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Abstract

The extent of provision of a public good often relies on social awareness and public support for it. This applies, in particular, to global reduction of greenhouse gases and its relevance for mitigating climate change. We examine the concept of "public awareness" by introducing a formal model that analyzes efforts to mitigate climate change in a setting with heterogeneous countries. In the theoretical part we examine the Nash equilibrium of the contribution game. The effects of awareness and economic parameters on mitigation efforts can be disentangled, raising the possibility of linking awareness of climate change with economic wealth. The second part provides some empirical observations and offers the rankings of countries regarding awareness for climate change, as well as an empirical relationship between awareness and economic wealth.

JEL Classification: C72, D74, H41, H87, Q42, Q54

Keywords: Environmental awareness, Public Goods, Kyoto protocol, regional economics, diversity

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Environmental Awareness*

The Case of Climate Change

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August 2016

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1 Introduction

In December 2015, the parties to the Kyoto Protocol reached an agreement for reducing anthropogenic greenhouse gas emissions – after years of negotiations. The outcome of the Conference of the Parties (COP 21) in Paris (`http://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf`) is generally considered positive, albeit insufficient regarding the ambitious goal of limiting global warming to 1.5 degrees. There seems to be some agreement among the scientific community that further actions are needed, in particular after 2030 (cf. `http://unfccc.int/resource/docs/2015/cop21/eng/07.pdf`).

The critical issues, impeding further reaching commitments so far, refer to sharing the cost of this global environmental commodity among highly diverse countries. In this context, Article 3.1 of the United Nations Framework Convention on Climate Change (UNFCCC) requires that the mitigation and adaptation efforts should be shared between the parties *"on the basis of equity and in accordance with their common but differentiated responsibilities and respective capabilities"*. If, in this context, we look at current efforts of various industrialized countries to mitigate climate change by making use of renewable energy sources (with and without hydroelectricity), we obtain the situation indicated in Figure 1 below.

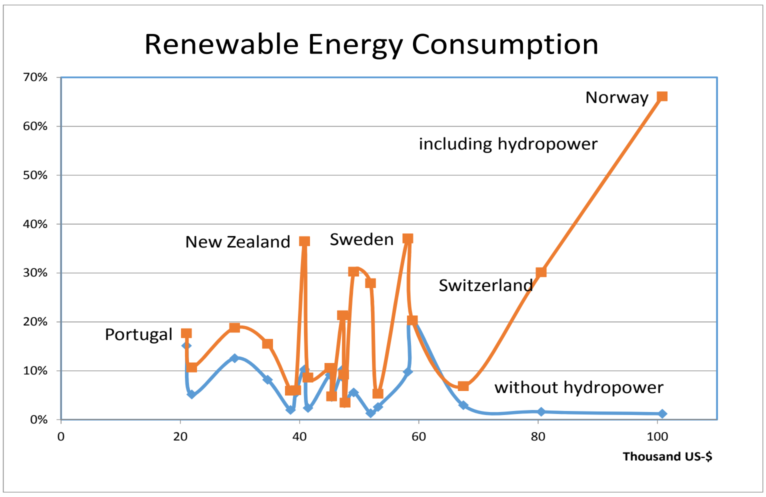

Figure 1: Share of energy consumption from renewable sources (with and without hydropower) depending on GDP (2013 thousand US-$, pc, ppp) of various industrialized countries (Source: Own calculations with data from `http://data.worldbank.org/` and `http://www.bp.com/`).

There is no clear structure detectable, not with respect to usual concepts of equity (cf. [8]), and not that of an "Environmental Kuznets Curve" (EKC) with the share of renewable energy consumption increasing with GDP per capita (cf. [15] and [29]). The conclusion is that the decisions to consume energy from renewable sources depend also on other parameters including societal and economic variables, on geographic and climatic conditions, and probably on "awareness" for climate change (cf. [31], p. 5), whatever part of diversity this variable comprises. Interestingly, "environmental awareness" has been used in marketing and social psychology as a means to conceptualize environmentally friendly behavior since the late 1960es (cf. [26]).

This paper therefore investigates effects of diversity on efforts to mitigate global warming. In particular, what role does "awareness" for climate change play in combination with economic variables? Should we expect a positive relationship between awareness and economic wealth? What can we learn about "awareness" in our model from empirical data?

As a result of the Lima Climate Change Conference in December 2014, the parties to the Kyoto Protocol were invited *"to communicate their intended nationally determined contributions well in advance of the twenty-first session of the Conference of the Parties in a manner that facilitates the clarity, transparency and understanding of the intended nationally determined contributions"* (cf. [31], p. 2). This implies that the decisions of the parties are to some extent dependent on each other. In the paper, we model this behavior by means of the Nash mechanism, which then reveals effects of diversity on equilibrium decision-making. The role "awareness" plays can then be investigated more clearly. The results obtained in this theoretical framework can be used for some empirical analyses regarding awareness for climate change.

The following section reviews the relevant literature, mainly with respect to climate change and reducing greenhouse gas emissions. Thereafter, we introduce the model with diverse countries. Observable diversity refers mainly to GDP per capita, and costs of renewable energy consumption. "Awareness" refers to not directly observable characteristics of a country. The Nash equilibrium, resulting from the interaction of the countries, allows some insight into the effects of diversity. In particular, properties of equilibrium burden sharing in its relation to equity and also in relation to observable characteristics can be analyzed. The then following section is dedicated to some empirical investigations. In particular, awareness will be estimated from observable data, allowing some conclusions of the dependence on observable characteristics. Some final remarks conclude the paper.

