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A. Lange and A. Ziegler

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Andreas Lange and Andreas Ziegler

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Andreas Lange (corresponding author)
University of Hamburg, Department of Economics
Von Melle Park 5, 20146 Hamburg, Germany
E-Mail: andreas.lange@wiso.uni-hamburg.de
Phone: +49 40 42838 4035, Fax: +49 40 42838 3243

Andreas Ziegler
University of Kassel, Department of Economics
Nora-Platiel-Str. 5, 34109 Kassel, Germany
E-Mail: andreas.ziegler@uni-kassel.de
Phone: +49/561/804-3038, Fax: +49/561/804-2501
and
ETH Zurich, Center of Economic Research

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Abstract

This paper studies the voluntary provision of public goods that is partially driven by a desire to offset for individual polluting activities. We first extend existing theory and show that offsets allow a reduction in effective environmental pollution levels while not necessarily extending the consumption of a polluting good. We further show a non-monotonic income-pollution relationship and derive comparative static results for the impact of an increasing environmental preference on purchases of offsets and mitigation activities. Several theoretical results are then econometrically tested using a novel data set on activities to reduce CO_2 emissions for the case of vehicle purchases in the U.S. and Germany. We show that an increased environmental preference triggers the use of CO_2 offsetting and mitigation channels in both countries. However, we find strong country differences for the purchase of CO_2 offsets. While such activities are already triggered by a high general awareness of the climate change problem in the U.S., driver's license holders in Germany need to additionally perceive road traffic as being responsible for CO_2 emissions to a large extent.

Keywords: public good, voluntary provision, climate change, CO_2 offsetting, vehicle purchase, discrete choice models

JEL: C25, C35, H41, Q54

1. Introduction

The voluntary provision of public goods has received increasing attention in the literature. Without being forced by corresponding regulations, people donate money to charities, volunteer for public causes, or behave in environmentally beneficial ways. Regarding the abatement of climate change as a specific environmental public good, CO_2 offsetting has recently been popularized. Through purchasing offsets, individuals compensate CO_2 emissions for which they are themselves responsible, for example, for emissions from air travel or vehicle use. The CO_2 offsets are generated in specific projects like investments in renewable energies, energy efficiency, or even reforestation.

This idea of CO_2 offsetting – even though very appealing to many – has also received substantial criticism. The mechanism of paying somebody else to reduce CO_2 emissions in order to compensate for one's own emissions has been described as a modern form of buying indulgences from the Catholic Church. Critics claim that offsets may be used as an excuse to indulge in polluting activities to a larger extent than would occur without this option. Conversely, proponents argue that offsets indirectly reduce CO_2 emissions to an extent that otherwise would not happen. This paper takes up the debate on CO_2 offsetting and sets out to extend both the theoretical literature on offsets as well as to provide new and important empirical insights on the link between CO_2 offsetting and emission-reducing (i.e. mitigation) activities when purchasing a new vehicle.

The existing academic literature on CO_2 offsetting is scarce. Many studies until now are instead published by non-governmental organizations or consulting firms (e.g. Business for Social Responsibility, 2007, WWF Deutschland, 2008, Clean Air-Cool Planet and Forum for the Future, 2008) and aim, for example, to support consumers in choosing credible and good-quality CO_2 offsetting providers or discuss the development of robust offsetting schemes. A first theoretical study by Kotchen (2009) analyzes the effects of the possibility of purchasing CO_2 offsets and shows that free-riding in large economies is reduced due to their presence. Two recent empirical studies (Brouwer et al., 2008, Akter et al., 2009) examine the willingness to pay for CO_2 offsetting of air travel passengers from around the world that were interviewed at Amsterdam Schiphol airport. Based on data from an online survey, MacKerron et al. (2009) similarly consider the willingness to pay for CO_2 offsetting of adults in the UK for a hypothetical flight between New York and London.

In this paper, we add to the literature by considering the relationship between CO_2 offsetting and alternative mitigation activities to reduce CO_2 emissions. We make both theoretical and empirical contributions. We set up a theoretical model of individual decision-making, which considers decisions on pollution-reducing activities given varying availability, costs, and acceptance of offsetting options. While our paper is related to the literature of voluntary provision of public goods (e.g. Andreoni, 1990, Kotchen, 2009), we explicitly consider individuals' decisions between polluting and non-polluting activities as well as include the option to purchase offsets.

We show that agents generally purchase offsets if their income exceeds a specific level. As such, the environmental pollution level (e.g. CO_2 emissions reduced by the offsets) first increases in income before it finally decreases. That is, we obtain a Kuznets curve effect for an effective pollution level (similar to Andreoni and Levinson, 2001). Contrary to claims that the availability of offsets necessarily leads to increases in the consumption of the polluting good, we find that the impact of offsets on this consumption is ambiguous. Importantly, we study comparative static results how an increase in the individual environmental preference, i.e. the feeling of responsibility for personal environmental pollution, affects purchases of offsets or decreases in the consumption of a polluting good. We demonstrate the determinants of the relative importance of these offsetting and mitigation channels for general preference structures as well as using specific examples.

Based on this theoretical modeling, we econometrically analyze different activities to reduce CO_2 emissions that relate to vehicle purchases. Specifically, we examine the relationship between stated intentions to purchase vehicles with lower emissions (mitigation) and to individually offset CO_2 emissions with the purchase of a new vehicle. Using unique representative data of driver's license holders in the U.S. and Germany, we demonstrate that agents from both countries are the more likely to use the CO_2 offsetting and mitigation channels to reduce the contribution to climate change, the higher the feeling of responsibility for CO_2 emissions. However, the triggers of using the CO_2 offsetting and mitigation channels differ between the two countries: For U.S. agents, a high general awareness of the climate change problem induces the use of both these channels. For German driver's license holders, however, the use of the CO_2 offsetting channel is only triggered when, additionally to evaluating climate change as an important problem, they also perceive road traffic as being responsible for CO_2 emissions to a large extent.

Our results thereby give several new theoretical and empirical insights about the role of CO_2 offsetting. The remainder of the study is organized as follows. Section 2 sets up a theoretical model and derives results on the link between the offsetting and mitigation channels. Section 3 then reports our econometric analysis. Section 3.1 describes the underlying data and variables, while section 3.2 provides a discussion and interpretation of our results. Section 4 provides a concluding discussion.

