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Awareness of Climate Change in a Diverse World

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Awareness of Climate Change in a Diverse World

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Abstract

"Awareness" for a public good is necessary to stimulate voluntary contributions towards the provision of this commodity. This applies in particular to the global reduction of greenhouse gases and its relevance for mitigation of climate change. The success of the new climate agreement to be concluded in Paris in 2015 thus depends on sufficient "awareness" for climate change, but also on the extent of diversity among the participating countries.

This papers develops a formal model with diverse countries mitigating climate change. Diversity thereby refers to awareness for global warming, population, GDP per capita and costs of renewable energy sources. The Nash mechanism coordinates individual decisions, and the effect of diversity on equilibrium contributions can be investigated in various ways.

The second part of the paper provides rankings of signatories of the Kyoto Protocol regarding awareness for climate change. In these empirical investigations, estimates for awareness are derived from observable data. Some results on the "Environmental Kuznets Curve" and some final remarks conclude the paper.

Keywords: Diversity, Kyoto Protocol, environmental awareness, regional economics

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

1 Introduction

With the first commitment period of the Kyoto Protocol ending in 2012, the parties to the Protocol have since tried, although to no avail so far, to agree on a second commitment period to continue reducing greenhouse gas emissions on a global scale and in a coordinated way. Nations are now working towards a new global climate change agreement, to be reached at the Conference of the Parties (COP 21) in Paris in late 2015 (cf. `http://www.c2es.org/international/2015-agreement`). The critical questions, impeding an agreement so far, refer to sharing the cost of this global environmental commodity among diverse countries with diversity including societal and economic variables and "awareness" for climate change. Interestingly, "environmental awareness" has been used in marketing and social psychology as a means to conceptualize environmentally friendly behavior since the late 1960s (cf. [19]).

This paper therefore investigates effects of diversity on efforts to mitigate global warming. What role does awareness for climate change play in this context? Can we rank countries regarding their awareness? To what extent is awareness dependent on economic parameters such as, for example, GDP per capita? Is there, to be more precise, an "Environmental Kuznets Curve" (EKC) relating a higher level of GDP per capita to a higher value of awareness? Are the resulting efforts to mitigate climate change characterized by "equity", an issue brought into the climate talks by the developing countries to operationalize the sharing of the carbon budget (cf. also [24], p. 5)?

As a result of the Lima Climate Change Conference in December 2014, the parties to the Kyoto Protocol were again invited *"to communicate their intended nationally determined contributions well in advance of the twenty-first session of the Conference of the Parties (by the first quarter of 2015 by those Parties ready to do so) in a manner that facilitates the clarity, transparency and understanding of the intended nationally determined contributions"* (cf. [24], 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 results obtained in this theoretical framework can in particular 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. Diversity refers mainly to GDP

per capita, costs of renewable energy consumption and awareness. 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 can be analyzed and a theoretical EKC can be derived. The then following section is dedicated to some empirical investigations. In particular, awareness will be estimated from observable data, and the empirical EKC will be analyzed. 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 ([17]), Olson ([16]), or Bergstrom et al. ([2]) among many others).

Interest in the concept of "environmental awareness" or "environmental consciousness" originated with the ecological movement in the 1960es. According to Soyez et al. ([19], p. 223), researchers in marketing and social psychology focused first on "personal characteristics", such as sociodemographic variables, of environmentally conscious people. In the 1970es and 1980es 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 [19], 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. [20]). 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. [18], p. 282) .

It seems to be plausible to assume that environmental commodities are characterized by a relatively high income elasticity, at least in somewhat developed countries. Consequently, demand for these commodities should rise, and environmental pollution should be reduced with real GDP per capita in-

creasing. The resulting functional relationship between GDP per capita and the level of pollution, the "Environmental Kuznets Curve" (EKC), could then be used as an indicator of a gradually emerging environmental awareness: a further increasing GDP per capita will be accompanied by similarly increasing efforts to reduce the pollution, once the maximum of the EKC is attained. Thus, diversity regarding awareness for climate change might be affected by diversity with respect to some economic characteristics.

In this 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 ([10], 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 estimates 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 invertet-U shape function of income for a sample of high-income countries (cf. [21]).