2 Literature Survey

The literature on the voluntary provision of public goods is abundant, covering nearly all aspects of theoretical and practical relevance (cf., for example, the seminal works by Samuelson ([23]), Olson ([21]), or Bergstrom et al. ([2]) among many others). This paper is based on these basic models.

The paper by Bergstrom et al. ([2]) is of particular interest because of a neutrality result obtained in the context of a Nash equilibrium determining the equilibrium contributions towards the public good. A redistribution of income among contributing countries, such that no country loses more income than its original contribution, yields a new Nash equilibrium in which each country adjusts the amount of its contribution by precisely the change in its income – and this redistribution has no effect on the equilibrium quantities of the public and private goods. In our context of mitigation efforts with possibly different costs for producing electricity from renewable sources, a financial support of the countries with lower costs would increase total mitigation efforts (cf. Result **??**).

These basic models on the provision of public goods have been adapted to the environmental context in various ways (cf. the papers mentioned below). Schumacher ([25]), for example, introduces "beliefs" to differentiate between environmental optimists and pessimists. One of the results points to the "double deprivation" of the pessimists: they believe that an environmental shock will destroy more of their wealth and they are willing to contribute more towards prevention.

Interest in the concept of "environmental awareness" or "environmental consciousness" originated with the ecological movement in the 1960s. According to Soyez et al. ([26], p. 223), researchers in marketing and social psychology focused first on "personal characteristics", such as sociodemographic variables, of environmentally conscious people. In the 1970s and 1980s environmentally friendly behavior was more explained in terms of environmentally friendly "attitudes" measurable by means of multi-item scales.

"Personal value orientation" as precursor of sustainable behavior was considered in a further stream of research followed by "cultural values", which have been investigated for the last ten years or so (cf. again [26], p. 224). Of course, cultural values form the basis for cross-cultural studies on environmentally friendly behavior, which are – for obvious reasons – of particular interest for researchers in marketing and social psychology. In this context Soyez analyzes how environmentally friendly behavior is influenced by cultural values, how national cultural values can be linked to personal pro-environmental behavior (cf. [27]). In a different, but nonetheless related context, Shum tests relationships between outcomes of environmental policy and attitudes towards the environment in order *"to develop a better understanding of environmental policy divergences and the mechanisms for environmental policy-making* (cf. [24], p. 282).

It seems to be plausible to assume that environmental commodities are characterized by a relatively high income elasticity, at least in industrialized and newly industrialized countries. Consequently, demand for these commodities should rise, and environmental pollution should be reduced with real GDP per capita further increasing. The resulting functional relationship between the level of pollution and GDP per capita points to aspects of an EKC. If such a relationship holds for a multitude of environmental issues, an increasing economic welfare would gradually help to solve local environmental problems. Regarding climate change, global greenhouse gas emissions will nonetheless continue to increase as long as sufficiently many countries raise their emissions. Stern (cf. [28]) discusses this case for global SO_2 emissions.

In a local context, Grossman and Krueger *"...find no evidence that environmental quality deteriorates steadily with economic growth. Rather, for most indicators, economic growth brings an initial phase of deterioration followed by a subsequent phase of improvement. The turning points for the different pollutants vary, but in most cases they come before a country reaches a per capita income of $8000"*. Their study uses urban air pollution, the state of the oxygen regime in river basins, fecal contamination of river basins, and contamination of river basins by heavy metals as indicators ([12], Abstract; the dollars are 1985 dollars).

Similarly, in a context of water pollution in countries in Central and Eastern Europe with the indicator "biological oxygen demand" (BOD), Archibald et al. find *"some evidence for the EKC hypothesis and estimate the per capita income turning point for industrial BOD effluents to be approximately 3800–5000 USD"* (cf. [1], Abstract). The analysis of Stern and Common on SO_2 emissions results in an inverted-U shape function of income for a sample of high-income countries (cf. [28]).

However, despite these promising examples, according to Stern the "Environmental Kuznets Curve" seems to be a hypothesized relationship between various indicators of environmental pollution and GDP per capita ([29], p. 1419). The concept emerged in the early 1990s with studies of the potential environmental impacts of the North Atlantic Free Trade Association (NAFTA). Stern provides an interesting survey on *"the rise and the fall of the EKC"*, characterizing the EKC as *"an essentially empirical phenomenon"*, with not much support from econometrics (cf. [29], p. 1420). Similarly, Huang et al. (cf. [15], Figure 3) show that there seems to be no empirical evidence supporting the EKC hypothesis for greenhouse gas emissions.

In the last years more and more advanced econometric techniques were employed to investigate existence or non-existence of the EKC. Fosten et al. (cf. [10]), for example, analyze the EKC with respect to CO_2 and SO_2 emissions in the UK, and provide a useful literature survey on the econometric methods used in this context. As our is based on the formal equilibrium outcomes of the Nash mechanism, the reader interested in econometric methods regarding the EKC is referred to these publications (cf. also [4], [13], [32], [36]). A comprehensive survey of the EKC hypothesis up to the year 2004 is provided by Dinda (cf. [6]). For further results on the EKC among the vast literature published more recently cf., for example, Kaika and Zervas ([16], [17]), and Dong et al. ([7]).