2. Model

We assume that each individual has preferences for the consumption of a non-polluting numeraire z and a polluting (e.g. CO_2 emitting) consumption good x, but may also experience some disutility from contributing to environmental pollution. This latter contribution we call individual pollution responsibility. We assume that one unit of pollution arises from each consumed unit of good x. We further assume that individuals can purchase offsets and thereby reduce pollution and thus their own responsibility. As such, responsibility is given by $r = x - \lambda y$ where $y \geq 0$ are the individual's purchases of offsets and $0 < \lambda \leq 1$ denotes the (society's) acceptability of offsets as a mean to reduce the own environmental pollution level. The responsibility r can be interpreted as the net contribution of an agent to pollution or as the effective environmental pollution level.

The utility of a consumer is hence given by

$$u = U(z, x, r)$$

where we assume standard properties (u increasing in z, x, $-r$, quasi-concave). We further assume that all goods (z, x, $-r$) are normal.

Our model follows the impure altruism model by Andreoni (1989, 1990): instead of feeling good about her own contributions to a public good, the agent feels bad about contributing to a public bad. It should be noted that we assume that the individual suffers from his own pollution responsibility r only, i.e. we do not explicitly consider damages from the aggregate pollution level across all individuals. However, the inclusion of this would not change the results qualitatively. Our model is related to Kotchen (2009), but explicitly allows for two different options for reducing environmental pollution: (i) by substituting consumption from the polluting good x to the non-polluting good z, or (ii) by purchasing offsets y.

The individual has exogenous income w that she spends on the different activities, leading to a budget constraint $w = z + x + py$. Here, the prices for x and z are normalized to one, the price for offsets y is denoted by p. Noting that $r = x - \lambda y$ and thus $y = (x - r) / \lambda$, it is helpful to rewrite the budget constraint as $w = z + x + p(x - r) / \lambda = z + x(1 + p / \lambda) + (-r) p / \lambda$ with $r \leq x$. Here, p / λ is the implicit price for reducing the own pollution responsibility. It depends on the price of offsets p as well as on their acceptability λ as a mean to reduce responsibility. For the remainder, we denote this effective price of offsets by $\sigma = p / \lambda$.

The optimization program can therefore be written as

$$\begin{aligned} &\max_{z,x,r} U(z,x,r) \\ &\text{subject to } \; w = z + x(1+\sigma) + (-r)\sigma \qquad (1) \\ &\text{and} \qquad r \leq x \end{aligned}$$

The first order conditions are straightforward:

$$\frac{U_x}{U_z}(z,x,r) + \frac{U_r}{U_z}(z,x,r) = 1 \qquad (2)$$

$$-\frac{U_r}{U_z}(z,x,r) \begin{Bmatrix} \leq \\ = \end{Bmatrix} \sigma \quad \text{if} \quad \begin{cases} r = x \\ r < x \end{cases} \qquad (3)$$

where $U_z = \partial U / \partial z$, $U_x = \partial U / \partial x$, and $U_r = \partial U / \partial r$.[1] Condition (2) states that the costs of consuming an additional unit of x have to be weighed with the additional consumption utility plus the negative effect from increased pollution responsibility. For simplicity,

[1] Corresponding notation will be used for the second derivatives (e.g. $U_{xx} = \partial^2 U / \partial x^2$ and $U_{xz} = \partial^2 U / \partial x \partial z$).

we hereby assume that a solution with positive consumption levels $x > 0$ and $z > 0$ exists. Condition (3) shows how the decision to purchase offsets is governed by the comparison of its costs σ with the marginal rate of substitution between responsibility and the consumption of the non-polluting good. We denote the solution to (1) by (z_O, x_O, r_O) where the index "*o*" refers to the availability of offsetting.

We can now use this model to examine the effects of increasing income w and changes in the effective price of offsets σ. It is convenient to define the consumption decision that arises if offsets are not available. In this case, equation (2) is satisfied with $x = r$:

$$\frac{U_x}{U_z}(z_N, x_N, x_N) + \frac{U_r}{U_z}(z_N, x_N, x_N) = 1 \tag{4}$$

We denote the resulting consumptions of the polluting and non-polluting goods by x_N and $z_N = w - x_N$. With (3), it is optimal for the individual to not purchase offsets if $-\frac{U_r}{U_z}(w - x_N, x_N, x_N) < \sigma$. Here, offsets are too expensive such that their availability does not change the consumption decision. For this case where the consumer does not purchase offsets, additional income w has an ambiguous effect: the consumption of more of the polluting good x must be balanced against the increased responsibility r that arises from the environmental pollution $(r = x)$. Therefore, when offsets are not available or sufficiently expensive, increased income w may result in (i) an increase or (ii) a decrease of the consumption of the polluting good x.[2]

When offsets are available and sufficiently cheap (i.e. $-\frac{U_r}{U_z}(w - x_N, x_N, x_N) > \sigma$, the consumer will purchase offsets. Here, $r < x$, and our normality assumption immediately implies that more income w leads to an increase in x and z, but r will decrease or stay constant. That is, even though more of the polluting good x is consumed, this higher pollution level is more than compensated by additional offsets. The same argument also implies that there is a threshold income level below which agents do not purchase offsets

[2] This is easily seen from (4) which together with the second order condition implies that the sign of $\partial x^N / \partial w$ coincides with the sign of $-U_{zz} + U_{xz} + U_{rz}$ which may be positive or negative.

and above which they do. In extreme cases, this income threshold may be zero, i.e. offsets are purchased for any income w, or infinity, i.e. no offsets are purchased for any income level.

We obtain the following proposition:

> ***Proposition 1:*** *Agents above a certain income threshold purchase offsets while those below do not. When purchasing offsets, further increases in income lead to an increasing consumption of the polluting good and increasing purchases of offsets such that the effective environmental pollution levels (responsibility) either decrease or stay constant.*

Proposition 1 demonstrates that the availability of offsets generally leads to a non-monotonic income-pollution relationship and thus a Kuznets curve effect: initially, increases in income lead to increases in the consumption of the polluting good and – since no offsets are purchased – environmental pollution levels increase. Above a specific income level, offsets are purchased and further increases in income generate less effective pollution levels since the higher consumption of the polluting good is more than compensated through offsetting.