According to Stern, the "Environmental Kuznets Curve" seems to be a hypothesized relationship between various indicators of environmental pollution and GDP per capita ([22], p. 1419). The concept emerged in the early 1990s with studies of the potential environmental impacts of 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. [22], p. 1420). Similarly, Huang et al. (cf. [12], 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. [8]), for example, analyze the EKC with respect to CO_2 and SO_2 emissions in the UK, and provide an excellent literature survey on the econometric methods used in this context. As our empirical approach to the EKC is based on the formal equilibrium outcomes of the Nash mechanism, the reader interested in these econometric methods is referred to these surveys (cf. also

[4], [11], [25], [28]). A survey of the EKC hypothesis up to the year 2004 is provided by Dinda (cf. [6]).

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 [14]) 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" ([7]). 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, among other things, 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. [7], 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. [29], p. 84). Similarly, Karytsas and Theodoropoulou *"examine the demographic and socioeconomic factors that determine someone's knowledge on different forms of renewable energy"* (cf. [13], Abstract).

So far the review of the literature. The following section introduces the assumptions of the formal model and develops the basic theoretical results, which will then applied to some empirical investigations.

3 The Model

The above considerations show that there is enough room and also a certain need for explicitly introducing "awareness" into an economic model to mitigate global warming. The following subsection presents the main assumptions of the model and emphasizes the aspect of diversity.

3.1 Basic Assumptions

The following assumptions define the relevant framework conditions of our model.

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, for example, the parties to the Kyoto Protocol, pursuing a certain environmental goal, mitigating climate change, for example. 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) 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 through reduction of 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, parameters α_i, $i \in N$, can be considered as indicators of "awareness" for global warming (cf. also [5]), allowing a ranking of the countries.

The next assumption refers to the production possibilities of the public good, i.e., to the costs of producing one kWh of electrical energy by means of renewable sources. There are, of course, cost differences for the various renewable energy sources (cf. [9]), and concrete costs depend on the exact

composition of these sources, which vary a lot across countries. 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 the data on "levelized cost of electricity" (LCOE).[1] We make the following assumption, which will be further elaborated 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 of all individuals towards the provision of the public good:

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

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.*

Then we obtain the following first order condition for individual 1 in country $i \in N$:[2]

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

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

[1] According to [9], 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] These first order conditions make clear that the α_i, $i \in N$, will typically assume high values, also a consequence of the particular ordinal transformation of our utility functions. This effect will later be weakened by dividing the α_i by the same sufficiently large number. This will not affect the ranking of the α_i.

in identical equilibrium contributions of all agents of this country. Thus $t_i^1 = \ldots = t_i^{k_i}$ 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.

Remark 3.1. *There are two other possible behavioral assumptions, which could be applied in the context considered here. They yield identical equilibrium outcomes, which are, however, to some extent different from the solutions that we obtain with Assumption 3.3.*[3]

1. *Each agent assumes that all other agents in the country will react symmetrically and takes this into account.*

2. *Instead of individual agents, the government of country i, $i \in N$, maximizes utility u_i with initial endowment of the private commodity then given by $W_i := k_i w_i$, corresponding to GDP_i.*

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.[4] In addition, governments cannot consistently and over a longer period of time neglect the preferences of the voters. Thus, we prefer to adopt the first model.

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. [15], [26]), 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.[5]

[3] If $t_i(\alpha_1, \ldots, \alpha_n)$, $i \in N$, is the solution under Assumption 3.3, then $t_i(k_i\alpha_1, \ldots, k_n\alpha_n)$, $i \in N$, is the solution for these modified behavioral assumptions.

[4] 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 technologies for the generation of electricity from renewable sources (cf., for example, `http://energytransition.de/`.

[5] The apparent failure so far to agree on a second commitment period of the Kyoto Protocol and to focus on the "two degree goal", i.e., to try to restrict global warming to a maximum increase of the average temperature to two degrees centigrade, demonstrate the lack of an appropriate supranational institution to coordinate these efforts in the context of climate change.