Recently, other empirical investigations revealed interesting aspects of the willingness to pay for climate actions. In this context Diederich and Goeschl *"uncover determinants* *of preferences for voluntary climate action, such as education, the information structure among the population, and exogenous environmental conditions"* ([5], Abstract). In a similar way, Borick et al. ([3], and Lorenzoni and Pidgeon [19]) study public views on climate change in the US and Canada, and in Europe and the US, respectively. The *"European's attitude towards climate change"* has been a topic of a special survey of "Eurobarometer" ([9]). The focus of this report was on, among other issues, *"the extent to which citizens feel informed about climate change"*. The results of the poll show that in about two thirds of the EU member states more than sixty percent of those interviewed consider global warming/climate change *"to be the most serious problem currently facing the world as a whole"* (cf. [9], p. 8).

Awareness regarding climate change has also been addressed in various publications. Zyadin et al., for example, investigate the perceptions regarding renewable energies of senior academics and early-stage researchers involved in renewable energy sciences (cf. [37], p. 84). Similarly, Karytsas and Theodoropoulou *"examine the demographic and socioeconomic factors that determine someone's knowledge on different forms of renewable energy"* (cf. [18], Abstract).

Weber and Wiesmeth investigate the issue of burden sharing in alliances (cf. [33], [34]), whereas Ekholm ([8]) and Ringius ([22]) discuss equitability in the context of climate change mitigation. For more fundamental aspects of equitable allocations cf. Moulin ([20]).

So far the review of the literature, which leaves us with a somewhat unclear picture. On the one hand we have empirical examples of an EKC, on the other hand we have the investigations of Stern (cf. [29]) and the empirical results of Huang et al. (cf. [15]), Dong et al. (cf. [7]) and our own introductory example in Figure 2. In order to clarify this situation and uncover the role of "awareness", the following section introduces the assumptions of the model based on awareness for climate change, and derives the formal results on burden sharing in the context of mitigating climate change. Empirical investigations will thereafter illustrate the practical role of awareness of climate change.

3 The Model

The above considerations show that there is enough room and also a certain necessity for explicitly introducing "awareness" into an economic model to mitigate global warming – to capture non-economic aspects of diversity among the countries. The first subsection presents the main assumptions of the model, emphasizing diversity.

3.1 Basic Assumptions

The following assumptions define the relevant framework conditions of our model. The basics of the model correspond to the model of Bergstrom et al. ([2]).

Assumption 3.1. *These first assumptions characterize countries as members of a union to mitigate climate change, the individuals living in these countries and the relevant commodities:*

a) There is a set $N = \{1, \ldots, n\}$ of countries. N constitutes a union of countries pursuing the environmental goal of mitigating climate change. There are k_i individuals in country i, $i \in N$.

b) There is one private commodity x and one public commodity y. In the context considered here, x is the gross domestic product (GDP), available for private consumption. The public commodity y is represented by the benefits of contributions to renewable energies (measured through renewable energy consumption).

c) Individuals in country i, $i \in N$, are characterized by the identical initial endowment w_i of the private commodity (thus, GDP per capita), and the identical utility function depending on consumption of the private commodity x and the public commodity y. For each $i \in N$, utility is given by the homothetic function $u_i(x_i, y) := x_i \cdot y^{\alpha_i}$ with the "awareness" parameter $\alpha_i > 0$.

"Renewable energy consumption" is used as an indicator regarding efforts to mitigate climate change by reducing greenhouse gas emissions. This public commodity is provided through the employment of renewable energy sources in the various countries, in our case parties to the Kyoto Protocol.

The parameter α_i is closely related to the marginal rate of substitution between the private and the public commodity. In fact,

$$\mathrm{MRS}_i(x, y) = \frac{u_{iy}(x, y)}{u_{ix}(x, y)} = \alpha_i \cdot \frac{x}{y}$$

for an arbitrary consumption bundle $(x, y) \in \mathbb{R}^2_{++}$. Therefore, a higher value of α_i indicates cet. par. a higher "willingness to pay" for an additional unit of the public commodity. In this sense, the values α_i, $i \in N$, can be considered as indicators of "awareness" for global warming (cf. also [5]), which allow a ranking of the countries.

The next assumption refers to the production possibilities of the public good, i.e., to the costs of producing 1 kWh of electrical energy by means of renewable sources. There are, of course, cost differences for the various renewable energy sources (cf. [11]), and concrete costs depend on the combination of these sources, which varies a lot across countries, also due to geographic and climatic conditions. Moreover, advanced technologies to generate electricity from renewable sources are more likely to be used in industrialized countries, and costs will also differ due to differences in wage rates and prices for suitable lots. In order to estimate the costs of generating electricity from renewable sources, we use data on "levelized cost of electricity" (LCOE).[1] We make the following assumption, which will be complemented with concrete numbers for LCOE in Section 4.