A decreasing effective price of offsets σ will decrease the effective price $1+\sigma$ for consuming the polluting good (while keeping responsibility constant). Since x_N is independent of σ, equation (3) implies that decreasing σ will make it more likely that agents purchase offsets. When offsetting is optimal, (2) and (3) imply that $-U_r / U_z = \sigma$ and $-U_r / U_x = \sigma / (1+\sigma)$ such that a further decrease in σ makes reducing responsibility relatively cheaper both versus consuming the non-polluting numeraire z as well as versus consuming the polluting good x. Joint with our normality assumption, decreases in σ therefore will always lead to a reduction in responsibility r. However, the consumption of the polluting good x may increase or decrease in σ, as is demonstrated in the example below.

We obtain the following proposition:

> ***Proposition 2:*** *Reductions in the effective price of offsets make purchases of offsets more likely as well as reduce the effective environmental pollu-*

tion levels (responsibility). The effect on the consumption of the polluting good is ambiguous.

In order to illustrate the previous discussion, we use a specific example of Cobb-Douglas preferences:

$$u = U(z,x,r) = z^{\alpha} x^{\beta} (\kappa - r)^{\gamma}$$

with $\alpha, \beta, \gamma, \kappa > 0$.

For this example, the consumption level x_N without offsetting options is given by (4):

$$\frac{\beta}{x_N} - \frac{\gamma}{\kappa - x_N} = \frac{\alpha}{w - x_N} \tag{5}$$

since $z_N = w - x_N$. Note that $-U_r / U_z = (\gamma / \alpha)(w - x_N)/(\kappa - x_N)$ again implies that agents with small income w will not purchase offsets as $-U_r / U_z < \sigma$.

In contrast, agents with sufficiently large income purchase offsets. For this case, the Cobb-Douglas structure also simplifies the solution. The budget equation implies $w + \sigma\kappa = z + x(1+\sigma) + (\kappa - r)\sigma$ such that the standard Cobb-Douglas solution gives:

$$\begin{aligned} z_O &= \frac{\alpha}{\alpha+\beta+\gamma}(w+\kappa\sigma) \\ x_O &= \frac{\beta}{\alpha+\beta+\gamma}\frac{1}{1+\sigma}(w+\kappa\sigma) \\ \kappa - r_O &= \frac{\gamma}{\alpha+\beta+\gamma}\frac{1}{\sigma}(w+\kappa\sigma) \end{aligned} \tag{6}$$

Offsets are purchased, however, only if the solution to (6) satisfies $x_O > r_O$. Otherwise the agent does not purchase offsets and hence $x_O = x_N$. That is, the offsetting level is given by:

$$y_O = \max[0, (x_O - r_O)/\lambda] \tag{7}$$

It follows immediately from (5) that x_N is increasing in income w and decreasing in the environmental preference parameter γ (i.e. a parameter for the feeling of responsibility for environmental pollution). Similarly, (6) confirms that x_O, z_O, and $-r_O$ increase in income, as it follows from our normality assumption. As an illustration to Proposition 2, we see that $-r_O$ increases when the effective price of offsets σ further decreases. However, the effect on the consumption of the polluting good is ambiguous:

$$\frac{\partial x_O}{\partial \sigma} = \frac{\beta}{\alpha + \beta + \gamma} \frac{\kappa - w}{(1+\sigma)^2} \tag{8}$$

For small income ($w < \kappa$), reductions in σ therefore lead to a decrease in the consumption of the polluting good, while the opposite holds if $w > \kappa$. This former income range only exists if the effective price of offsets is sufficiently small.

We illustrate these effects in Figure A.1, which shows the consumption of the polluting good *x* without the availability of offsets (red line). It is increasing in income w. For sufficiently large effective prices of offsets, offsetting unambiguously increases the consumption of *x* (black line), while offsetting leads to a reduction of the resulting pollution responsibility r (green line). For smaller offset prices, the income threshold above which agents purchase offsets is reduced. Then, the availability of offsets may also lead to reductions in the consumption of the polluting good (as seen in the dashed black line relative to the red line). This confirms the claim in Proposition 2. The reason for this effect is that offsetting gets cheaper relative to consuming both the non-polluting numeraire *z* and the polluting good *x*. This change in relative prices may lead to a reduction in the consumption of the polluting good.

We now turn to the effects of increases in the environmental preference as captured by γ in the example. Intuitively, increases in the feeling of responsibility for environmental pollution will unambiguously lead to a reduced effective pollution level, i.e. the level of consumption of the polluting good *x* is reduced by purchasing offsets. However, this can be achieved through (i) reduced consumption of the polluting good – the *mitigation channel* – or (ii) increased purchases of offsets – *the offsetting channel*. The extent to which these two channels are used when γ increases, depends on the specific preference structure, the income levels of the agents, as well as the strength of environmental preference.

We already have seen in the example that offsetting occurs only above a specific income level. Increases in γ therefore lead to reduced pollution responsibility only via the mitigation channel for small income levels. For large income levels, both the offsetting and mitigation channels are used. We illustrate these effects in Figure A.2. An increase in of γ has several effects: first, the income threshold above which agents will purchase offsets decreases as is seen from (7) using (6) since:

$$\frac{\partial(x_O - r_O)}{\partial\gamma} = \frac{w + \kappa\sigma}{(\alpha+\beta+\gamma)^2}\left(-\frac{\beta}{1+\sigma} + \frac{\alpha+\beta}{\sigma}\right) > 0 \quad (9)$$

Second, the consumption of the polluting good *x* decreases (see (6)). Third, the purchases of offsets increase (see (9)) such that the effective environmental pollution level is reduced even beyond the reduction of the consumption of *x*.

More generally, since purchases of offsets only occur if individual's income w and the acceptability of offsets λ relative to their price p are sufficiently high, an increased environmental preference will lead to the reduction in effective pollution levels primarily via reductions in the consumption of the polluting good, i.e. the mitigation channel, for low income levels and high prices for offsets. The offsetting channel is relatively more important if income is sufficiently large.

We obtain the following proposition:

> ***Proposition 3:*** *An increase in the environmental preference of an agent leads to a reduction in the effective environmental pollution level. The relative importance of the offsetting channel versus the mitigation channel to reduce pollution depends on the preferences as well as on the income and the price and acceptability of offsetting as a means to reduce environmental pollution responsibility. The offsetting channel is the more important, the higher their acceptability and the smaller the price of offsets, the larger the income level, and the larger the environmental preference.*

In our econometric analysis, we examine the relationship between the CO_2 offsetting and mitigation channels as well as environmental preference and income in the U.S. and Germany.