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 values $t^n = (t_1^n, \ldots, t_n^n) \in I\!R_{++}^n$ for the Nash-equilibrium:

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

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

with $\hat{\alpha}_i$ implying 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:

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

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

Proof. 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^n. This equation reads:

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

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

provided in equilibrium:

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

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

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

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

Returning to individual contributions t_i^n and total contributions T, we arrive at the following results (remember that w_i is given by GDP_i per capita, $i \in N$):

Corollary 3.1. *A higher awareness for the public good in consideration together with a higher GDP per capita results cet. par. in a higher individual contribution towards the provision of the public good.*

Corollary 3.2. *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 analysis investigates 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 given parameters characterizing these countries?

Let $T_i := k_1 t_i^n$ denote the total contribution of country i, $i \in N$, in equilibrium. Then we obtain the following result regarding burden sharing:

Theorem 3.2. *For any two countries i and j in N relative burden sharing is related to awareness and "real" GDP per capita, resp. "real" GDP, in the following way:*

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

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

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

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

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

thus arriving at the desired result. □

This theorem shows first of all that proportional burden sharing (with respect to "real" income) for mitigating climate change is the exception, although it is often considered equitable or fair.[6] 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, it is possible that despite of a high GDP per capita, a proportionally lower share of the burden results from a low awareness. We thus immediately obtain the following corollaries:

Corollary 3.3. *If in spite of of a lower real GDP per capita a country contributes more towards the provision of the public good, then this is the result of a higher awareness for the public good in consideration.*

Corollary 3.4. *With respect to proportional burden sharing, we have the following result: assume that $\alpha_i\hat{w}_i = \alpha_j\hat{w}_j$ for all $i, j \in N$. Then, again for all $i, j \in N$:*

$$\frac{t_i}{\hat{w}_i} = \frac{t_j}{\hat{w}_j} \quad or \quad \frac{\beta_i t_i}{w_i} = \frac{\beta_j t_j}{w_j} \quad and \quad \frac{T_i}{\hat{W}_i} = \frac{T_j}{\hat{W}_j} \quad or \quad \frac{\beta_i T_i}{W_i} = \frac{\beta_j T_j}{W_j}.$$

In addition, these results allow the consideration of some kind of a "theoretical" EKC with $T_i/\hat{W}_i$ as indicator of environment-friendly behavior:

Corollary 3.5 (EKC). *Assume w.l.o.g. that $\alpha_1\hat{w}_1 \leq \ldots \leq \alpha_n\hat{w}_n$. Then $T_1/\hat{W}_1 \leq \ldots \leq T_n/\hat{W}_n$. Thus, relative contributions towards the provision of the public commodity increase with modified GDP per capita $\alpha\hat{w}$.*

[6] Consider in this context, for example, the goal of 2% of GDP for defense contributions of NATO member states.

Of course, this does not imply the existence of a regular EKC. Nevertheless, this result shows once more the influence of awareness on equilibrium contributions and helps to separate the effects of economic variables and awareness.

The following examples, which will be extended in Section 4, demonstrate how these results can be applied to obtain some first insight regarding the relevance of "awareness" in the context of global warming.