Assumption 3.2. *In country i, $i \in N$, β_i units of the private good can be turned into one unit of the public good. Thus, each country has access to a technology with constant returns to scale to produce the public commodity. β_i should be understood as the average LCOE according to the mix of renewable sources applied in country i.*

Then utility of, for example, individual 1 of country i, $i \in N$, can be rewritten using the contributions t_j^m, $j = 1, \ldots, k_m$; $m \in N$, of all individuals towards the provision of the public good:

$$\begin{aligned}
&v_i(t_1^1, \ldots, t_1^{k_1}; \ldots; t_n^1, \ldots, t_n^{k_n}) := \\
&= (w_i - \beta_i t_i^1) \cdot (t_1^1 + \ldots + t_1^{k_1} + \ldots + t_n^1 + \ldots + t_n^{k_n})^{\alpha_i} = \\
&= x_i^1 \cdot y^{\alpha_i} = u_i(x_i^1, y)
\end{aligned}$$

We make the following assumption with respect to the utility-maximizing behavior of the individuals in each country i, $i \in N$:

Assumption 3.3. *Individual agents maximize utility given the actions of all other agents in all countries.*

Although decisions on the application of renewable energy sources are often initiated and stimulated by governments, individual households or companies play an important role in this context.[2] In addition, governments cannot consistently and over a longer period of time neglect the preferences of the voters. This supports the behavioral assumptions of this model. However, it is also possible to assume that individual countries are the decision-makers. This leads to slightly different, but not structurally different results.

We then obtain the following first order condition for individual 1 in country $i \in N$:

$$\beta_i(t_1^1 + \ldots + t_1^{k_1} + \ldots + t_n^1 + \ldots + t_n^{k_n}) = \alpha_i(w_i - \beta_i t_i^1).$$

As the left hand sides of these first order conditions for the individuals of country i are identical, the right hand sides must be identical, too, resulting in identical equilibrium

[1] According to [11], p. 36, *"the method of levelized cost of electricity (LCOE) makes it possible to compare power plants of different generation and cost structures with each other. . . . The calculation of the average LCOE is done on the basis of the net present value method, in which the expenses for investment and the payment streams from earnings and expenditures during the plant's lifetime are calculated based on discounting from a shared reference date. The cash values of all expenditures are divided by the cash values of power generation."*

[2] A good example is provided by the German "Energiewende" with a large number of private households and business companies using the roofs of houses or vacant lots to install equipment for the generation of electricity from renewable sources (cf., for example, `http://energytransition.de/`.

contributions of all agents of this country. Thus $t_i^1 = \ldots = t_i^{k_i} =: t_i$ in equilibrium for each $i \in N$. Consequently, the first order conditions for $i \in N$ can be rewritten as follows:

$$k_1 t_1 + \ldots + (k_i + \alpha_i) t_i + \ldots + k_n t_n = \alpha_i w_i / \beta_i = \alpha_i \hat{w}_i$$

with "real" income $\hat{w}_i := w_i/\beta_i$ measured in kWh of electricity from renewable sources.

As already indicated, the Nash mechanism is certainly among the most prominent approaches towards describing the interactions of the countries or, rather, the individuals, regarding the provision of this particular public good. Other forms of interactions, leading to, for example, egalitarian-equivalent allocations or core allocations (cf. [20], [33]), require a more intense cooperation among the partner countries, which, in general, can only be guaranteed by a supranational institution endowed with sufficient administrative power. There is no such institution for the cases considered here.[3]

3.2 Equilibrium Contributions

In the next step, we look for the solution, the Nash equilibrium, resulting from these interactions via the Nash mechanism. We thereby restrict the analysis to the consideration of interior solutions, which are relevant in most practical situations. For all cases we use real income $\hat{w}_i := w_i/\beta_i$, $i \in N$. As already mentioned, under Assumption 3.3 the first order conditions for an interior solution are given by:

$$k_1 t_1 + \ldots + (k_i + \alpha_i) t_i + \ldots + k_n t_n = \alpha_i \hat{w}_i \quad \text{for each} \quad i \in N.$$

We then obtain the following proposition for the values $t = (t_1, \ldots, t_n) \in \mathbb{R}^n_{++}$ for the Nash-equilibrium. The proof of Proposition **??** is provided in the Appendix.

Proposition 3.1. *First of all, the solution $t = (t_1, \ldots, t_n) \in \mathbb{R}^n_{++}$ is symmetric in the sense that t_i can be obtained from t_j by replacing in t_j each occurrence of the index j with the index i and vice versa. Moreover, t_1 is given by:*

$$\begin{aligned} t_1 = {} & [k_2(\alpha_1 \hat{\alpha}_2 \ldots \alpha_n)\hat{w}_1 - k_2(\hat{\alpha}_1 \alpha_2 \ldots \alpha_n)\hat{w}_2 + \ldots + k_n(\alpha_1 \ldots \hat{\alpha}_n)\hat{w}_1 - \\ & - k_n(\hat{\alpha}_1 \alpha_2 \ldots \alpha_n)\hat{w}_n - (\alpha_1 \ldots \alpha_n)\hat{w}_n] \; / \\ & / \; [k_1(\hat{\alpha}_1 \alpha_2 \ldots \alpha_n) + \ldots + k_n(\alpha_1 \ldots \hat{\alpha}_n) + (\alpha_1 \alpha_2 \ldots \alpha_n)] \end{aligned}$$

with $\hat{\alpha}_i$ meaning that this factor has to be replaced by 1. By using $\bar{\alpha}_i := (\alpha_1 \ldots \hat{\alpha}_i \ldots \alpha_n)$ and $\bar{\alpha} := (\alpha_1 \ldots \alpha_n)$, we can simplify this expression in the following way:

$$t_1 = \frac{k_2 \bar{\alpha}_2 \hat{w}_1 - k_2 \bar{\alpha}_1 \hat{w}_2 + k_3 \bar{\alpha}_3 \hat{w}_1 - \ldots + k_n \bar{\alpha}_n \hat{w}_1 - k_n \bar{\alpha}_1 \hat{w}_n + \bar{\alpha} \hat{w}_1}{k_1 \bar{\alpha}_1 + \ldots + k_n \bar{\alpha}_n + \bar{\alpha}}.$$

Again we assume that an interior solution with $t_i > 0$, $i \in N$, exists for the given constellation of the parameters.