3. Econometric Analysis

3.1. Data and Variables

For our empirical analysis we use unique representative data from Computer Assisted Web Interviews in the U.S and Germany among driver's license holders between the ages of 18 and 64. The interviews were conducted between December 2007 and February 2008. Overall, 1231 respondents from the U.S. and 1000 respondents from Germany participated in the survey (for further details of the used data see also Ziegler et al., 2012). In these interviews driver's license holders were particularly asked for the likelihood of purchasing CO_2 offsets with the purchase of a new vehicle. Response options were "very likely", "somewhat likely", "somewhat unlikely", and "very unlikely". Based on this, we construct the dummy variable "*purchase of CO_2 offsets*" that takes the value one for the response option "very likely". This variable corresponds directly to the use of the offsetting channel to reduce CO_2 emissions as described in Section 2.

Driver's license holders were further asked to what extent the CO_2 or climate discussion will change their behavior when it comes to purchasing a vehicle. Response options were "not at all", "purchase of a smaller vehicle", "purchase of a vehicle with a smaller engine with less hp", "purchase of a vehicle with different fuel or alternative drive systems", "purchase of a vehicle with lower fuel consumption", "purchase of a vehicle with low emissions", "I am going to give up my vehicle entirely in future", and "other". In this respect, the respondents could decide for several alternatives. On this basis we construct two dummy variables: "*purchase of less-emitting vehicle*" takes the value one if at least one of the response options "purchase of a smaller vehicle", "purchase of a vehicle with a smaller engine with less hp", "purchase of a vehicle with lower fuel consumption", or "purchase of a vehicle with low emissions" was chosen. Furthermore, "*purchase of vehicle with alternative drive systems*" directly refers to the aforementioned response option.[3] These variables capture the use of the mitigation channel to reduce CO_2 emissions as discussed in Section 2.

[3] Examples for alternative fuels in vehicles are gas (e.g. natural gas, liquid petroleum gas), hydrogen, or biofuel, while examples for alternative driving systems or propulsion technologies are electric or hybrid.

With respect to the feeling of responsibility for environmental pollution as modeled in our theory, we define two variables that capture this environmental preference. Driver's license holders were asked how important they consider the topic climate change. Response options were "the topic is extremely important to me", "the topic is important to me", "the topic is only of little importance to me", and "the topic is of no importance to me". Driver's license holders were also asked how convinced they are that climate change is already taking place today. Response options were "thoroughly convinced", "largely convinced", "rather unconvinced", and "not convinced at all". Based on this, we construct the dummy variable "*relevance of climate change*" that takes the value one if at least one of the first alternatives (i.e. "extremely important", "thoroughly convinced") for both questions was chosen. This variable is an indicator for general environmental preference or awareness of the climate change problem, but it does not necessarily capture the feeling of responsibility with respect to the CO_2 emissions that the individual causes by her vehicle purchase.

Driver's license holders were therefore also asked whether road traffic is responsible for a large proportion of CO_2 emissions. Response options were "a very large proportion", "a large proportion", "a small proportion", and "no role". Based on this, we construct a stronger indicator for the own feeling of responsibility for environmental pollution in our specific analysis of CO_2 emissions in road traffic. That is, we consider a combined dummy variable "*feeling of responsibility*" that takes the value one if "*relevance of climate change*" takes the value one and if the response option "a very large proportion" was chosen with respect to the responsibility of road traffic for CO_2 emissions.

Regarding the main socio-economic variable from our theory, we analyze household income. In order to reflect the different common questioning techniques in the two countries, driver's license holders in the U.S. were asked for the yearly pre-tax income, while Germans were asked for the monthly net income of all household members. The given response options comprised different income groups. We use those to construct the dummy variable "*higher household income*" that takes the value one if the yearly pre-tax household income is higher than $60000 for US respondents and if the monthly net household income is higher than €2500 for their German counterparts.

Our data further allow us to control for additional socio-economic and socio-demographic variables. Concerning the educational background of driver's license holders, we consider the dummy variable "*higher education*" for the highest education level that takes the value one if U.S. respondents have at least attained a "college graduate" or if German respondents have at least attained "abitur". In addition, we consider the variable "*age*", measured in years, and the dummy variable "*gender*" that takes the value one if the driver's license holders are male. Moreover, we include several indicators for marital and household status. Regarding marital status, we consider the two dummy variables "*single*" and "*living together with partner*" (including "living with partner" and "married"). Other response options in the questionnaire for the marital status were "widowed" and "divorced or separated". Regarding household status, we examine the variable "*household size*", which refers to the number of people in the household, as well as the dummy variable "*children in household*" that takes the value one if children until 18 years are living in the household. Finally, we analyze an indicator for the intensity of the use of the underlying good, i.e. we include the variable "*log average driven kilometers per year*". Table B.1 reports the means and standard deviations of all these variables for the U.S. and Germany, respectively.

3.2. Results

We first analyze the determinants of the use of the offsetting and mitigation channels to reduce CO_2 emissions separately. For this, we examine the dependent dummy variables "*purchase of CO_2 offsets*", "*purchase of less-emitting vehicle*", and "*purchase of vehicle with alternative drive systems*". In order to capture possible correlations between these dependent variables, we do not consider three univariate binary probit models, but examine one joint multivariate binary probit model which connects the three single equations for each dummy variable (e.g. Greene, 2008).[4] We particularly examine the impact of

[4] While univariate binary probit models can be straightforwardly estimated by the maximum likelihood method, we had to apply the simulated counterpart of this method which incorporates the Geweke-Hajivassiliou-Keane (GHK) simulator (Börsch-Supan and Hajivassiliou, 1993, Geweke et al., 1994, Keane, 1994) for the estimation in the multivariate probit models. In this respect, we used 50 random draws in the GHK simulator. Furthermore, we consider now and in the following the robust estimations of the standard deviation of the parameter estimates (White, 1982). The corresponding simulated maximum likelihood es-

feeling of responsibility for CO_2 emissions by driver's license holders as discussed above. The upper part of Table B.2 reports the corresponding estimation results. In the U.S., the environmental preference variable has an expected highly significantly positive effect on all three activities to reduce the contribution to climate change. In contrast, the impact on the use of the mitigation channels is surprisingly not significant (at common significance levels) in Germany, i.e. the feeling of responsibility has only a significantly positive effect on the use of the CO_2 offsetting channel in this country.