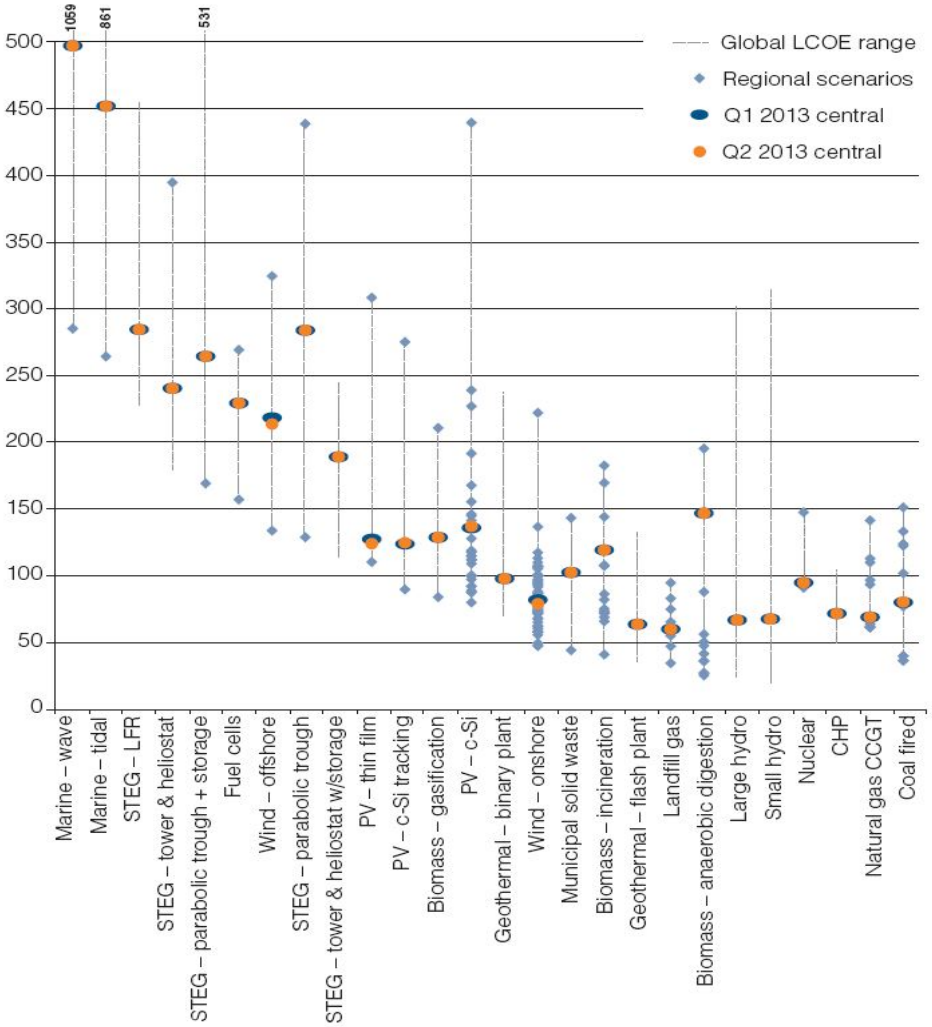

Figure 1: Global levelised cost of energy in Q2 2013 (USD/MWh) (Source: Bloomberg New Energy Finance. Cf. Figure 3 in [27], p. 11. Used by permission of the World Energy Council, London, `http://www.worldenergy.org`).

We first have to specify the values of the parameters β_i for the countries on the list. There are some publications, which provide data on the levelized costs of electricity from renewable sources (cf. Footnote 1, [9], [23], [27]).

Figure 1 illustrates the substantial regional differences among levelized costs for the various renewable energy sources. As already mentioned, the concrete costs in one country depend on the general economic situation, but also on the mix of renewable energy sources in the generation of electricity. We thus assume that developing and transformation countries make use of the relatively cheaper sources such as onshore wind power plants or simple biogas plants, whereas offshore wind plants or solar power plants tend to be more common in the industrialized world.

The values of the parameters β_i used in Example 3.1 are then, at least to some extent, supported through empirical investigations (cf. again the corresponding data in [9], [23], [27]). More details on the costs of renewable energy consumption follow in Section 4. Table **??** provides some rough estimates of these costs depending on GDP per capita.

Example 3.1. *2013 data for GDP per capita w_i (ppp, current US-$), and LCOE β_i of renewable energy consumption (US-$ per kWh):*

Country	w_i	β_i	Country	w_i	β_i
USA	53,960	0.34	Brazil	14,750	0.09
Canada	42,610	0.27	Turkey	18,760	0.11
Germany	44,540	0.28	China	11,850	0.07
UK	35,760	0.22	India	5,350	0.03

Table 1: Sources: `http://data.worldbank.org/` for GDP per capita, and [9], [23], [27] for the estimates on LCOE of renewable energy consumption.

From the data of Table 1 we can now calculate "real" GDP per capita measured in units (kWh) of renewable energy consumption: $\hat{w}_i = w_i/\beta_i$.

Example 3.2. *2013 data for "real" GDP per capita $\hat{w}_i$ (in kWh), and renewable energies consumption per capita (kWh), corresponding to individual contribution t_i in country i. The renewable sources include wind, geothermal, solar, biomass and waste.*

Country	$\hat{w}_i$	t_i	Country	$\hat{w}_i$	t_i
Canada	157,815	541	Brazil	163,889	292
USA	158,706	820	China	169,286	140
Germany	159,071	1,627	Turkey	170,545	129
UK	162,545	750	India	178,333	41

Table 2: Real GDP and renewable energy consumption per capita (Sources: Data from Table 1 and from `http://www.bp.com/`).

