Universitat Autònoma
de Barcelona

From global to local

behind the relationship between the economy and the environment

Matías Piaggio

Universitat Autònoma de Barcelona

FROM GLOBAL TO LOCAL

BEHIND THE RELATIONSHIP BETWEEN THE ECONOMY AND THE ENVIRONMENT

PHD THESIS

Matías Piaggio

May 2013

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Advisor	Advisor

PhD in Applied Economics
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To the memory of my father,

who never let me walk alone

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Introduction

The consequences of economic activity on the environment can be analyzed at different levels and along multiple scales. Gibson et al. (2000) provides a very complete survey on the concept of scales and the human dimensions of global scale. As they remark, social scientists have worked with scales not precisely determined, in contrast to natural scientists. Choices over scale, extent, and resolution are critical for social scientists, because patterns that appear at one level of resolution or extent may be lost at different levels.

The scale can be defined by several criteria, like spatial, temporal, quantitative, or analytical dimensions used by scientists to measure the study objects and processes. Level is a term employed to refer to a region along a measurement dimension (Gibson et al., 2000). This document will focus the analysis at different levels of a spatial scale. It will refer to the international, national, and regional dimensions of political jurisdiction. This choice is based on the fact that different problems at different scales deserve different diagnostic methods and policy instruments: e.g. greenhouse gas emissions reduction requirements must be based on a global benchmark, because emissions produced in one political territory impact in other countries. But while the instruments for mitigating policies must be supported through international agreements, each national government chooses its mitigation policies in reference to its own economic structure and the impact of these policies on national growth and development.

The general objective of this thesis is to analyze the relationship between the economy and the environment at different scales. This must be understood as choosing a research problem at each dimension, and to apply the tools that better fit to analyze each problem. Of course, most human activities have consequences measured at different levels and along multiple scales. But it is not the concern of this thesis to develop a multiple scale analysis of the total impact of economic activities. The present document is divided in three parts. Each part corresponds to one dimension, and policy implications are directly derived from the analysis.

Part I approaches the relationship between the environment and the economy from an international dimension. The analysis of the relationship between economic activity and pollution from a macroeconomic perspective gave rise to huge literature since the seminal work of Grossman and Krueger (1991). Early works suggest this relationship to follow an inverted-U shaped relationship (Environmental Kuznets Curve, EKC). This was explained by the greater requirement of natural resources and waste generation in the early stages of economic growth (scale effect). As economic activity level increases, pollution decelerates and conducts to a decreasing section of the path because of changes in the economic structure towards less polluting activities (composition effect), jointly with the capacity of technological substitution towards less polluting processes that higher incomes allows (technological effect).

But the relationship behind the EKC hypothesis can be generated by different structural models because it can be driven by different underlying factors (Perman and Stern, 1999). In this way, an apparent inverted-U relationship could be consequence of a statistical result stemming from other factors, so that the observed relationship between environmental degradation and economic growth would in fact be spurious. In the late 90’s and early years of the following decade several authors started considering that the relationship between environmental degradation and income could differ across countries, where countries with similar activity level could be passing different relationship paths (Perman and Stern, 1999 and 2003; List and Gallet, 1999; Dijkgraaf and Vollebergh, 2005; Martínez-Zarzoso and Bengochea-Morancho, 2003 and 2004 and Dijkgraaf et al., 2005). Also, wide literature of empirical analysis at national level has emerged since then.

Analyzing path heterogeneity is an important task, because policy implications are going to be different if a turning point is expected, or if paths could diverge for countries with similar economic activity levels. In this line, Chapter 1 analyzes the assumption of identical functional form and parameters among countries in the long-run relationship between carbon dioxide emissions (CO_2) and economic activity. It explores the homogeneity of the functional form, the parameters, and the turning point, when appropriate, of this relationship for 31 countries (28 OECD, Brazil, China, and India) during the period 1950 to 2006 using cointegration analysis, a highly overlapped sample over time between countries.

The relationship between the economy and the environment from a national perspective is conducted in Part II. National productive structure plays a salient role in the impact of economic activities on the environment. Understanding this relationship allows to design policies to avoid and/or mitigate environmental problems (Hoekstra, 2005). Productive sectors employ natural resources and pollute directly to satisfy their final demand, but also for providing inputs to the rest of the economy. In this sense, productive sectors total environmental responsibility involves both, direct and indirect components. This is very important for policy design, because different polluting nature will deserve different policy measures. While technical improvements and better practices will be effective only in direct polluters, demand policies can also be relevant for highly indirect polluters. Part II is divided in two chapters, as described below.

Chapter 2 seeks to identify key sectors, in reference to greenhouse gases in Uruguay in 2004. This will allow to precisely determine the role played by the different productive sectors and their relationship with other sectors. Also, sectors liability is decomposed between the pollution generated through its own production processes and the pollution indirectly generated in the production processes of other sectors. This helps to distinguish the best policy channels for controlling and reducing emissions, complementing the National Climate Change Response Plan (NCCRP) lines of action. In addition, emissions are split into two final demand components. This allows to both, analyze the role of external demand, and to consider the scope of internal demand policies.

Key sectors analysis provides an overview about the relationship between the productive structure and the environment. However, sometimes it is more important to focus on specific sectors, and studying their environmental linkages with greater complexity (Alcántara, 1995). Seeking this purpose, Chapter 3 analyzes agro-industrial subsystem methane emissions and services subsystem carbon dioxide emissions in Uruguay in 2004. Agro-industrial sectors represent the main Uruguayan exports productive chain. Also, they are responsible of almost all methane and nitrous oxide emissions. Decomposing in detail those sector emissions would help for better understanding the relationship of this subsystem with the rest of the economy. Also, since the early 70's emerged the idea that services have low impact on the environment because they consume less energy, given that they are lower capital intensive sectors. But services provision implies interactions with several other economic agents that are reached through the combination of operations, conditioning, and travel that requires direct energy consumption (and hence pollution), but also other sectors to pollute (Fourcroy et al., 2012). Several authors have empirically rejected the non-materiality of services (Suh, 2006; Nansai et al., 2007; Alcántara and Padilla, 2009; and Fourcroy et al., 2012). Despite carbon dioxide emissions only represent 16.6% of total Uruguayan GHGs in 2004, half of them are directly related to services sectors. Also, the NCCRP only tackles transport sector emissions in its lines of action, giving priority to the reduction of energy consumption emissions, while energy efficiency is addressed in general terms. In this sense, decomposing services subsystem relationship with the rest of the economy would allow to shed light on the materiality of this sectors in the Uruguayan economy, as well as help to orientate the design of mitigation policies.

Finally, Part III takes a local perspective for approaching the analysis between economic activities and the environment. Communal property regimes have become an attractive alternative for the conservation and sustainable use of common pool resources (CPRs). Hardin (1968) proposed to establish either private or state property rights as a solution to avoid the so-called *tragedy of the commons*. But market contracts and governments often fail to prevent overexploitation because the necessary information to design and enforce beneficial exchanges and directives cannot be effectively used by judges and government officials (Bowles and Gintis, 2002). In this way, communal property regimens can in some cases fill this incomplete contracts gap enhancing cooperation by enforcing social norms (Ostrom, 1990; Feeny et al. 1990; Baland and Platteau, 1996; Ostrom et al., 1999 and Ostrom, 2000; Bowles and Gintis, 2002).