However, it should be noted that this analysis considers heterogeneous dependent variables. For example, "*purchase of CO_2 offsets*" having a value of one means that it is very likely that the driver's license holders purchase CO_2 offsets with the purchase of a new vehicle. However, these respondents comprise two types of agents: those who also use a mitigation channel, i.e. also state to change their behavior when it comes to purchasing a vehicle, and those who do not state to change their behavior in this respect. In order to capture this heterogeneity, we now split the corresponding dependent variables by defining mutually exclusive alternatives that can be analyzed with multinomial logit models.

We consider two separate approaches that combine the offsetting variable "*purchase of CO_2 offsets*" with the mitigation variables "*purchase of less-emitting vehicle*" and "*purchase of vehicle with alternative drive systems*", respectively. As a consequence, the first approach considers the four mutually exclusive alternatives "*purchase of CO_2 offsets and less-emitting vehicle*", "*only purchase of less-emitting vehicle*", "*only purchase of CO_2 offsets*", and "*no purchase of CO_2 offsets or less-emitting vehicle*" as omitted category. The second approach comprises the alternatives "*purchase of CO_2 offsets and vehicle with alternative drive systems*", "*only purchase of vehicle with alternative drive systems*", "*only purchase of CO_2 offsets*", and "*no purchase of CO_2 offsets or vehicle with alternative drive systems*" as omitted category. For both approaches, Table B.3 reports the corresponding distribution of the driver's license holders across the four alternatives for the U.S. and Germany, respectively.

timations (in the same way as all further estimations and also the descriptive statistics discussed above) were performed with STATA.

The upper parts of Table B.4 and Table B.5 report the corresponding estimation results. One main result for both the U.S. and Germany refers to the robust and highly significantly positive effect of the environmental preference variable on the use of both the CO_2 offsetting channel and the mitigation channel, i.e. on "*purchase of CO_2 offsets and less-emitting vehicle*" and "*purchase of CO_2 offsets and vehicle with alternative drive system*" (compared with the omitted categories that comprise none of the respective activities to reduce CO_2 emissions). Furthermore, the feeling of responsibility for CO_2 emissions has a significantly higher positive effect on the likelihood of only purchasing CO_2 offsets with the purchase of a new vehicle compared with only the stated change of behavior when it comes to purchasing a vehicle in both countries.[5] These differences between the activities to reduce CO_2 emissions are even stronger for German driver's license holders such that the feeling of responsibility for CO_2 emissions has only a positive impact on "*only purchase of vehicle with alternative drive systems*" at the 10% significance level (Table B.5) and even no significant impact on "*only purchase of less-emitting vehicle*" (Table B.4).

We can summarize the results as follows:

> ***Result 1:*** *In the U.S. and in Germany, an increased feeling of responsibility for CO_2 emissions has a positive impact on the use of the CO_2 offsetting and mitigation channels to reduce the contribution to climate change when it comes to purchasing a vehicle. By comparing the relative importance of the use of the CO_2 offsetting channel and the mitigation channel, an increased feeling of responsibility has a more positive effect on only purchasing CO_2 offsets. This difference is stronger for German driver's license holders compared with their U.S. counterparts.*

This result is largely consistent with our theoretical analysis in Section 2: the use of the offsetting and mitigation channels should positively depend on environmental preference. Beyond the threshold where agents purchase offsets, the feeling of responsibility for en-

[5] This result can be shown when "*only purchase of less-emitting vehicle*" instead of "*no purchase of CO_2 offsets or less-emitting vehicle*" as well as "*only purchase of vehicle with alternative drive systems*" instead of "*no purchase of CO_2 offsets or vehicle with alternative drive systems*" are used as omitted categories in the multinomial logit models. The corresponding estimation results are not reported for brevity, but are available upon request.

vironmental pollution was predicted to primarily induce agents to use more the offsetting channel rather than the mitigation channels.

In the theoretical model, it was additionally predicted that income has a positive effect on the use of the offsetting and mitigation channels. Furthermore, it was predicted that the use of the offsetting channel through an increased environmental preference is more important for high income. These theoretical results are not rejected by our econometric analysis. According to Table B.2, Table B.4, and Table B.5, however, our income variable has no robust significant effect on any activity to reduce the contribution to climate change. Similarly, separate estimations for U.S. and German driver's license holders with higher and lower income levels do not show any robust difference with respect to the impact of our environmental preference variable.[6] These ambiguous results could be affected by our specific income variable which only refers to household income since data on individual income are not available.

Two aspects that were outside our theoretical analysis are additionally worthwhile to note: first, our estimation results never show that males have a significantly higher propensity to any activity to reduce CO_2 emissions. In contrast, Table B.2 shows that females state to purchase less-emitting vehicles to a significantly higher extent than males in Germany. Furthermore, the results in Table B.4 reveal that females have a significantly higher propensity to "*only purchase of less-emitting vehicle*" in both the U.S. and Germany and additionally a significantly higher propensity to "*purchase of CO_2 offsets and less-emitting vehicle*" in Germany. Second, Table B.2 and Table B.5 suggest that in both the U.S. and Germany a higher education has a significantly positive effect on the stated purchase of vehicles with alternative drive systems as one mitigation channel to reduce CO_2 emissions. This result is in line with our intuition on characteristics of purchasers of, for example, hybrid or electric cars.

The previous analysis including only "*feeling of responsibility*" as explanatory variable shows very similar estimation results for U.S. and German driver's license holders. When additionally including "*relevance of climate change*", which represents a weak indicator

[6] The corresponding estimation results are not reported for brevity, but are available upon request.

for general environmental preference or awareness of the climate change problem as discussed above, however, important differences arise between these two countries with respect to the impact on the activities to reduce CO_2 emissions. The lower parts of Table B.2, Table B.4, and Table B.5 report the corresponding estimation results. It should be noted that technically the variable "*feeling of responsibility*" is an interaction term of the variable "*relevance of climate change*" and the variable that refers to the question whether road traffic is responsible for a large proportion of CO_2 emissions. It should also be noted that only the estimates and z-statistics for these two environmental preference variables are reported, while all other explanatory variables were also included in the estimations. The estimation results for these variables are qualitatively almost identical to those in the upper parts of Table B.2, Table B.4, and Table B.5 and are therefore not reported for brevity.[7]

The main result is that in the U.S. the weak indicator for a high general awareness of the climate change problem is already the main driver for the use of the CO_2 offsetting and mitigation channels. As a consequence, the additional perception that road traffic is responsible for CO_2 emissions to a large extent has no strong contribution to the activities to reduce CO_2 emissions in this country. In contrast, this perception plays a crucial role for German driver's license holders since it is the main driver for the likelihood of purchasing CO_2 offsets with the purchase of a new vehicle as well as the use of both the CO_2 offsetting channel and the mitigation channel according to the estimation results in the multinomial logit models in Table B.4 and Table B.5.