It is interesting to note that the levels of real GDP per capita are – given the values of the β_i – not too much different from one another. In view of Theorem 3.2 this implies that awareness α_i is to a large extent determined by the level t_i of renewable energy consumption.

If we then compare, again according to Theorem 3.2, the data of Germany and the data of China, for example, with all other countries in the above list, then we obtain the numbers in Table 2, from which we can immediately derive some first results regarding awareness for climate change.

Country	Germany t_G/t_i	Germany $\hat{w}_G/\hat{w}_i$	China t_C/t_i	China $\hat{w}_C/\hat{w}_i$
Canada	3.007	1.008	0.258	1.073
USA	1.984	1.002	0.170	1.067
Germany	1.000	1.000	0.086	1.064
UK	2.169	0.979	0.186	1.041
Brazil	5.572	0.971	0.479	1.033
China	11.621	0.940	1.000	1.000
Turkey	12.612	0.933	1.085	0.993
India	39.683	0.892	3.414	0.949

Table 3: Comparison of the countries (Source: Own calculations from the data provided in Table 1).

From the data of Table 3 in combination with Table 2 we obtain immediately the following conclusions regarding awareness for climate change:

- For Germany we have $t_G/t_i > \hat{w}_G/\hat{w}_i$ for each other country on the list. Therefore also $\alpha_G\hat{w}_G > \alpha_i\hat{w}_i$ for each of these countries, and awareness in Germany exceeds that in any other country on the list with the possible exception of both the USA and Canada, because real GDP per capita in Germany is above that in the USA and Canada.

- For China we obtain $t_C/t_i > \hat{w}_c/\hat{w}_i$ only for Turkey and India. Again, we obtain $\alpha_C\hat{w}_C > \alpha_i\hat{w}_i$ for these countries, and because real GDP per capita in China is below real GDP per capita both in Turkey and India, awareness for climate change in China is higher.

- A similar analysis for India reveals that $t_I/t_i < \hat{w}_I/\hat{w}_i$ for each country i on the list. Therefore $\alpha_I\hat{w}_I < \alpha_i\hat{w}_i$ and $\alpha_I < \alpha_i$ for each country i on the list, because India has the highest real GDP per capita.

The following section on empirical investigations will provide further details on awareness and on the possible existence of the EKC.

4 Empirical Analysis

With this empirical analysis we want to derive concrete values 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. As already indicated in the introductory section, we thereby focus on the 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 the values of the cost factors β_i for countries i in consideration, i.e., the cost of 1 kWh of electricity generated by means of renewable sources.

As already mentioned in Subsection 3.2, there is a substantial range of costs, depending on the situation of a particular country (labor costs, ...) and on the combination of technologies to generate electricity from renewable sources (cf. also Figure 1). For more detailed case studies we refer to [9] for Germany, to [23] for India, and to [27] for a global energy perspective.

As the analysis in this part of the paper has an exemplary character, we link β_i to w_i (GDP per capita of a country i) in the following simple way:

Assumption 4.1. *Assume that LCOE are 0.02 US-$ per kWh for a country with a GDP per capita (PPP) of 5,000 US-$ (India), and 0,35 US-$ per kWh for a country with a GDP per capita (PPP) of 55,000 US-$ (US). We then draw a straight line through these pair of coordinates to obtain the following equation:* $\beta(w) := -0.013 + 0.0000066 \cdot w$.

Observe that, for example, this procedure yields costs of $\beta_I = 0.022$ US-$ for India, of $\beta_C = 0.065$ US-$ for China, of $\beta_G = 0.281$ US-$ for Germany, per kWh electricity from renewable sources in each case. In general, for countries, for which there are relevant data, this procedure seems to generate quite reasonable estimates for the actual costs of renewable energies. However, a more careful analysis would, of course, have to be based on reliable estimates of the β_i.