Chapter 4 provides experimental evidence on the effectiveness of non-monetary punishment (NMP) by peers in promoting cooperation among communities of Uruguayan fishermen when exploiting a common pool resource. Assessing the relevance of NMP as a tool to enhance cooperation is of particular importance in regard to community management of common pool resources, because informal sanctions typically take place in that setting. Besides, due to the absence of monetary incentives, non-monetary punishment allows better isolation of the presence of pro-social emotions when an individual reacts to being punished relative to costly punishment. We also analyze whether behavior regarding NMP differs in a context in which individuals exploiting a common pool resource belong to different communities in relation to the case in which only individuals from the same community are allowed to exploit the resource. Several studies show that individuals may achieve greater levels of cooperation when interacting with members of their own group rather than with outsiders, because of conditional social preferences on group membership (Bandiera et al., 2005; Miguel and Gugerty, 2005; Ruffle and Sosis, 2006; Goette et al. 2012; Bernhard, et al., 2006; Chen and Xin, 2009). This means that also the channels through which NMP effectiveness is transferred can be conditioned by the group composition.

The chapters contained in this thesis approach the relationship between economic activity and environment. This represents a common thread along the thesis, but every chapter can be read independently, and approaches the analysis from a different level.

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Part I

The relationship between the economy and the environment from a global perspective

CHAPTER 1

CO_2 EMISSIONS AND ECONOMIC ACTIVITY: HETEROGENEITY ACROSS COUNTRIES AND NON STATIONARY SERIES[a]

Abstract

This chapter explores the relationship between CO_2 emissions and economic activity for 31 countries (28 OECD, Brazil, China, and India) during the period 1950 to 2006 using cointegration analysis. Single country long run relationships are estimated, and equality in the functional form, the parameters, and the turning point, when appropriate, are rejected. This confirms the relevance of considering the differences among countries in the relationship between air pollution and economic activity to avoid wrong estimations and conclusions.

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1.1 Introduction

The Environmental Kuznets Curve (EKC) hypothesis suggests the existence of an inverted-U shaped relationship between environmental degradation and income level.

Grossman and Krueger (1991) argued that there are three channels that explain this path. In early stages of economic growth, the greater requirement of natural resources and waste generation increases environmental degradation (scale effect). This growing path might lead to changes in the economic structure towards less polluting activities (composition effect), which along with the increase in the capacity of higher income countries to face technological substitution towards less polluting processes (technological effect) would lead to a turning point in the relationship and to the decreasing section of the curve. Therefore, the transition from the increasing to the decreasing section of the curve in the relationship between environmental degradation and economic activity would arise when the composition and technological effects worked in the indicated direction and overcame the scale effect[1].

However, an EKC can be driven by different underlying factors, so that the relation behind the hypothesis can be generated by different structural models (Perman and Stern, 1999). The literature highlights the distribution of power (Torras and Boyce, 1998), income-elasticity of the demand for environmental quality (McConnell, 1997; Dasgupta et al. 2002), environmental regulation and international agreements (de Bruyn, 1997) or structural transitions, like the oil price shocks in the 1970s (Moomaw and Unruh, 1997). Also, an EKC can be reached by individual countries through the displacement of polluting activities to other countries (the ‘pollution haven hypothesis’, Stern et al., 1996; Cole et al., 1997). In this way, although an inverted-U relationship can be empirically shown, this can be a statistical result stemming from other factors, which might imply that the observed relationship between environmental degradation and economic growth is spurious. Moreover, these factors might vary across countries and be different for different pollutants.

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[1] The existence of composition and technological effects do not necessarily imply a result as the one suggested by the EKC hypothesis. For this to be the case, it is required that the composition effect involves a reduction of polluting sectors in absolute and not only in relative terms. As for the technological change, it might sometimes involve new processes with new (and sometimes unknown) pollutants or efficiency improvements leading to the increase of extractive or other environmentally damaging activities (Roca and Padilla, 2003). Therefore, it depends on the type of technological and composition change that these effects compensate or reinforce the scale effect for a specific pollutant.

Earlier works ignored that the relationship between environmental degradation and income can be different across countries (or regions), both in the functional form as well as the parameters and the turning point (Grossman and Krueger, 1991 and 1995; Shafik and Bandyopadhyay, 1992; Selden and Song, 1994; Carson et al. 1997; Cole et al. 1997 and Vincent, 1997). This issue was first studied in the late 1990s and early 2000s (Perman and Stern, 1999 and 2003; List and Gallet, 1999; Dijkgraaf and Vollebergh, 2005; Martínez-Zarzoso and Bengochea-Morancho, 2003 and 2004 and Dijkgraaf et al., 2005). Following the same concerns, a series of analyses of the EKC at national level has emerged, (among them Vincent, 1997; de Bruyn et al., 1998; Moomaw and Unruh, 1997; Lekakis, 2000; Roca et al., 2001, Friedl and Getzner, 2003; Deacon and Norman, 2006; Egli, 2004; Hung and Shaw, 2004; Shen, 2006; Piaggio, 2008; Song et al., 2008; Halicioglu, 2009; Wang, 2009, Menyah and Wolde-Rufael, 2010, and Jalil and Feridun, 2011).

Moreover, until the study of Perman and Stern (1999), the statistical properties of the data employed were not considered. The analysis using non-stationary series has to be carried out taking into account this characteristic.

The traditional EKC approach not only ignores that economies with the same level of activity might present different functional forms with respect to the relationship between income and environmental degradation, but also assumes the same parameters in this relationship across countries. However, there may be countries whose scale effect is still more important than the composition and technological effects (or other determinants which may lead to a decrease in emissions), while other countries with a similar economic activity level may show a decreasing relationship between pollution and income. While the first ones show a linear relation between pollution and economic activity level, the last ones show a quadratic relationship (an inverted-U). Finally, the scale effect can take relevance again after a decreasing path, giving place to a cubic, or N-shaped, path.

An EKC estimated from cross-section, or panel data when the series are hardly or not overlapped over time across countries, can simply reflect the juxtaposition of a positive relationship between environmental degradation and income in rich countries with a negative one in developing countries, and not a relationship operating for both kinds of countries (Vincent, 1997). This problem can be solved if the panel data set has overlapped observations for large periods (Egli, 2004). However, this would not solve the problem of assuming homogeneity in the functional form of the relationship between environmental degradation and income among countries.

In light of the above, the analyses that assume the same functional form and parameters across countries might in fact not reflect the behavior of the relationship between environmental degradation and income for these at the individual level. So, the conclusions that, after certain point, environmental degradation decreases with greater economic activity for the more developed countries might be wrong. Consequently, more attention should be paid to individual countries behavior in order to assess the possible benefits of the increase in economic activity on environmental quality for each country (de Bruyn et al., 1998). To impose *a priori* the constraint of homogeneity between countries in the functional form and the parameters might be a statistical device more than a model that appropriately approximates reality. Carson (2010) argues that the analysis should distinguish between a “weak” version of the EKC hypothesis, for a particular political jurisdiction, and a “strong” one, applying for the different political jurisdictions.

The objective of this chapter is to analyze the assumption of identical functional form and parameters among countries in the long-run relationship between carbon dioxide emissions (CO_2) and economic activity. The analysis is carried out for 31 countries (28 OCDE countries, Brazil, China and India) over the period 1950–2006. The time period considered in this chapter is longer than the one from previous studies. This is very important, because a longer period increases the degree of overlapping across the countries series that might have different functional forms. This is particularly relevant as a consequence of the important economic growth of the European countries in the post war period, and the exponential growth of several countries in the early XXI century. First, the functional form homogeneity will be tested through the estimation of the relation for each individual country. For those countries with the same functional forms the homogeneity in the parameters of the long run relationship would be tested, allowing variations among them in both short term adjustments and in the rate of convergence to the long run relationship. As a result, the functional form for each country will be determined. Also, unlike previous studies, homogeneity in the turning point among the countries that present one would be tested. This is a weaker restriction than the previous one, because it allows countries to reach the same threshold through different paths. This analysis will help the policy instruments design, because similar countries with different paths would require different tools. The use of cointegration techniques would avoid the possibility of a spurious relationship between CO_2 emissions and economic activity. The present chapter will explicitly define the functional form of the apparent long run relationship for each country. This analysis is useful to guide the analysis of the determinants behind each country behavior, which would help to think over the policy instruments design involving countries with similar economic levels but different paths.