[3] The apparent difficulties to agree and reliably implement a 2-degree goal demonstrate the lack of an appropriate supranational institution to coordinate these efforts in the context of climate change.

Returning to individual equilibrium contributions t_i^n and total equilibrium contributions $T = k_1 t_1 + \ldots + k_n t_n$, we arrive at the following results, which follow immediately from Proposition 3.1 (remember that w_i is given by GDP_i per capita, $i \in N$):

Result 3.1. *A higher awareness for the public good results cet. par. in a higher individual contribution towards the provision of the public good. Similarly, a higher GDP per capita results cet. par. in a higher individual contribution towards the provision of the public good. Moreover, total contributions T increase with increasing w_i of the participating countries and also with higher "awareness", i.e., with increasing values of α_i, $i \in N$.*

The following result is a consequence of the neutrality theorem of Bergstrom et al. (cf. [2], p. 28ff) to our context. The proof is provided in the Appendix.

Result 3.2. *Assume that $\beta_i > \beta_j$ for $i, j \in N$ and consider a monetary transfer $\Delta > 0$ from country i to country j, such that positive contributions t_i^Δ and t_j^Δ continue to result in equilibrium. Then total equilibrium contributions increase: $T^\Delta > T$.*

Next, we investigate the issue of burden sharing in this context. What can be said with respect to the contributions of the various countries in relation to the economic parameters characterizing these countries?

Let $T_i := k_i t_i$ denote the total contribution of country i, $i \in N$, in equilibrium. Then we obtain the following result regarding burden sharing. The proof is again given in the Appendix:

Theorem 3.1. *For any two countries i and j in N relative burden sharing is related to awareness and "real" GDP per capita, $\hat{w}_i$, resp. "real" GDP, $\hat{W}_i$, in the following way:*

$$\frac{t_i}{\hat{w}_i} \leq \frac{t_j}{\hat{w}_j} \Longleftrightarrow \alpha_i \hat{w}_i \leq \alpha_j \hat{w}_j, \quad \textit{or} \quad \frac{T_i}{\hat{W}_i} \leq \frac{T_j}{\hat{W}_j} \Longleftrightarrow \alpha_i \hat{w}_i \leq \alpha_j \hat{w}_j.$$

This theorem shows first of all that proportional burden sharing (with respect to "real" income) for mitigating climate change is the exception, although it could provide a basis for an equitable or fair allocation in this context. Moulin analyzes theoretical issues of equitable allocations (cf. [20]), whereas Horstmann and Scholz (cf. [14]) address more practical aspects in the context of mitigation of climate change.

Moreover, a proportionally higher share of the burden arises not only from a higher GDP or GDP per capita. The effect of "awareness" has to be taken into account. Thus, disentangling the influences of awareness and GDP per capita, it is possible that despite of a high GDP per capita, a proportionally lower share of the burden results from a low level of awareness.

The following corollary reformulates this result and relates it to the issue of equity, and the empirical context of Figure 2 below. Its proof follows immediately from Theorem 3.1.

Corollary 3.1 (EKC). *Assume w.l.o.g. that* $w_1 \leq \ldots \leq w_n$. *Then* $\beta_1 t_1/w_1 \leq \ldots \leq \beta_n t_n/w_n$, *and* $\beta_1 T_1/W_1 \leq \ldots \leq \beta_n T_n/W_n$, *if and only if* $\beta_1\alpha_1 w_1 \leq \ldots \beta_n\alpha_n w_n$.

Thus, the question, whether the share of GDP for expenses on renewable energies increases with GDP, is in particular dependent on the level of awareness of climate change. Obviously, the combination of the two variables plays a role: a lower awareness can be compensated through a higher real GDP per capita and vice versa. What can be said empirically about the structures of both α and $\hat{w}$ depending on GDP per capita?

The following section addresses these empirical issues in a basic and preliminary context. In particular, the question of an increasing function $\alpha(w)$, will be investigated. These results depend critically on empirical values for LCOE, the levelized costs of renewable energy production, for which we have only rough estimates.

4 Empirical Analysis

With this empirical analysis we want to derive first estimates for the awareness parameter – given the ordinal specification of our utility functions – from the observable data on population, GDP, and renewable energy consumption and the herewith associated cost estimates. In addition, in view of Corollary 3.1 the goal is to understand the empirical relationship between awareness and GDP per capita. As already indicated in the introductory section, we focus on countries, which are parties to the Kyoto Protocol.

4.1 The Formal Background

We investigate and evaluate the share of "Renewable Energy Consumption" in various countries as an indicator of awareness regarding climate change. The first step consists in determining roughly the values of the cost factors β_i for countries i in consideration, i.e., the LCOE of 1 kWh of electricity generated by means of renewable sources.