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

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

with "real" GDP per capita $\hat{w}_i := w_i/\beta_i$. These equations can be rewritten as follows: $T = \alpha_i(\hat{w}_i - t_i^n)$ with total contributions towards the provision of the public good, i.e., total spending on renewable energy sources, of the member states, given by $T = k_1 t_1^n + \ldots + k_n t_n^n$. 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^n:

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

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. Those Annex I countries, which ratified the Kyoto Protocol, agreed to reduce greenhouse gas emissions according to the targets set by the Kyoto Protocol (the targets were provided in Annex B to the Kyoto Protocol (cf. `http://unfccc.int/kyoto_protocol/items/3145.php`)).

- 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. In addition, they have to "take all practicable steps" to promote the development and transfer of environmentally friendly technologies to EIT Parties and developing countries. Funding provided by Annex II Parties is channeled mostly through the Convention's financial mechanism.

- Non-Annex I Parties are mostly developing countries. Certain groups of developing countries are recognized by the Convention as being es-

pecially vulnerable to the adverse impacts of climate change, including countries with low-lying coastal areas and those prone to desertification and drought. Others (such as countries that rely heavily on income from fossil fuel production and commerce) feel more vulnerable to the potential economic impacts of climate change response measures. The Convention emphasizes activities that promise to answer the special needs and concerns of these vulnerable countries, such as investment, insurance and technology transfer.

- The 49 Parties classified as least developed countries (LDCs) by the United Nations are given special consideration under the Convention on account of their limited capacity to respond to climate change and adapt to its adverse effects. Parties are urged to take full account of the special situation of LDCs when considering funding and technology-transfer activities.

Table 4 presents the results for the values of GDP per capita (2013 US-$, ppp) and "environmental awareness" for selected Annex II Parties.[7] The countries are ranked according to the values of environmental awareness.[8]

Country:	GDPpc	α_i	Country:	GDPpc	α_i
Denmark	44,460	5.121	Canada	42,610	5.034
Norway	66,520	5.120	Ireland	35,090	4.999
Sweden	44,760	5.103	France	37,580	4.997
US	53,960	5.095	Japan	37,630	4.995
Switzerland	56,580	5.086	UK	35,760	4.994
Germany	44,540	5.080	Italy	34,100	4.986
Finland	38,480	5.060	New Zealand	30,750	4.986
Austria	43,840	5.056	Spain	31,850	4.984
Netherlands	43,210	5.046	Portugal	25,360	4.897
Belgium	40,280	5.039	Greece	25,630	4.873
Australia	42,540	5.038			

Table 4: Ranking of Annex II Parties regarding "environmental awareness" in terms of renewable energy consumption. (Source: Own calculations with data taken from `http://data.worldbank.org/` and `http://www.bp.com/`).

[7] Table 4 does not include the Annex II countries Iceland, Luxembourg, Turkey, and the European Union, which is, as a regional economic integration organization, itself a Party to the UNFCCC.

[8] The values of the estimated parameter α_i are divided by 10^6 in order to increase readability (cf. also Footnote 2).

Countries with a supposedly high environmental awareness (Denmark, Norway, 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 the abundance of hydroelectricity in some countries affects the value of "awareness". We do not consider consumption of electricity from hydro power plants part of "renewable energy consumption", as the availability of hydroelectricity is largely dependent on appropriate geographical conditions.

4.3 The Environmental Kuznets Curve

One of the prominent questions arising in this context refers to the existence of the "Environmental Kuznets Curve" (EKC), a functional relationship between GDP per capita and awareness for climate change with awareness eventually rising with GDP per capita (cf. [22] and [12]). Figure 2 presents the result based on the cost function $\beta(w) := -0.013 + 0.0000066 \cdot w$ for renewable energies.