We can summarize the results as follows:

> ***Result 2:*** *In the U.S. and Germany, an increased feeling of responsibility for CO_2 emissions has a positive impact on the use of the CO_2 offsetting and mitigation channels to reduce the contribution to climate change. However, the drivers for using the CO_2 offsetting channel differ between U.S. and German driver's license holders. The use of the CO_2 offsetting and mitigation channels in the U.S. is already triggered by a high general*

[7] The corresponding estimation results are again available upon request.

awareness of the climate change problem, while in Germany agents need to additionally perceive road traffic as being responsible for CO_2 emissions to a large extent for the purchase of CO_2 offsets.

While the results are consistent with country-specific specifications of our theoretical model in Section 2, we can clearly only speculate why these results occur. One reason could be an increased acceptability of CO_2 offsetting in the U.S. as a means to reduce CO_2 emissions. In terms of our theoretical model, this makes agents more likely to be in the domain where they purchase offsets. As such, increases in the general awareness of the climate change problem may well already lead to the use of this CO_2 offsetting channel. In Germany, however, we may speculate that some agents with such an environmental preference may not consider CO_2 offsetting as a feasible way to reduce CO_2 emissions. Only if their feeling of responsibility for CO_2 emissions is further enhanced through perceiving road traffic as being responsible for CO_2 emissions to a large extent, they may be in the domain where the offsetting channel is used.

It is noteworthy that the indicated differences in the triggers of CO_2 offsetting are consistent with the position of most member states of the European Union with respect to flexible mechanisms within the Kyoto protocol like the clean development mechanism: these were only hesitantly accepted, but still it is required that a substantial fraction of CO_2 emission reductions have to be achieved domestically. Individual agents that follow the same view on responsibility would primarily use the mitigation channel.

4. Conclusions

In this paper, we studied the link between offsetting and mitigation activities to reduce CO_2 emissions. Examples of CO_2 offsetting particularly relate to air travel and vehicle use. We provided both new theoretical and empirical insights. Our theoretical model indicated that the availability of offsets will reduce the effective environmental pollution levels. In fact, for increasing income pollution will eventually decline such that a Kuznets curve effect is obtained. The initial consumption of the polluting good does, however, mostly increase due to purchases of offsets, but may also decrease for specific preference structures. By considering increases in the environmental preference of agents, we were able to derive comparative static results on the relative importance of the importance of the offsetting channel versus the mitigation channel to reduce environmental pollution. While initially only the mitigation channel is used, for sufficiently large feelings of pollution responsibility, individuals will extend the purchase of offsets, but potentially will not further increase the use of the mitigation channel, i.e. will not further reduce the consumption of the polluting good.

We then econometrically studied the relationship between the CO_2 offsetting and mitigation channels when purchasing a new vehicle as well as environmental preference and income. Based on representative data of driver's license holders in the U.S. and Germany, we found that a feeling of responsibility for CO_2 emissions is a crucial driver for the use of the CO_2 offsetting and mitigation channels to reduce the contribution to climate change in both countries. However, our results also hint at some differences between the U.S. and Germany. While an increased awareness of the climate change problem already increases the use the CO_2 offsetting and mitigation channels in the U.S., German agents need to additionally perceive road traffic as being responsible for CO_2 emissions to a large extent for the use of the CO_2 offsetting channel. In this paper, we only speculated about the reasons for these differences. Further research and additional empirical analyses on the basis of data that are not available so far are necessary to gain a thorough understanding of the role of the offsetting channel and the mitigation channel and potential cultural differences in the acceptability of CO_2 offsetting.

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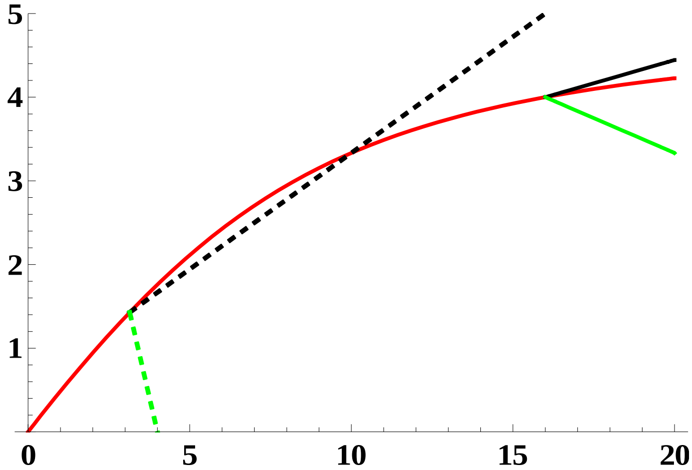
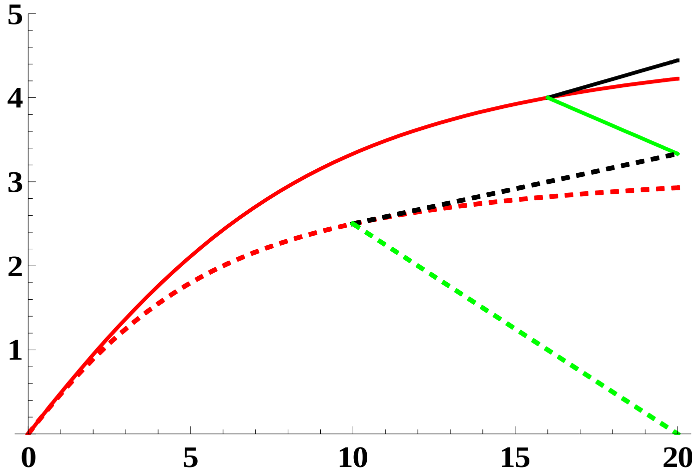
Appendix A: Figures

Figure A.1



The red line shows the consumption of the polluting good x as a function of income w *that results without the availability of offsets (parameters in the example:* $\alpha = \beta = \gamma = 1$, $\kappa = 10$*). The availability of offsets changes the consumption of x to black lines, the resulting pollution responsibility levels are given by the respective green lines (solid lines for* $\sigma = 2$*, dashed lines for* $\sigma = 0.2$*).*