In the next section, the conceptual framework of the EKC hypothesis and the relationship between economic growth and environmental degradation adjusted to our analysis is presented. Section 1.3 presents the methodology and data used. Section 1.4 details the analysis results. Section 1.5 presents the final remarks.

1.2 Conceptual framework

The EKC hypothesis arises from a reduced model specification. Therefore, it can be the result of one or more different structural relationships, because it is an empirical phenomenon. So, this is in fact an apparent relation analysis between environmental degradation and economic activity. In line with previous works, the reduced form model relates environmental degradation level with economic activity for each country, which can follow a lineal, quadratic or cubic functional form:

$$(1)\ E_{it} = \alpha_i + \beta_1 Y_{it} + \beta_2 Y_{it}^2 + \beta_2 Y_{it}^3 + \varepsilon_{it}$$

where *E* denotes the indicator of environmental degradation or pressure per capita and *Y* is income per capita. Subscript *i=1,…, N* indicates countries, subscript *t = 1, …, T* is the time period indicator, and ε is the error term normally distributed. The correct functional form for each country can be specified from the equation above.

Following Perman and Stern (1990 and 2003) and Carson (2010), a “weak” EKC would result if $\beta_{1i}>0$, $\beta_{2i}<0$, and $\beta_{3i}=0\ \forall\ i$, but these parameter would have different values for different countries. A “strong” version would result if $\beta_{1i}=\beta_1$ *and* $\beta_{2i}=\beta_2\ \forall\ i$.

In the same way, an *N* relation would result if $\beta_{1i}>0$, $\beta_{2i}<0$, y $\beta_{3i}>0$, where there would exist a second turning point. Finally, the relationship will be monotonous (increasing or decreasing) when $\beta_{2i}=\beta_{3i}=0$. A “strong” version of a monotonous relationship would occur when $\beta_{1i}=\beta_1\ \forall\ i$.

Empirically, any of the functional forms (lineal, quadratic or cubic) can be reached. Therefore, the functional form that best fits each country would be determined before the parameter homogeneity analysis.

When a quadratic or cubic functional form is determined, it is also relevant to study if the turning point is the same among countries. It is possible that countries with different reaction (elasticities) of emissions to economic activity reach the turning point for the same level of economic activity. This factor is relevant, because there could be support for directing policy making toward reaching the turning point, no matter what the path is. Therefore, the threshold from which environmental degradation is too high or irreversible would be a relevant piece of information to interpret the policy implications of supporting the EKC hypothesis for each country. It could be that from certain level of degradation it may not be feasible to revert environmental damage (Panayotou, 1997).

There are no theoretical foundations that support the functional form and parameters homogeneity restriction for different countries. Perman and Stern (1999 and 2003) reject parameters homogeneity in the case of SO_2 emissions for 74 countries between 1960 and 1990, assuming a quadratic functional form. Cole (2005) rejects the constant coefficients assumption across countries for SO_2 (110 countries between 1984 and 2000), NOx (26 countries, for 1975, 80, 85, and 90) and CO_2 emissions (110 countries, 1984-2000).

Martínez-Zarzoso and Bengochea-Morancho (2003 and 2004) reject functional form homogeneity in the case of CO_2 emissions between two groups of countries (19 Latin

American and 22 OECD countries over 1975–1998). List and Gallet (1999) do not reject quadratic functional form homogeneity in the cases of NO_X and SO_2 emissions for 48 USA states over 1929–1994, while they find that the parameters are different among states. Dijkgraaf and Vollebergh (2005) and Dijkgraaf et al. (2005) reject parameters homogeneity in a cubic specification in the case of CO_2 emissions for a 24 OECD countries panel between 1960 and 2000. Finally, Musolesi et al. (2010) conclude that different dynamics are associated with the different sub-samples of countries considered for CO_2 emissions in a panel of 109 countries between 1959 and 2001.

Until the late 1990s the empirical literature ignored the analysis of the stationarity of the variables, which could have led to the estimation of spurious relations (Grossman and Krueger, 1991 and 1995; Shafik and Bandyopadhyay, 1992; Carson et al. 1997; Cole et al. 1997; Vincent, 1997 and de Bruyn et al., 1998). Both environmental degradation and income series use to be non-stationary (their parameters are not constant throughout time). Therefore, employing the variables in levels —without any stationary transformation— for the estimation of a long run relationship between environmental degradation and income would result in non robust estimators. This would make the application of inference tests impossible, and the relationship could be spurious, unless the series were cointegrated (Enders, 2004).

In the literature on the relationship between environment and economic activity, the time series stationarity analysis and cointegration analysis when the series are non stationary have been developed by various authors in the last decade, both for panel data and for individual countries studies (Perman and Stern, 1999 and 2003; Lekakis, 2000; Roca et al., 2001; Friedl and Getzner, 2003; Egli, 2004; Dinda and Coondoo, 2006; Wagner, 2008; Piaggio, 2008; Song et al., 2008; Halicioglu, 2009; Lee and Lee, 2009 and Wang, 2009).

1.3 Methodology and data

1.3.1 Empirical strategy

The EKC hypothesis refers to a long run phenomenon, and thus might be estimated via cointegration analysis. Pesaran et al. (2001) develops the bound testing (BT) for the cointegration analysis of the relationship of variables in levels. For this chapter purpose, BT presents some advantages with respect to more frequent cointegration tests (Engle and Granger, 1987; Johansen and Juselius, 1990 and Johansen, 1991) because it can be applied when there is uncertainty about the degree of integration of the series involved, where all of them can be I(1), I(0) or a combination of both[2]. Long run economic series with integration order higher than one would be hard to believe, understand and interpret[3]. The BT approach will allow to determine the existence of a stationary linear combination of the variables involved that led to a long run relationship, dealing with the non linear transformation of non stationary series problem. This methodology has been previously employed by Perman and Stern (2003), Iwata et al. (2010a and 2010b), Menyah and Wolde-Rufael (2010) and Jalil and Feridun (2011).

Writing equation (1) as an Autoregressive Distributed Lag model, ADRL (p,p_1,p_2,p_3), for each single country in an Error Correction Model (ECM) form, BT allows to determine the existence of a long run relationship. The dynamic model allows to overcome the issue that deviations from the long run equilibrium are not instantaneously corrected (as suggests the static specification presented in equation (1)). This assumption is more plausible (and will be empirically tested), as it might be reasonable to expect that the adjustment between environmental degradation and economic activity to be slow (Perman and Stern, 1999).

In this way, once the existence of a long run relationship is tested, the following transformation of the ECM is estimated employing Non-Linear Least Squares (NLLS):

$$(2) \qquad \Delta E_t = \sum_{m=1}^{p} \theta_m \Delta E_{t-m} + \sum_{n=0}^{p_1} \xi_n \Delta Y_{t-n} + \sum_{i=0}^{p_2} \delta_i \Delta Y_{t-i}^2 + \sum_{j=0}^{p_3} \gamma_j \Delta Y_{t-j}^3 + \alpha_0 [E_{t-1} - \mu^* - \beta_1 Y_t - \beta_2 Y_t^2 - \beta_3 Y_t^3] + \varepsilon_t$$

where the number of lags, p, p_1, p_2 and p_3 are independently chosen for each country, following from general to particular criteria (Hall, 1991)[4]. The term within brackets

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[2] I(q) indicates the degree of integration of the series, being the q^{th} difference of the series a stationary transformation.

[3] While Wagner (2008) argues theoretically that non linear transformations of series in general do not preserve the integration properties of variables and hence can change the stochastic behavior (which leads to the necessity of a different asymptotic theory for such regressions), Granger and Hallman (1991) show empirically that monotonous non linear transformations of I(1) series are also I(1).