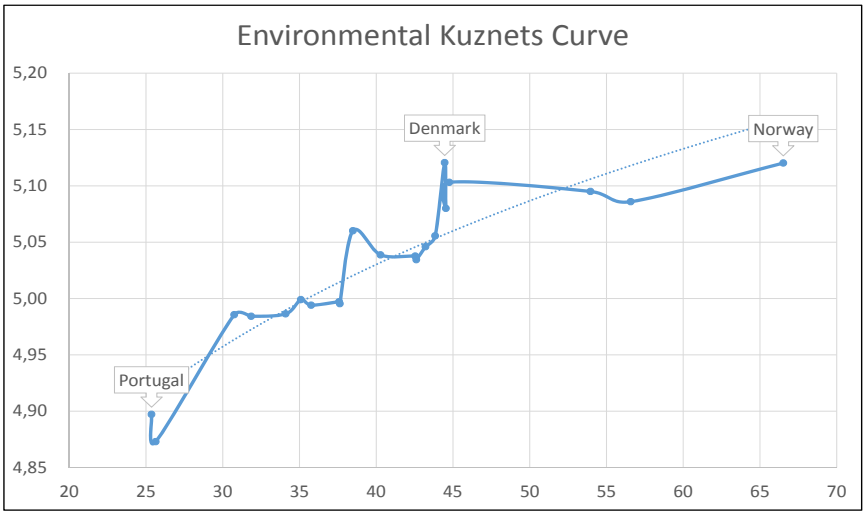

Figure 2: Awareness regarding climate change depending on GDP per capita (2013 US-$, ppp) of the Annex II countries listed in Table 4 with cost function $\beta(w) := -0.013 + 0.0000066 \cdot w$. (Source: Own calculations).

There is, thus, a rather clear tendency for higher environmental awareness to be associated with a higher GDP per capita. This result is, therefore, in favor of a classical "Environmental Kuznets Curve". A more extended analysis comprising all signatories of the UNFCCC would show that countries

such as India or China are ranked among the lower third of all countries. The recent efforts regarding investments in renewable energy sources in China do not yet show off. Countries which are endowed with fossil fuels, in particular Canada, Norway, the US, Australia and Russia, reveal a comparatively high awareness regarding climate change.

However, these results depend to a substantial degree on the specification of the cost function $\beta = \beta(w)$ for consumption of renewable energies. Small changes can lead to quite different conclusions. This can be illustrated by means of the cost function $\beta = 0.03 + 0.000004 \cdot w$ instead of $\beta(w) := -0.013 + 0.0000066 \cdot w$. Thus, costs increase for low income countries and decrease for high income countries. Indeed, β increases from 0.02 US-$ to 0.05 US-$ per kWh for a country with a GDP per capita of 5,000 US-$, and decreases from 0.35 US-$ to 0.25 US-$ per kWh for a country with GDP per capita of 55,000 US-$. Figure 3 shows the then resulting structure of the functional relationship between "awareness" and GDP per capita.

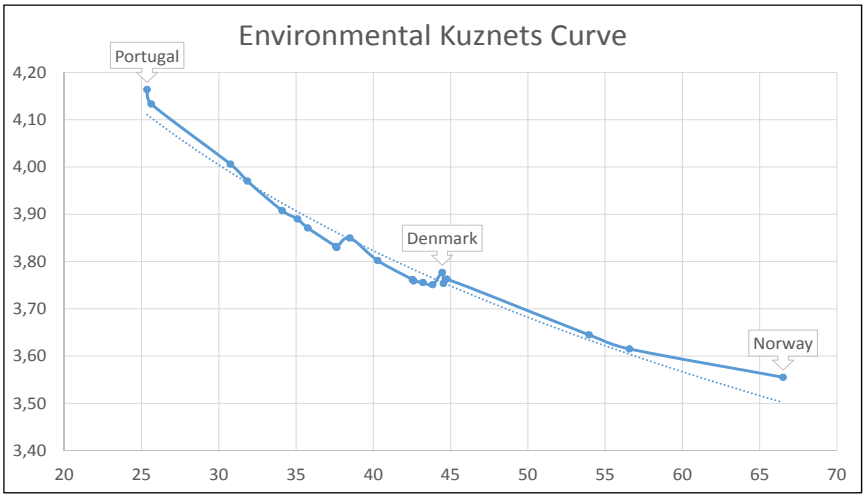

Figure 3: Awareness regarding climate change depending on GDP per capita (2013 US-$, ppp) of the Annex II countries listed in Table 4 with alternative cost function $\beta(w) = 0.03 + 0.000004 \cdot w$. (Source: Own calculations).