Figure A.2



The red lines shows the consumption of the polluting good x as a function of income w *that results without the availability of offsets (parameters in the example:* $\alpha = \beta = 1$, $\sigma = 2$, $\kappa = 10$*). The availability of offsets changes the consumption of x to black lines, the resulting pollution responsibility levels are given by the respective green lines (solid lines for* $\gamma = 1$*, dashed line for* $\gamma = 2$*).*

Appendix B: Tables

Table B.1: Descriptive statistics (means and standard deviations)

	U.S.		Germany	
	Mean (standard deviation)	Number of observations	Mean (standard deviation)	Number of observations
Purchase of CO_2 offsets	0.23 (0.42)	962	0.24 (0.43)	872
Purchase of less-emitting vehicle	0.52 (0.50)	1213	0.63 (0.48)	1000
Purchase of vehicle with alternative drive systems	0.31 (0.46)	1213	0.28 (0.45)	1000
Relevance of climate change	0.39 (0.49)	1059	0.41 (0.49)	973
Feeling of responsibility	0.11 (0.32)	1165	0.08 (0.27)	989
Higher household income (yearly pre-tax income more than $60000)	0.50 (0.50)	1153	--	--
Higher household income (monthly net income more than €2500)	--	--	0.46 (0.50)	776
Higher education (at least “college graduate”)	0.51 (0.50)	1213	--	--
Higher education (at least “Abitur”)	--	--	0.49 (0.50)	999
Age (in years)	42.36 (12.36)	1213	42.07 (10.36)	1000
Gender (male)	0.44 (0.50)	1213	0.54 (0.50)	1000
Single	0.24 (0.42)	1207	0.24 (0.43)	996
Living together with partner	0.62 (0.49)	1207	0.67 (0.47)	996
Household size (number of persons in household)	2.60 (1.29)	1208	2.56 (1.20)	997
Children in household	0.33 (0.47)	1212	0.35 (0.48)	1000
Average driven kilometers per year (in thousand)	18.83 (15.89)	1213	14.93 (9.62)	1000

Table B.2: Simulated maximum likelihood estimates (simulated z-statistics) in multivariate (binary) probit models (50 random draws in the GHK simulator), dependent variables: Purchase of CO_2 offsets, purchase of less-emitting vehicle, purchase of vehicle with alternative drive systems

	U.S.			Germany		
	Purchase of CO_2 offsets	Purchase of less-emitting vehicle	Purchase of vehicle with alternative drive systems	Purchase of CO_2 offsets	Purchase of less-emitting vehicle	Purchase of vehicle with alternative drive systems
Feeling of responsibility	0.66*** (5.11)	0.44*** (3.28)	0.39*** (3.07)	0.75*** (4.26)	0.17 (0.93)	0.20 (1.10)
Higher household income	-0.06 (-0.62)	0.10 (1.13)	0.14 (1.52)	-0.01 (-0.09)	0.23** (2.01)	-0.03 (-0.26)
Higher education	-0.08 (-0.79)	-0.00 (-0.05)	0.28*** (3.13)	0.05 (0.45)	0.05 (0.45)	0.23** (2.15)
Age (in years)	-0.00 (-0.41)	-0.01** (-1.96)	-0.00 (-0.95)	0.01 (1.59)	0.00 (0.58)	-0.01** (-2.40)
Gender (male)	-0.05 (-0.49)	-0.11 (-1.28)	-0.13 (-1.44)	-0.02 (-0.18)	-0.31*** (-2.94)	0.09 (0.87)
Single	0.20 (1.15)	-0.21 (-1.34)	-0.01 (-0.09)	0.31 (1.34)	-0.17 (-0.84)	-0.16 (-0.73)
Living together with partner	0.20 (1.33)	-0.23* (-1.69)	0.11 (0.78)	0.31 (1.52)	0.08 (0.45)	-0.10 (-0.51)
Household size (number of persons in household)	-0.14** (-2.41)	0.02 (0.42)	-0.10* (-1.91)	-0.10 (-1.33)	-0.07 (-1.06)	-0.05 (-0.74)
Children in household	0.29** (1.98)	-0.05 (-0.34)	0.16 (1.17)	0.29* (1.79)	-0.01 (-0.07)	0.16 (1.06)
Log average driven kilometers per year	-0.02 (-0.42)	-0.03 (-0.71)	0.07* (1.74)	0.09 (0.99)	0.01 (0.18)	-0.00 (-0.02)
Constant	-0.39 (-0.73)	0.96 (1.90)	-1.00 (-2.01)	-2.24 (-2.33)	0.30 (0.40)	0.05 (0.07)
Number of observations	920			693		
Relevance of climate change	0.70*** (6.36)	0.52*** (5.00)	0.40*** (3.92)	0.24** (2.02)	0.19* (1.71)	0.22* (1.95)
Feeling of responsibility	0.20 (1.38)	0.06 (0.42)	0.10 (0.67)	0.60*** (3.17)	0.06 (0.31)	0.06 (0.31)
Other explanatory variables and constant	yes					
Number of observations	858			687		

Note:
*** (**, *) means that the appropriate explanatory variable has an effect at the 1% (5%, 10%) significance level

Table B.3: Number of observations (percentage rates) for different alternatives in multinomial logit models (total number of observations in the U.S. = 854, total number of observations in Germany = 677)

	U.S.	Germany
Multinomial logit model with no purchase of CO_2 offsets or less-emitting vehicle as omitted category		
No purchase of CO_2 offsets or less-emitting vehicle	252 (29.51%)	186 (27.47%)
Only purchase of CO_2 offsets	62 (7.26%)	49 (7.24%)
Only purchase of less-emitting vehicle	402 (47.07%)	334 (49.34%)
Purchase of CO_2 offsets and less-emitting vehicle	138 (16.16%)	108 (15.95%)
Multinomial logit model with no purchase of CO_2 offsets or vehicle with alternative drive systems as omitted category		
No purchase of CO_2 offsets or vehicle with alternative drive systems	432 (50.59%)	357 (52.73%)
Only purchase of CO_2 offsets	96 (11.24%)	112 (16.54%)
Only purchase of vehicle with alternative drive systems	222 (26.00%)	163 (24.08%)
Purchase of CO_2 offsets and vehicle with alternative drive systems	104 (12.18%)	45 (6.65%)