[4] A general model for a given p, p_1, p_2 and p_3 value, large enough, is specified. Then, the lag is reduced, determining the value of each of them for the lag of greater degree statistically significant.

represents the error correction term (ECT). Besides the improvement in the consistence provided by the estimation method, this specification, presents three more advantages: i) it allows to identify the long run relationship, the short run dynamic and the coefficient of adjustment to the long run equilibrium relationship (α), ii) if the series in levels are cointegrated, the ECM is a linear combination of stationary variables. Then, estimations are robust, and conventional inference procedures can be applied, and iii) this specification allows testing different restrictions among individuals (Perman and Stern, 1999 and 2003).

Cointegration analysis and the estimation of the long run relationship by means of the ECM should be reiterated for the cubic, quadratic and linear specifications. In this way, the path that bests fits the long run relationship between CO_2 emissions and income level for each single country will be determined (if one exists). For those countries that do not satisfy the BT cointegration test, or that the model estimated is not satisfactory for the functional form that the BT indicates, a unit roots analysis through the Augmented Dickey-Fuller test (ADF) and the cointegration analysis through Engel-Granger test (1987) should be carried out (Enders, 2004). Then, when the series are I(1) and are cointegrated the ECM may be estimated for each specification[5].

A reduced form model captures the whole direct and indirect relationship between economic activity and environmental degradation, including the effects linked to the omitted (or unobserved) variables which are correlated with both economic activity and time (Mazzanti and Musolesi, 2011), so that the inclusion of additional variables would distort the analysis (List and Gallet, 1999). Therefore, it is not possible to assess what causes the relationship to exist. This kind of analysis allows for the study of apparent elasticities, not being an analysis of the determinants of environmental pollution. As it is a uniequational specification, it does neither solve the problem of a possible feedback between the variables. However, as it is developed through a cointegration analysis, the estimated parameters will be superconsistent, not being affected by the endogeneity bias of the variables (Veerbeek, 2005).

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[5] Engle-Granger cointegration test is seen as the most appropriate one for the present analysis, because a priori we explore the existence of only one cointegration relation. The test proposed by Johansen and Juselius (1990) and Johansen (1991) becomes complex in the presence of non linear transformations of one of the variables, as it allows for the existence of more than one cointegration relationship.

The ECM specification is employed by Perman and Stern (1999 and 2003) for SO_2 emissions, and Martínez-Zarzoso and Bengochea-Morancho (2003 and 2004) and Dinda and Coondoo (2006) for CO_2 emissions, all of them working with panel data. Egli (2004), for various contaminants, and Iwata et al. (2010a and 2010b), Menyah and Wolde-Rufael (2010) and Jalil and Feridun (2011), for CO_2 emissions, employed it for individual countries. Finally, Haciglou (2008) and Piaggio (2008) applied it to study CO_2 emissions for individual countries but in a multi equation specification.

Once the correct functional form is specified and the long run relationship is estimated through the ECM, the homogeneity of parameters among countries with equal functional form is studied, allowing the short run coefficients and the quantity of lags to be different among countries. This will be tested computing confidence intervals (CI)[6] for the parameters of the long run relation. The same exercise is carried out with respect to the coefficient of adjustment of deviations from the long run relationship (α).

A similar strategy is followed for testing the turning point homogeneity. The turning point for countries with a quadratic functional form in equation (2) is given by $\hat{\theta} = -\frac{\widehat{\beta_1}}{2\widehat{\beta_2}}$. From this, the turning point CI will be computed for the turning point of those countries that show an inverted-U relationship[7]. A similar procedure might be developed with respect to those with cubic functional form.

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[6] IC: $\left[\hat{\beta} \pm z_{\alpha/2}\frac{s_{\hat{\beta}}}{\sqrt{n}}\right]$, where $s_{\hat{\beta}}$ is the standard deviation associated to the estimated parameter $\hat{\beta}$, $(1-\alpha)$ is the confidence level, n is the sample size, and z is the value of the standardized Normal distribution for $\alpha/2$ confidence level.

[7] $\hat{\theta} = -\frac{\widehat{\beta_1}}{2\widehat{\beta_2}} \sim \text{Normal}\left(\hat{\theta}, V(\hat{\theta})\right)$ given the distribution of parameters β_1 and β_2. Employing the Delta Method, following Hayashi (2000: pp. 93–94) and Greene (2003, p. 70), $As.Var\left(\hat{\theta}\right) = \begin{pmatrix} \frac{-1}{2\beta_2} & \frac{\beta_1}{2\beta_2^2} \end{pmatrix} \begin{pmatrix} \sigma_{\beta_1\beta_1} & \sigma_{\beta_1\beta_2} \\ \sigma_{\beta_2\beta_1} & \sigma_{\beta_2\beta_2} \end{pmatrix} \begin{pmatrix} \frac{-1}{2\beta_2} \\ \frac{\beta_1}{2\beta_2^2} \end{pmatrix}$

1.3.2 Data

The analysis takes into account 31 countries (28 OECD countries[8], Brazil, China and India) between1950–2006[9]. This time period is longer than the one from previous studies on the homogeneity of the parameters for CO_2 emissions, which increases the possibility of taking into account countries with overlapped income levels but heterogeneous paths. Moreover, the sample contains almost all countries (except Iceland and Luxembourg) committed to quantitative limits in CO_2 emissions through Annex B of the Kyoto Protocol (United Nations, 1998). Despite of the data for the countries that were members of the Council of Mutual Economic Assistance (COMECOM) until 1989 can be no reliable, we decided to keep these countries into the sample because of two reasons: first, we prefer to keep as much countries involved in the Kyoto protocol as possible; second, they are responsible of an important part of total emissions. In 2006 the countries of the former Soviet Union alone emitted 8.6% of total CO_2 emissions (Boden et al., 2009). Moreover, this is the best data available for this kind of analysis.

CO_2 emission data is published by the Carbon Dioxide Information Analysis Center (CDIAC) (Boden et al., 2009). It is consistent with the one of the World Bank (2005) for the period 1960–2005, allowing to take into account ten more years. CO_2 emissions are measured in metric tons of CO_2. Logarithmic transformation of emissions per capita (*co2pc*) is employed.

Economic activity at national level employed is estimated and transformed to 1990 Geary-Khamis dollars (which corrects by purchasing power parity, PPP) by Maddison (2003), updated to 2006 by the same author for 155 countries[10]. The National Accounts System was set up in 1950 in various countries, which allows having reliable information. Logarithmic transformation of per capita growth domestic product for the

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[8] Australia, Austria, Belgium, Canada, former Czechoslovakia (after 1992 the values for Czech Republic and Slovakia are added), Denmark, Finland, France, Germany (for the period 1950–1990 the information for the German Federal Republic and the German Democratic Republic are added), Greece, The Netherlands, Hungary, Ireland, Italy, Japan, South Korea, Mexico, Norway, New Zealand, Poland, Portugal, Spain, Sweden, Switzerland, Turkey, UK, USA, and former Soviet Union (from 1992 the values of Estonia, Georgia, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Moldova, Russia, Tajikistan, Turkmenistan, Ukraine and Uzbekistan are added). Two OECD countries, Iceland and Luxembourg, are excluded due to lack of information for the entire period.

[9] Except for Belgium, for which we took the period 1952–2006, as it presented atypical values for the two first years of the sample.

[10] http://www.ggdc.net/maddison/

variable in levels, and its quadratic and cubic transformation are used (gdppc, gdppc2, and gdppc3, respectively).

1.4. Results

1.4.1 Cointegration analysis

Following Pesaran et al. (2001) we will carry out the contrast several times, including up to four lags, due to the sensitiveness of the analysis to the quantity of lags included. Table 1.1 summarizes the results of the F-statistic of the Wald test for the linear, quadratic and cubic specification of equation (2).