To the question: "You personally have taken action aimed at helping to fight climate change?" asked in the "Special Eurobarometer 300" (cf. [7], p. 26), Sweden (87%) and Denmark (68%); Germany (66%) occupy the leading ranks. Italy (49%) and Portugal (45%) lag behind with their shares of positive answers. Thus, there is some support for the first EKC.

Nevertheless, the issue of existence of a classical "Environmental Kuznets Curve" remains at least unclear in the framework considered here. This

coincides with the results and conclusions obtained in [22] and [12].

The following subsection addresses briefly the issue of "equity" in the context of carbon sharing.

4.4 Equity

In order to solve the allocation problem regarding reductions of greenhouse gas emissions, the participants in the climate talks, in particular those from developing countries, are postulating an "equitable" allocation. Of course, the question is, how to operationalize "equity".

A first approach can be found in the recent announcement between the US and China to "equalize" their emissions. The United States intends to achieve an economy-wide target of reducing its emissions by 26%-28% below its 2005 level in 2025. China intends to achieve the peaking of CO_2 emissions around 2030 and intends to increase the share of non-fossil fuels in primary energy consumption to around 20% by 2030 (cf. the press release from Nov 11, 2014: `http://www.whitehouse.gov/the-press-office/)`. In an editorial "US-China climate deal: maker or breaker?" in the internet journal "DownToEarth" from Dec 15, 2014, the Indian environmentalist Sunita Narain claims that this announcement means *"that the US and China have agreed to "equalize" their emissions by 2030. The US would reduce emissions marginally from its current 18 tonnes per capita and China would increase from its current seven-eight tonnes. Both the polluters would converge at 12-14 tonnes per person per year"* (cf. `http://www.downtoearth.org.in`).

Equal per capita emission reductions, as an approach to equity, correspond to identical levels of awareness in our model, if "real" GDP per capita is identical across countries. Now, "real" GDP per capita is obtained from dividing w_i by β_i, which increases with the level of w_i according to our specifications of the cost function $\beta = \beta(w)$. Thus, this procedure tends to equalize real GDP per capita. In fact, regarding the Annex II countries on the list, real GDP per capita varies between the minimum of 156,138 kWh and 164,274 kWh renewable energy consumption per capita, whereas GDP per capita (ppp) varies between 25,360 US-$ and 66,520 US-$. Consequently, there is some justification for assuming identical levels of real GDP per capita.

We observe substantial differences and "equity" in this sense is not observable, not even among the industrialized Annex II countries. Only the first seven countries are contributing more than the average, the others are lagging behind.

Clearly, this argument can justifiably be only applied in situations, where

the countries are comparable regarding their real GDP per capita measured in kWh renewable energy consumption. However, prices for renewable energy increasing with GDP per capita tends to equalize these values. The results then show that the issues of equity is not even adequately solved among the Annex II countries. With respect to developing countries, other aspects of equity, such as historical greenhouse gas emissions, must be taken into account.

From the formula $\alpha_i = T/(\hat{w}_i - t_i)$ we can then conclude that with identical $\hat{w}_i$, $i \in N$, awareness α_i is strictly correlated with t_i: a higher level of t_i induces a higher level of α_i. Table 5 provides a ranking of the Annex II countries with respect to renewable energy consumption and, thus, with respect to awareness.

Country:	t_i	Country:	t_i	Country:	t_i
Denmark	2883.50	Belgium	1121.55	Australia	655.41
Sweden	2302.10	Ireland	1084.94	Greece	564.35
Finland	2175.28	Austria	986.62	Canada	541.16
New Zealand	2016.11	Italy	958.99	Norway	472.56
Germany	1627.82	US	819.72	France	394.94
Spain	1589.98	Netherlands	795.35	Japan	327.71
Portugal	1518.53	UK	750.28	Switzerland	265.08

Table 5: Ranking of Annex II countries under the assumption of identical levels of real GDP per capita. (Source: Data from `http://www.bp.com/`).

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 separation from other economic variables. The existence of a "theoretical" EKC summarizes these effects.

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. Unfortunately, the existence of an empirical EKC is strongly dependent on these cost estimates.

The last section raises the issue of an equitable sharing the carbon burden. In the context of this model, "equity" could imply equal per capita emission reductions on the basis of identical levels of real GDP per capita. However, again differences in awareness prevent the implementation of this simple equity concept.

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