There is a substantial range of costs, depending on the situation of a particular country (cost of equipment, labor costs, climatic situation, ...) and on the combination of technologies to generate electricity from renewable sources (cf. Figure 3 in [35], p. 11). For more detailed case studies on LCOE we refer to [11] for Germany, to [30] for India, and to [35] for a global energy perspective. However, precise data on average LCOE in a particular country seem not to be available so far. In order to complete our empirical analysis, we thus have to make some rudimentary assumptions regarding the values of the β_i, $i \in N$.

In order to approximate the scarcely available empirical data, we define the function $\beta(w)$ in the following simple way: $\beta(w) := -0.1 + 0.0000066 \cdot w$. This leads to LCOE of approximately 0.07 US-$ per kWh for a country with a GDP per capita (PPP) of 25,000 US-$ (Portugal), of approximately 0.19 US-$ for a country with a GDP per capita (PPP) of 45,000 US-$ (Germany), and of approximately 0,26 US-$ per kWh for a country with a GDP per capita (PPP) of 55,000 US-\$ (US). $\beta(w)$ then connects these pair of coordinates by a straight line. The values for the β_i, $i \in N$, correspond approximately to some estimates provided in the literature, although precise data are required for a sound analysis. Observe that with this specification of $\beta(w)$ the function $\hat{w}(w) = w/\beta(w)$ decreases with w increasing.

If we look again at current efforts of various industrialized countries to mitigate climate change by making use of renewable energy sources (without hydroelectricity), we obtain the situation indicated in Figure 2, with the LCOE given by the above function $\beta(w)$.

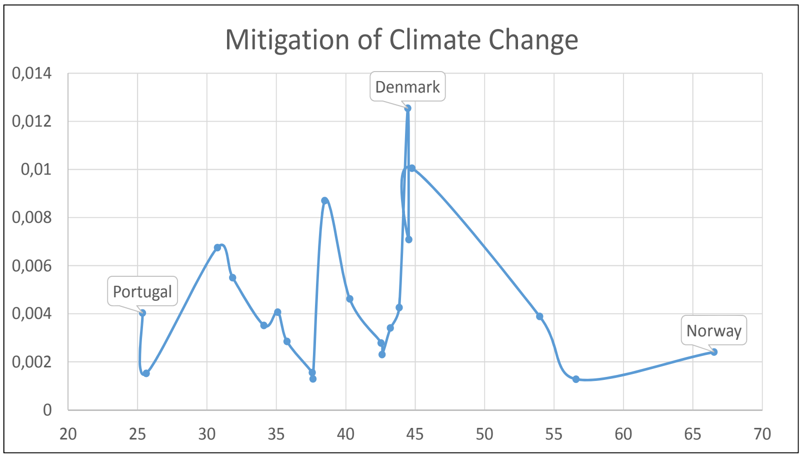

Figure 2: Share of Expenses on Renewable Energies depending on GDP pc (2013 thousand US-\$, ppp) of various industrialized countries (Source: Own calculations using $\beta(w)$ above with data from `http://data.worldbank.org/` and `http://www.bp.com/`).

Again, there is no clear structure detectable, In particular the share of expenses of GDP on renewable energy consumption does not increase with GDP per capita (cf. also Figure 1). Consequently, in view of Corollary 3.1, $\beta_i \alpha_i w_i$ cannot increase with GDP pc w_i of these countries.

For the formal background of the empirical investigations, we consider the variables α_i as functions of the variables $(T_j, k_j, w_j, \beta_j)_{j \in N}$. Instead of solving the expressions for the equilibrium contributions for the parameters α_i, $i \in N$, we make directly use of the first order conditions for the interior Nash equilibrium:

$$k_1 t_1 + \ldots + (k_i + \alpha_i) t_i + \ldots + k_n t_n = \alpha_i \hat{w}_i, \ i \in N,$$

with "real" GDP per capita $\hat{w}_i := w_i/\beta_i$. These equations can be rewritten as follows: $T = \alpha_i(\hat{w}_i - t_i)$ with total contributions towards the provision of the public good, i.e., total spending on renewable energy sources, of the member states, given by $T = k_1 t_1 + \ldots + k_n t_n$. Consequently, the values of the α_i, $i \in N$, result immediately from the observable, or computable parameters T, $\hat{w}_i$ and t_i:

$$\alpha_i = \frac{T}{\hat{w}_i - t_i} \quad \text{for} \quad i \in N.$$

The first analysis investigates climate-sensitive behavior of Annex II Parties to the Kyoto Protocol, industrialized countries in the OECD with self commitments to reduce greenhouse gas emissions.

4.2 Annex II Countries

The United Nations Framework Convention on Climate Change (UNFCCC), resulting from the "Earth Summit" in Rio de Janeiro in 1992, divides countries into three main groups according to differing commitments (`http://unfccc.int/parties_and_observers/items/2704.php`):

- Annex I Parties include the industrialized countries that were members of the OECD (Organisation for Economic Co-operation and Development) in 1992, plus countries with economies in transition (the EIT Parties), including the Russian Federation, the Baltic States, and several Central and Eastern European States.
- Annex II Parties consist of the OECD members of Annex I, but not the EIT Parties. They are required to provide financial resources to enable developing countries to undertake emissions reduction activities under the Convention and to help them adapt to adverse effects of climate change.