Some countries of the sample allow for the existence of a long run relationship for the variables of interest for more than one functional form. This might result, for example, from quadratic forms that have not achieved the maximum, or that have just surpassed it, or from cubic forms with tiny decreasing sections, that might both be approached through linear models. Therefore, the adequate functional form for each country would be determined from the cointegration analysis jointly with the estimation of equation (2) for each one of the functional forms in the countries confirming the existence of a long run relationship[11]. Table 1.1 shows that BT is not conclusive for 24 cases, while it indicates that there is not a long run relationship for any functional form for France, United Kingdom, USA and Brazil. When the BT is inconclusive, Iwata et al. (2010a and 2010b) argue that the non existence of a cointegration relationship may be rejected or not according to the test of significance of the parameter of adjustment (α) of equation (2).

From the analysis above, when BT does not reject the existence of a long run relationship equation (2) is estimated. Therefore, the preferred functional form for each country is determined. The results indicate the existence of a long run relationship between CO_2 emissions and economic activity, both in per capita terms, for 18 countries of the sample (1 cubic, 14 quadratic and 3 linear). From the 17 countries for which a quadratic specification is possible, 14 present the turning point within the sample, which confirms an inverted-U path. The other 3 are very close to achieving it. Sweden also

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[11] For the choice of the functional form we employed different statistical and analytical tools, such as the *t-statistic* significance of the parameters, the Schwartz information Criteria, and taking into account if the turning point estimated is lower than the maximum level of income reached by each country.

presents the turning points within the values of the sample. Finally, there is no long run relationship between the variables involved for any functional form for 3 of them (former Czechoslovakia, Hungary, and former Soviet Union). Table 1.2 summarizes each country functional form. Table A1.1 of the Appendix summarizes the ECT estimation of equation (2) for each one of the possible functional forms

Table 1.1 - CO2 emissions and economic activity bound testing cointegration test

	Lineal[a]					Quadratic[b]					Cubic[c]				
Lags	**0**	**1**	**2**	**3**	**4**	**0**	**1**	**2**	**3**	**4**	**0**	**1**	**2**	**3**	**4**
AUS	4.09[d]	7.66**	1.02	0.80	0.72	5.12**	4.93**	1.35	0.72	0.84	2.31	0.51	2.03	1.82	NA
AUT	1.50	0.86	1.17	1.25	0.78	4.25*	2.87	3.92[d]	2.15	1.62	3.31[d]	2.10	4.11*	3.86*	2.93[d]
BEL	4.91*	2.96	2.37	1.73	0.89	9.78***	3.20[d]	2.07	1.65	1.36	9.31***	1.70	2.17	1.14	0.93
CAN	0.65	0.49	0.78	1.50	2.14	2.57	3.08	1.54	1.88	3.53[d]	2.35	3.40[d]	2.19	1.54	2.81[d]
CZE	8.01***	3.37	3.12	3.96	5.1*	4.63*	2.87	2.08	1.96	1.99	3.14[d]	1.73	1.39	0.36	0.56
DEN	2.16	2.14	1.75	1.73	1.42	9.66***	5.53**	5.84**	7.23**	3.27[d]	7.05***	4.61**	4.98**	5.79***	3.58[d]
FIN	2.82	2.63	2.81	4.54[d]	3.71	3.22[d]	2.58	2.19	1.61	1.25	2.81[d]	2.46	2.95[d]	1.90	1.32
FRA	1.21	1.49	1.55	2.17	1.69	1.84	1.79	2.07	1.78	1.01	2.22	1.53	2.51	3.03[d]	2.75[d]
GER	1.39	0.36	0.54	0.62	0.75	1.33	1.92	1.67	1.23	1.26	3.89*	2.62	2.26	2.23	0.80
GRE	4.27[d]	5.07*	6.27**	7.58**	7.45**	5.64**	6.15**	6.35**	4.43**	5.30**	2.88d	2.69	2.18	1.37	1.16
HOL	1.23	0.63	0.55	0.85	0.93	3.16	2.45	3.50[d]	2.60	2.07	2.88[d]	2.01	2.92[d]	2.52	2.07
HUN	13.01**	8.69***	2.80	4.73[d]	4.43[d]	3.84[d]	3.29[d]	0.63	0.49	0.51	3.15[d]	3.87*	1.10	2.49	1.81
IRE	1.94	2.20	4.73[d]	5.73**	8.32**	7.12***	3.86[d]	2.75	1.87	3.25[d]	7.80***	5.14**	3.34[d]	2.08	1.90
ITA	6.50**	2.85	2.75	2.54	1.78	3.67[d]	5.38**	1.75	1.98	2.31	3.10[d]	4.82**	1.72	3.17[d]	3.36[d]
JAP	1.16	3.26	1.95	1.73	1.84	2.01	4.35**	2.65	1.10	1.79	1.54	2.85[d]	1.82	2.36	2.73[d]
KOR	24.53**	12.57***	19.36**	8.56**	3.97**	21.19***	8.41***	10.20**	7.06**	3.39[d]	15.58***	6.28**	9.75***	3.50[d]	1.95
MEX	1.09	0.67	0.13	0.49	0.66	1.67	1.50	2.36	1.49	1.52	1.67	1.53	3.48[d]	2.64	3.59[d]
NOR	2.20	1.60	1.51	1.89	2.53	3.54[d]	1.30	1.62	0.82	1.54	3.22[d]	1.86	2.77[d]	2.42	1.41
NZL	2.70	2.50	1.11	2.22	2.23	2.52	2.41	2.68	2.21	3.20[d]	3.12[d]	1.72	1.63	1.80	1.96
POL	5.23**	3.26	1.72	1.54	1.46	2.38	0.82	0.50	0.03	0.06	1.93	1.59	1.06	0.42	0.46
POR	0.04	0.13	0.11	0.06	0.06	6.68***	3.69[d]	2.50	2.82	3.73[d]	6.95***	3.75[d]	2.25	3.01[d]	4.59**
SPA	0.14	0.09	0.02	0.02	0.12	3.24[d]	1.19	1.62	1.00	1.20	2.25	1.06	1.17	0.91	1.27
SWE	4.41[d]	3.58	2.83	4.43[d]	3.60	1.48	0.74	0.89	0.83	1.23	2.12	2.46	2.55	3.26[d]	2.45
SWI	1.44	0.89	2.76	4.60[d]	6.42**	5.83**	8.05***	3.82[d]	3.37[d]	2.20	5.67***	7.02**	1.57	3.14[d]	1.67
TUR	0.64	1.16	2.65	2.31	1.65	7.51***	6.86***	3.28[d]	2.17	2.88	5.14**	4.62**	2.38	2.19	3.39[d]
UK	3.97	1.61	1.89	1.70	1.33	2.61	1.65	1.86	1.36	0.83	2.16	1.43	1.70	1.22	0.70
USA	0.53	0.90	1.71	1.74	3.10	1.14	1.11	0.78	0.96	1.17	1.98	1.26	0.54	0.71	0.47
USS	4.53[d]	2.21	3.27	2.33	1.06	4.57*	1.38	2.83	1.76	0.54	3.29[d]	0.92	2.58	2.04	1.76
BRA	3.75	3.48	2.18	3.63	0.81	2.50	1.93	1.61	1.46	1.57	2.65	1.83	1.70	1.65	1.25
CHN	6.70***	3.88	4.67[d]	7.22**	5.25*	2.64	2.99	2.49	3.46[d]	3.51[d]	3.63[d]	4.39**	2.86[d]	2.78[d]	3.80*
IND	0.10	0.58	2.59	1.71	1.66	4.25*	3.82*	1.16	1.14	0.75	2.50	2.39	0.59	0.86	0.37

