
Adj. R^2	0.86	0.25	0.32	0.70	0.30	0.22
Obs	3775	3640	3776	3811	3770	3757

Standard errors in parentheses. Stars indicate levels of statistical significance of 0.1, 0.05, 0.01, respectively. The optimal number of groups was selected by model selection criterion BIC and is displayed for each sub index at the bottom of the respective column.