Country:	GDPpc	α_i	Country:	GDPpc	α_i
Norway	66,520	0.407	Switzerland	56,580	0.386
US	53,960	0.380	Sweden	44,760	0.352
Denmark	44,460	0.351	Germany	44,540	0.350
Austria	43,840	0,346	Netherlands	43,210	0.343
Canada	42,610	0,340	Australia	42,540	0.340
Belgium	40,280	0.330	Finland	38,480	0.322
Japan	37,630	0.315	France	37,580	0.314
UK	35,760	0.304	Ireland	35,090	0.300
Italy	34,100	0.293	Spain	31,850	0.277
New Zealand	30,750	0.269	Greece	25,630	0.215
Portugal	25,360	0.213			

Table 1: Ranking of Annex II Parties regarding "awareness". (Source: Own calculations with data taken from `http://data.worldbank.org/` and `http://www.bp.com/`; values of the α_i for readability multiplied with factor 100).

Table 1 presents the results for the values of GDP per capita (2013 US-$, ppp) and "environmental awareness" for selected Annex II Parties. The countries are ranked according to the values of environmental awareness.

Countries with a supposedly high environmental awareness (Norway, Switzerland, US, Sweden, ...) lead this list of Annex II countries. The only surprise is that the Southern European countries Italy, Spain, Portugal and Greece with a lot of sunshine appear towards the lower end of the ranking.

Observe that in this table we do not include consumption of electricity from hydro power plants, as the availability of hydroelectricity is largely dependent on appropriate geographical conditions. Nevertheless, the abundance of hydroelectricity in some countries might affect consumption of electricity from the other renewable sources. This might in turn have an effect on the empirical value of "awareness", not taken into account in the above estimations (cf., however, Figure 3)

4.3 The Empirical Relationship Between Awareness and Economic Wealth

One of the prominent questions arising in this context refers to the relationship between awareness of climate change and GDP per capita. More precisely, this is the question, whether this relationship reveals aspects of an EKC (cf. [29], [15], [16], [17], [7]). Figure 3 presents the result based on the LCOE function $\beta(w) := -0.1 + 0.0000066 \cdot w$ for renewable energies with and without hydropower.

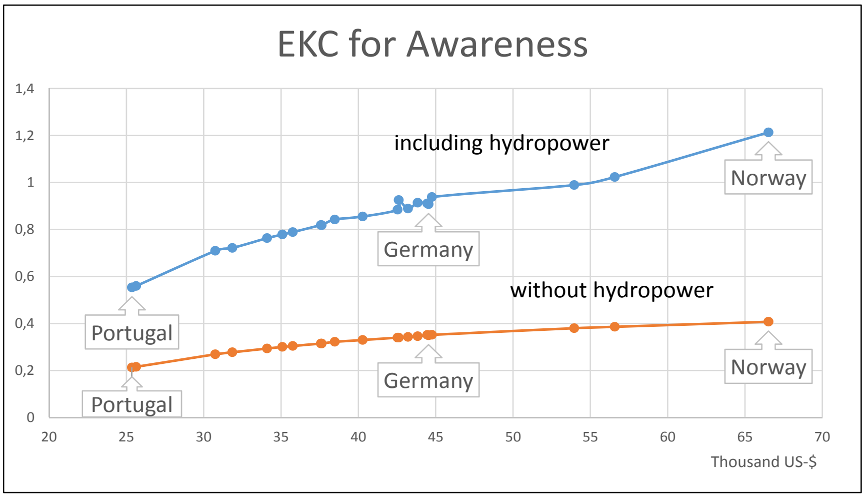

Figure 3: Awareness depending on GDP pc (2013 thous. US-\$, ppp) of the Annex II countries listed in Table 1 with $\beta(w)$ given above. (Source: Own calculations with data from `http://data.worldbank.org/` and `http://www.bp.com/`).

There is, thus, a rather clear tendency for higher environmental awareness to be associated with a higher GDP per capita. This result is in favor of the upward sloping part of a classical "Environmental Kuznets Curve", implying that activities for mitigating climate change increase with economic wealth.

We know from Corollary 3.1 that the behavior of $\beta_i \alpha_i w_i$ determines the behavior of $\beta_i t_i / w_i = \beta_i T_i / W_i = \beta_i T_i / \mathrm{GDP}_i$, $i \in N$. In this sense, the empirical curve $\alpha(w)$ from

Figure 3 and the downward sloping function $\hat{w}(w)$ "explain" the structure of Figure 2. Although awareness shows an increasing trend, this positive effect is more than compensated through the negative income effect resulting from the decreasing "real" income.

5 Concluding Remarks

The theoretical part of this paper analyzes the interaction of the agents of various countries regarding efforts to mitigate climate change. These efforts are measured by renewable energy consumption and the interaction is governed by the Nash mechanism. The results demonstrate the influence of "awareness", in addition to the economic variable "GDP per capita" on burden sharing.

The empirical part of the paper makes use of the first-order conditions to allow an explicit computation of the awareness parameters for various countries. The results are dependent on the levelized costs of energy from renewable sources, for which there are only more or less rough estimates. The estimates of LCOE applied here lead to aspects of an empirical EKC for awareness of climate change.

Future research in this context could focus on this more or less latent variable "awareness". Which parameters influence awareness, and how could awareness be raised in order to accelerate efforts to mitigating climate change.