[a] 1% CV (6.84;7.84), 5% CV (4.98;5.73) and 10% CV (4.04;4.78)

[b] 1% CV (5.15;6.36), 5% CV (3.79;4.85) and 10% CV (3.17;4.41)

[c] 1% CV (4.29;5.61), 5% CV (4.35;3.23) and 10% CV (3.77;2.72)

***, **,* significant at 1%, 5% and 10% respectively

[d] inconclusive at 1%

Moreover, for those countries that BT did not indicate the existence of a cointegration relation (France, UK, USA and Brazil), and for those that BT did not reject it for at least one of the specifications but was not possible to estimate a satisfactory long run relationship (Germany, Mexico, New Zealand, Poland, Portugal, Spain and Turkey), a unit root analysis through the ADF statistic and a cointegration analysis through the Engle-Granger test are implemented. All the series for all the countries are I(1). Mexico is the only one for which a long run relationship does not exist for any functional form Again equation (2) is computed for those functional forms for which a long run relationship exists. Following previous criteria, there is a long run inverted-U relationship for France, Germany and USA, and linear for New Zealand, Portugal, Spain, Turkey and Brazil. Poland does not present any satisfactory specification.

Finally, the United Kingdom shows an inverted linear relationship. This is an atypical result, but it can be interpreted as evidence in favor of the EKC. The UK is one of the more ancient industrialized economies. In this way, it is reasonable to assume that because its prior to 1950 industrial maturity stage, it has faced the post war economic growth stage through less polluting processes. In this way, the UK would be on the decreasing segment of the EKC during the period of analysis[12].

Table 1.2 summarizes results, 26 of the 31 countries of the sample do not reject the existence of a long run relationship between economic activity and CO_2 emissions between 1950 and 2006 (7 linear, 17 quadratic, 1 cubic, and 1 inverted linear). The result obtained confirms the existence of different relationships even among countries with similar activity levels. The fact that for some countries no long term relation was found can be consequence of data reliability, as may be the case of the countries that were members of the COMECON (former Czechoslovakia, Hungary, Poland and former Soviet Union), or because of an anomalous behavior at the end of the period in the case of Mexico, as a consequence of the crisis it experienced in 1994.

Comparing these results with other analyses for the same pollutant for individual countries, they are consistent with the ones of Iwata et al. (2010b) for France (for the period 1960–2003), Jalil and Feridun (2011) for China (1953 – 2006), and Iwata et al.

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[12] Individual countries charts distinguishing between short-run and long-run relationships and the results from the unit roots and cointegration tests are available from the authors upon request.

(2010a) for Finland (1977–2003) and Japan (1966–2003). The last one tests —and obtains positive evidence of— the existence of a quadratic path for South Korea (1977–2003) and Spain (1968–2003), in contrast with the linear model supported by our results. Both works quoted take into account the share of nuclear power in total energy generation for each country. However, the linear specification for Spain is consistent with Roca and Padilla (2003) for the period 1980–2000, who also included factors referred to the energy sources structure.

Table 1.2 - Summary of long term relationship estimation

Model	Country	Decision Method
Linear	BRA	EG
	GRE	BT
	KOR	BT
	NZL	EG
	POR	EG
	SPA	EG
	TUR	EG
	UK*	EG
Quadratic	AUS	BT
	AUT	BT
	BEL	BT
	CAN	BT
	CHN	BT
	DEN	BT
	FIN	BT
	FRA	EG
	GER	EG
	HOL	BT
	IND	BT
	IRE	BT
	ITA	BT
	JAP	BT
	NOR	BT
	SWI	BT
	USA	EG
Cubic	SWE	BT
No relation	CZE	BT
	HUN	BT
	MEX	EG
	POL	EG
	USS	BT

* inverted linear

In contrast with our results, Friedl and Getzner (2003) found a cubic relationship for Austria (1960–1999), introducing the weight of imports and industry in total income.

Haciloglu (2008) also found a different path from ours for Turkey (1960–2005), specifying a cubic functional form introducing the consumption of commercial energy and open grade, contrary to the linear one estimated here. However, analyzing the adjustment of Haciloglu’s model, it seems that it approaches a linear relation through a cubic path but with a tiny decreasing section. Egli (2004) specifies a linear functional form for Germany (1966–1999), including industry participation in product and open grade, in contrast with the quadratic form found by us. The differences in the results may be mainly due to the longer time period considered in our work, and to the fact that some of the above mentioned works include other independent variables that might be conditioning the functional form.

As mentioned above, different functional forms of the relationship between economic activity and carbon dioxide emissions for countries with similar economic activity levels mean that the various variables that modulate the relationship have different intensity in different countries. In those countries with a linear functional form the scale effect —the impact of production growth on emissions— is stronger, while there are countries with similar activity levels where the changes in the composition of production and technological improvements (or other variables, such as international trade, institutional factors, etc.) might have helped to diminish emissions while continued economic growth. This chapter shed lights over which kind of relationship must be explained for each country, and is a kick off for analyzing the determinants of similar paths.

1.4.2 Homogeneity of the parameters and the turning point

Homogeneity of the parameters for models with linear and quadratic functional form is carried out separately. The homogeneity of the ECT parameter analysis can be done jointly for all the countries. CI overlaps are depicted in Figures 1.1 to 1.4[13].

The parameters of the long run relationship depict the reaction (elasticity) of carbon dioxide emissions to variations in economic activity (because the model specification is in logarithms). In this way, heterogeneity in the long run parameters means that the emissions of the different countries do not respond in the same way to activity level

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[13] The results are similar constructing 90% and 99% CI.

variations. As we mentioned above, this is an apparent relation analysis, and a next step would be to study the real determinants that explain each coefficient and functional form. In any case, we can conclude from this research that similar levels of economic activity have dissimilar impact on carbon dioxide emissions in different countries.

For those countries that follow a linear functional form, the analysis rejects at 95% confidence the existence of groups of more than 2 countries with the same parameters (3 at 99%) (Figure 1.1). This means that while for all countries of this group economic growth has a direct impact on emissions, this impact —the elasticity of emissions to growth in economic activity— is not equal among them. For example, an increase in the economic activity level of Korea is associated to a lower increase in pollution than the same increase in Turkey. The factors that explain this difference must be explored avoiding the assumption that they are the same for all countries.