Table B.4: Maximum likelihood estimates (z-statistics) in multinomial logit models, omitted category: No purchase of CO_2 offsets or less-emitting vehicle

	U.S.			Germany		
	Only purchase of CO_2 offsets	Only purchase of less-emitting vehicle	Purchase of CO_2 offsets and less-emitting vehicle	Only purchase of CO_2 offsets	Only purchase of less-emitting vehicle	Purchase of CO_2 offsets and less-emitting vehicle
Feeling of responsibility	1.96*** (4.52)	1.10*** (3.12)	1.92*** (5.15)	1.29** (2.48)	0.22 (0.54)	1.42*** (3.32)
Higher household income	-0.79** (-2.35)	0.03 (0.18)	0.20 (0.86)	-0.12 (-0.31)	0.37* (1.72)	0.29 (1.04)
Higher education	0.32 (1.06)	0.03 (0.19)	-0.32 (-1.44)	0.43 (1.21)	0.09 (0.42)	0.04 (0.16)
Age (in years)	0.01 (1.09)	-0.01 (-0.73)	-0.02* (-1.75)	0.05*** (2.67)	0.01 (1.33)	0.01 (0.63)
Gender (male)	-0.50 (-1.62)	-0.51*** (-2.98)	-0.36 (-1.49)	-0.34 (-0.98)	-0.63*** (-3.12)	-0.54** (-2.02)
Single	0.26 (0.52)	-0.33 (-1.03)	-0.00 (-0.00)	0.66 (0.97)	-0.16 (-0.41)	0.30 (0.55)
Living together with partner	0.02 (0.04)	-0.41 (-1.58)	0.00 (0.00)	0.62 (1.02)	0.17 (0.49)	0.73 (1.51)
Household size (number of persons in household)	-0.09 (-0.47)	0.11 (1.11)	-0.19 (-1.45)	-0.21 (-0.84)	-0.07 (-0.55)	-0.27 (-1.50)
Children in household	-0.08 (-0.16)	-0.25 (-0.96)	0.36 (1.08)	0.36 (0.69)	-0.19 (-0.66)	0.53 (1.37)
Log average driven kilometers per year	-0.01 (-0.11)	-0.03 (-0.37)	-0.06 (-0.56)	-0.01 (-0.03)	-0.06 (-0.47)	0.19 (1.02)
Constant	-1.57 (-1.00)	1.28 (1.27)	1.15 (0.88)	-3.75 (-1.14)	0.90 (0.64)	-2.79 (-1.38)
Pseudo R^2	0.04			0.04		
Number of observations	854			677		
Relevance of climate change	1.37*** (3.85)	0.90*** (4.06)	2.08*** (7.44)	0.23 (0.61)	0.29 (1.40)	0.68** (2.50)
Feeling of responsibility	0.93* (1.89)	0.42 (1.07)	0.58 (1.41)	1.13** (1.97)	0.04 (0.09)	1.00** (2.17)
Other explanatory variables and constant	yes					
Pseudo R^2	0.08			0.04		
Number of observations	805			672		

Note:
*** (**, *) means that the appropriate explanatory variable has an effect at the 1% (5%, 10%) significance level

Table B.5: Maximum likelihood estimates (z-statistics) in multinomial logit models, omitted category: No purchase of CO_2 offsets or vehicle with alternative drive systems

	U.S.			Germany		
	Only purchase of CO_2 offsets	Only purchase of vehicle with alternative drive systems	Purchase of CO_2 offsets and vehicle with alternative drive systems	Only purchase of CO_2 offsets	Only purchase of vehicle with alternative drive systems	Purchase of CO_2 offsets and vehicle with alternative drive systems
Feeling of responsibility	1.26*** (4.20)	0.59** (2.16)	1.47*** (4.88)	1.50*** (4.12)	0.65* (1.73)	1.44*** (2.90)
Higher household income	0.16 (0.64)	0.48*** (2.59)	-0.08 (-0.34)	-0.21 (-0.83)	-0.17 (-0.77)	0.07 (0.21)
Higher education	-0.22 (-0.94)	0.44** (2.40)	0.24 (1.03)	0.23 (0.96)	0.43** (2.04)	0.31 (0.85)
Age (in years)	-0.02* (-1.82)	-0.01* (-1.80)	0.00 (0.07)	0.02* (1.68)	-0.02 (-1.62)	-0.03 (-1.40)
Gender (male)	0.18 (0.73)	-0.18 (-1.04)	-0.45* (-1.83)	-0.36 (-1.56)	-0.09 (-0.45)	0.65 (1.62)
Single	0.14 (0.32)	-0.08 (-0.23)	0.36 (0.89)	0.29 (0.63)	-0.35 (-0.89)	1.29 (1.14)
Living together with partner	0.33 (0.82)	0.27 (0.99)	0.44 (1.23)	0.48 (1.20)	-0.20 (-0.57)	1.29 (1.19)
Household size (number of persons in household)	-0.19 (-1.42)	-0.12 (-1.21)	-0.39** (-2.55)	-0.22 (-1.32)	-0.07 (-0.53)	-0.29 (-1.20)
Children in household	0.31 (0.93)	0.19 (0.73)	0.64* (1.72)	0.65* (1.90)	0.27 (0.94)	0.88 (1.62)
Log average driven kilometers per year	-0.10 (-0.94)	0.09 (1.01)	0.13 (1.38)	0.10 (0.65)	-0.04 (-0.32)	0.26 (0.58)
Constant	0.23 (0.18)	-1.35 (-1.28)	-2.39 (-2.09)	-3.17 (-1.83)	0.49 (0.35)	-4.98 (-1.12)
Pseudo R^2	0.04			0.04		
Number of observations	854			677		
Relevance of climate change	1.41*** (5.06)	0.60*** (2.88)	1.58*** (5.94)	0.45* (1.86)	0.44** (2.14)	0.60* (1.73)
Feeling of responsibility	0.35 (1.02)	0.15 (0.50)	0.45 (1.34)	1.21*** (3.08)	0.36 (0.91)	1.06** (1.96)
Other explanatory variables and constant	yes					
Pseudo R^2	0.07			0.04		
Number of observations	805			672		

Note:
*** (**, *) means that the appropriate explanatory variable has an effect at the 1% (5%, 10%) significance level

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