Appendix

Proof of Proposition 3.1: For the proof we note that the system of first order conditions is symmetric in the sense that symmetrically exchanging indices leads from one equation to the other ones. Therefore, this property is retained for the solutions. Next, we show that the first one of these first order conditions is fulfilled by plugging in the above values of t_i. This equation reads:

$$(k_1 + \alpha_1)t_1 + k_2 t_2 + \ldots + k_n t_n = \alpha_1 \hat{w}_1.$$

From straightforward calculations we immediately obtain the following expression for the total quantity of the public commodity $T = k_1 t_1 + \ldots + k_n t_n$ provided in equilibrium:

$$\begin{aligned} T &= \frac{(\alpha_1 \ldots \alpha_n)(k_1 \hat{w}_1 + \ldots + k_n \hat{w}_n)}{k_1(\hat{\alpha}_1 \ldots \alpha_n) + \ldots + k_n(\alpha_1 \ldots \hat{\alpha}_n) + (\alpha_1 \ldots \alpha_n)} = \\ &= \frac{k_1 \bar{\alpha} \hat{w}_1 + \ldots + k_n \bar{\alpha} \hat{w}_n}{k_1 \bar{\alpha}_1 + \ldots + k_n \bar{\alpha}_n + \bar{\alpha}} = \frac{k_1 \hat{w}_1 + \ldots + k_n \hat{w}_n}{k_1/\alpha_1 + \ldots + k_n/\alpha_n + 1}. \end{aligned}$$

Thus, it remains to show: $T + \alpha_1 t_1 = \alpha_1 \hat{w}_1$. Canceling out α_1 and rearranging the terms by means of the above formula we obtain:

$$\begin{aligned} &(T/\alpha_1 + t_1)(k_1 \bar{\alpha}_1 + \ldots + k_n \bar{\alpha}_n + \bar{\alpha}) = k_1 \bar{\alpha}_1 \hat{w}_1 + \ldots + k_n \bar{\alpha}_1 \hat{w}_n + \\ &+ k_2 \bar{\alpha}_2 \hat{w}_1 - k_2 \bar{\alpha}_1 \hat{w}_2 + k_3 \bar{\alpha}_3 \hat{w}_1 + \ldots + k_n \bar{\alpha}_n \hat{w}_1 - k_n \bar{\alpha}_1 \hat{w}_n + \bar{\alpha} \hat{w}_1 = \\ &= k_1 \bar{\alpha}_1 \hat{w}_1 + \ldots + k_n \bar{\alpha}_n \hat{w}_1 + \bar{\alpha} \hat{w}_1 = \hat{w}_1(k_1 \bar{\alpha}_1 + \ldots + k_n \bar{\alpha}_n + \bar{\alpha}), \end{aligned}$$

and the desired result follows. By making use of symmetry considerations, the other equations are also fulfilled with these values of the t_i, $i \in N$. □

Proof of Result 3.2: For a total monetary transfer Δ from country i to country j each individual has to contribute the amount Δ/k_i and each individual of country j obtains the amount Δ/k_j. Consider then

$$T = \frac{k_1\hat{w}_1 + \ldots + k_n\hat{w}_n}{k_1/\alpha_1 + \ldots + k_n/\alpha_n + 1}$$

from the proof of Proposition 3.1 above. We can similarly calculate T^Δ and investigate the difference to T by focussing on the relevant terms:

$$T^\Delta - T = \frac{k_i(\hat{w}_i - \Delta/(k_i\beta_i)) + k_j(\hat{w}_j + \Delta/(k_j\beta_j)) - k_i\hat{w}_i - k_j\hat{w}_j}{k_1/\alpha_1 + \ldots + k_n/\alpha_n + 1} = \frac{-\Delta/\beta_i + \Delta/\beta_j}{k_1/\alpha_1 + \ldots + k_n/\alpha_n + 1}.$$

But this last expression is positive for $\beta_i > \beta_j$. $\square$

Proof of Theorem 3.1: In order to simplify the notation, we compare $t_1\hat{w}_2$ with $t_2\hat{w}_1$. A straightforward calculation using real GDP and the nominators of the above terms yields:

$$\begin{aligned}
&t_1\hat{w}_2 \leq t_2\hat{w}_1 \iff \\
&k_2\bar{\alpha}_2\hat{w}_1\hat{w}_2 - k_2\bar{\alpha}_1\hat{w}_2^2 + \ldots + k_n\bar{\alpha}_n\hat{w}_1\hat{w}_2 - k_n\bar{\alpha}_1\hat{w}_2\hat{w}_n + \bar{\alpha}\hat{w}_1\hat{w}_2 \leq \\
&k_1\bar{\alpha}_1\hat{w}_1\hat{w}_2 - k_1\bar{\alpha}_2\hat{w}_1^2 + \ldots + k_n\bar{\alpha}_n\hat{w}_1\hat{w}_2 - k_n\bar{\alpha}_2\hat{w}_1\hat{w}_n + \bar{\alpha}\hat{w}_1\hat{w}_2.
\end{aligned}$$

Simplifying and substituting $\hat{W}_i$ for $k_i\hat{w}_i$, $i \in N$, yields:

$$\begin{aligned}
&t_1\hat{w}_2 \leq t_2\hat{w}_1 \iff \\
&(\hat{W}_1 + \ldots + \hat{W}_n) \cdot \bar{\alpha}_2\hat{w}_1 \leq (\hat{W}_1 + \ldots + \hat{W}_n) \cdot \bar{\alpha}_1\hat{w}_2 \\
&\iff \alpha_1\hat{w}_1 \leq \alpha_2\hat{w}_2,
\end{aligned}$$

thus arriving at the desired result. $\square$

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