Figure 1.1: CI 95% - Linear Model

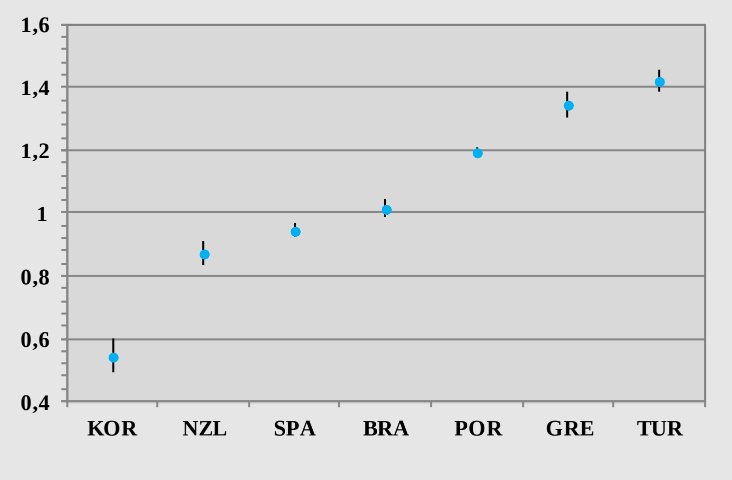


Figure 1.2: CI 95%- Quadratic Model

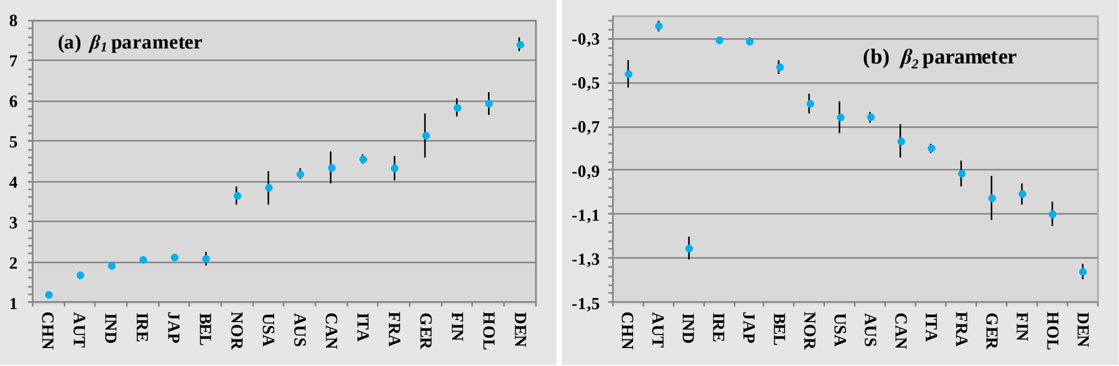


Figure 1.3: CI 95% - Long run relationship adjustment coefficient

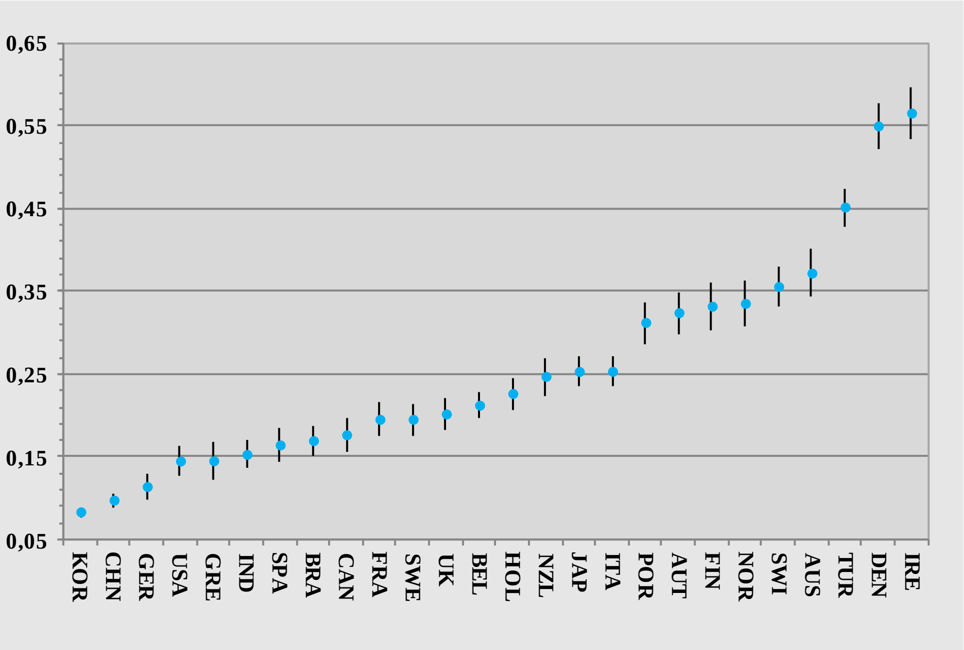
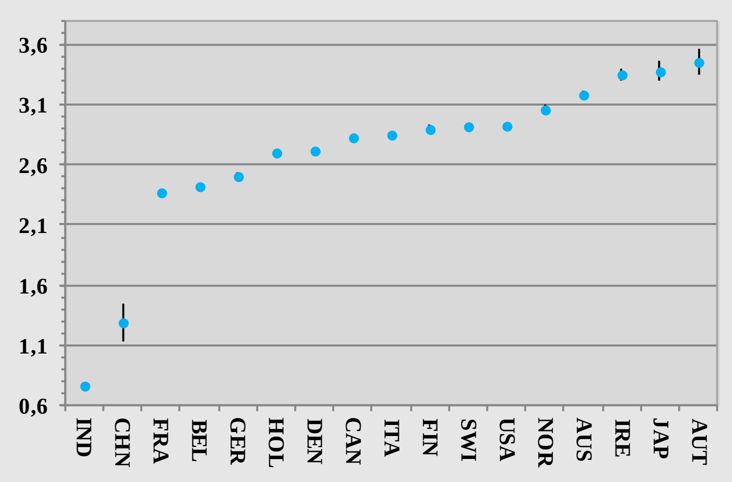


Figure 1.4: CI 95% - Turning Point



For those that the quadratic path fits better, different long run relationship parameters also means differences in emissions elasticity, but in this case, concavity of the curve is also considered. That is, variations of emissions in reference to variations in economic activity can be different among countries both in the increasing stage, as well as in the rate that they decrease when reaching the turning point. The β_1 parameter could be interpreted as the impact of the scale effect—direct relationship between the increase in the level of economic activity and emissions—while β_2 would indicate emissions deceleration due to other factors when the level of economic activity increases. For example, comparing the cases of China and Denmark, in the later case both estimated parameters are greater (in absolute terms). This indicates that the shape of the apparent relationship between emissions and GDP per capita in the case of Denmark would have a steeper slope and a faster deceleration, while in the case of China the inverted-U shape would be flatter. Parameter homogeneity of the long run quadratic relation is rejected for any possible group with more than 4 countries at 95% CI (5 at 99%) (Figure 1.2a and Figure 1.2b)[14]. This result is consistent with the ones of Dijkgraaf and Vollebergh (2005), Martínez-Zarzoso and Bengochea-Morancho (2003 and 2004), Dijkgraaf et al. (2005), Cole (2005) and Musolesi et al. (2010).

The ECT can be interpreted as the change in pollution that is attributed to the disequilibrium between the actual and the equilibrium models. That is, ECT differences between countries means that they react different to last period deviations from the long run relationship and some countries will take more periods than others to adjust to it. In the light of the above estimates, for example, when China (α=-0.10) deviates from the long run equilibrium relationship, it would take ten years to return to it, while Denmark (α=-0.55) only would need a little bit less than two years. Equality in the ECT adjustment parameter among countries is rejected for any group of countries with more than 8 countries at 95% confidence (10 at 99%) (Figure 1.3). This means that short-run deviations from their respectively long run relationships take different time periods to adjust among countries.

In summary, the relation between economic activity and carbon dioxide emissions is different among countries, both in functional form and the parameters of the long run relation of countries with same functional form. In no cases have we found any group of countries with more than five members with homogeneous parameters.

In spite of this, it is interesting to study if the turning points occur for the same level of economic activity, since it could be that some countries achieved it for the same level despite presenting different paths. This test is run for those countries showing an inverted-U form. Figure 1.4 shows that turning point equality for all the countries is

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[14] Switzerland was excluded from the figure because it presents atypical values, while Sweden and UK are not included because their functional form is unique.

clearly rejected, and there are no groups with more than 4 countries at 95% confidence (5 at 99%).

This means that countries that experienced an inverted-U path reached the maximum level of emissions for different economic activity levels. It must be highlighted that, despite the results reject an identical turning point for the whole sample of countries, there are some groups of countries for which this hypothesis is not rejected, even though the long run relation parameters were different among them. For example, Canada, USA, Finland, Italy and Switzerland are countries with different paths, but present statistically homogeneous turning points (they achieved it at the same threshold). If it were possible to generalize this result to the all countries, this would mean that policies must focus on avoiding high environmental non reversible damages. Other cases are Ireland, Japan and Austria, and Denmark and The Netherlands.

Therefore, the questions to beg here are first, what are the factors explaining paths homogeneity for some countries, and second, what are the determinants that make countries with heterogeneous paths achieve the maximum level of emissions for the same activity level.

1.5 Conclusions

The present chapter supports the existence of a long run relationship between CO_2 emissions and GDP per capita for 26 of the 31 countries over the period 1950–2006. However, the functional form specification of these relationships is not homogeneous, being 7 linear, 17 quadratic, 1 cubic and 1 inverted linear. Moreover, the equality of the elasticities of the long run relationship for different countries is not supported, independently of the functional form. Finally, the assumption of an equal turning point for countries showing an inverted-U relationship is also rejected. Nonetheless, it might be noted that there are cases in which countries with different paths achieve the turning point for a similar GDP per capita level.

The contribution of the present chapter is three fold. First, it reinforces that we must be cautious about studies that carry out the estimations of the relation between CO_2 emissions and economic activity without considering that the series are non stationary (Grossman and Krueger, 1991 and 1995; Shafik and Bandyopadhyay, 1992; Carson et al. 1997; Cole et al. 1997; Vincent, 1997; de Bruyn et al., 1998; and Hung and Shaw, 2004). We reject the existence of a long run relationship between CO_2 emissions and economic activity level for some countries (former Czechoslovakia, Hungary, Mexico, Poland, and former Soviet Union). Not considering this problem, above quoted works might include countries for which the relation is a spurious one.

Second, we rejected the assumption of equal functional form and parameters among countries (or regions). This is not tested in most studies (Grossman and Krueger, 1991 and 1995; Shafik and Bandyopadhyay, 1992; Selden and Song, 1994; Carson et al. 1997; Cole et al. 1997 and Vincent, 1997; Hung and Shaw, 2004 and Song et al., 2008). Therefore, panel data of countries (or regions) works that do not test for differences in the relationship among countries should be taken with a grain of salt, because assuming this restriction may lead to consider countries with the same GDP per capita level but different paths in the same way, or to wrongly assume that they will reach the turning point for the same GDP per capita level. In this way, we support the argument stated by de Bruyn et al. (1998) stipulating that in order to distinguish possible benefits stemming from economic activity growth in environmental quality, the study should focus on the analysis of the relationship between these factors at single country level. In this way, the functional form homogeneity analysis helps to identify countries with similar paths, and can give clues about which are their determinants.

The results of the present research are consistent with previous related literature (Dijkgraaf and Vollebergh, 2005; Martínez-Zarzoso and Bengochea-Morancho, 2003 and 2004; Cole, 2005; and Musolesi et al., 2010) on the problematic assumption of parameters and functional form homogeneity of the long run relation between CO_2 emissions and economic activity level, both per capita, employing a longer period sample, and estimating single country relationships for each relevant functional form. The greater degree of overlapping is an important improvement, specially for analyzing functional forms homogeneity, because it extends the overlap between more and less developed countries. This is highlighted by the fact that different functional forms are found for countries with similar level of economic activity.

Following Carson (2010), this result rejects the optimistic view of the EKC, where developing countries might ignore environmental problems until they become developed. Developed countries can and have to consider this problem, since nothing guarantees a path as the one of the EKC for all countries (and neither the existence of a common path for them) (Dasgupta et al., 2002). Example of this is the case of France and Spain, which for similar levels of economic activity show a different relationship.

Finally, the assumption that the different countries showing an inverted-U relationship have the same turning point is rejected. However, there are groups of countries with different elasticities but similar turning points (but the level of emissions achieved in this point might be different). Moreover, there are some emergent countries, like China and India, which show a long run inverted-U relationship with lower turning points than the ones of the developed countries showing inverted-U relationships. This may lead to a less pessimistic interpretation of the results, in the sense that the long term relationship between emissions and economic activity can start decreasing from lower levels of economic activity (and environmental degradation) than the ones reached by developed countries. Although this is not strong evidence in favor of the optimistic view of the EKC, it suggests that it would be interesting to analyze the determinants for these countries.

In any case, results above clearly deny that economic growth will automatically drive to an EKC. Even less that the turning point will be achieved for reasonable pollution levels. This would depend on the real determinants behind the relationship, where energy and environmental policies, institutions, and trade play an important role. We explicitly define the functional form of the apparent long run relation for each country. This would help to think over the policy instruments design involving countries with similar economic levels but different paths.

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Appendix

Table A1.1 - Error Correction Term - ECM cubic, quadratic and linear model

	AUS			AUT			BEL			CAN			CZE			DEN		
	Cubic	Quad.	Linear	Cubic	Quad.	Linear	Cubic	Quad.	Linear	Cubic	Quad.	Linear	Cubic	Quad.	Linear	Cubic	Quad.	Linear
ADRL	(0,0,0,0)	(0,0,0)	(1,1)	(0,2,2,2)	(0,0,0)	(0,0)	(0,0,0,0)	(0,0,0)	(0,0)	(0,0,0,0)	(0,0,0)	(0,3)	(1,0,0,0)	(0,0,0)	(1,1)	(0,0,0,0)	(0,0,0)	(0,1)
alfa	-0.45	-0.37	-0.07	-0.30	-0.32	-0.04	-0.19	-0.21	-0.13	-0.16	-0.18	-0.09	0.01	-0.02	0.01	-0.53	-0.55	-0.11
t-statistic	*-3.47*	*-3.38*	*-1.92*	*-2.73*	*-3.32*	*-1.29*	*-2.59*	*-3.52*	*-1.89*	*-2.10*	*-2.30*	*-1.73*	*0.27*	*-0.79*	*0.42*	*-4.52*	*-4.96*	*-1.84*
C	-9.40	-3.13	-9.43	-9.89	-6.08	0.37	-6.48	-6.75	-9.19	21.29	-3.60	-8.52	11.21	-8.60	0.01	5.14	0.69	-8.48
t-statistic	*-1.95*	*-5.01*	*2.04*	*-3.11*	*-14.14*	*1.31*	*-6.04*	*-9.22*	*-39.02*	*0.99*	*-1.92*	*-19.24*	*2.99*	*-0.88*	*0.00*	*0.63*	*0.81*	*-9.23*
GDPPC(-1)	3.26	-4.18	0.00	1.84	-1.68	0.00	-2.59	-2.08	-0.06	-33.57	-4.35	-0.32	-7.11	-5.03	-5.60	-12.75	-7.40	-0.19
t-statistic	*0.57*	*-8.43*	*0.08*	*0.45*	*-4.37*	*0.00*	*-1.82*	*-3.49*	*-0.65*	*-1.34*	*-2.91*	*-1.90*	*-1.11*	*-0.59*	*-0.47*	*-1.29*	*-10.84*	*-0.55*
GDPPC^2(-1)	-2.25	0.66		-0.72	0.24		0.72	0.43		12.07	0.77		5.81	2.26		3.47	1.36	
t-statistic	*-1.01*	*6.77*		*-0.41*	*2.88*		*1.01*	*3.40*		*1.26*	*2.64*		*1.63*	*0.90*		*0.89*	*10.18*	
GDPPC^3(-1)	0.37			0.07			-0.05			-1.44			-1.34			-0.27		
t-statistic	*1.31*			*0.27*			*-0.43*			*-1.19*			*-2.07*			*-0.54*		
Interventions																		
Step															1970			
Impulse																		
Turning Point	3.07	3.19		5.36	3.46		2.39	2.42		2.61	2.83		0.88	1.11		2.70	2.72	
	0.95			1.68			7.15			2.97			2.01			5.75		
Schwartz iC	-3.84	-4.03	-3.86	-2.68	-3.10	-3.86	-3.14	-3.21	-2.97	-3.43	-3.46	-3.49	-3.51	-3.81	-3.71	-2.15	-2.21	-1.86
JB	1.08	0.83	0.58	0.45	0.75	0.75	0.10	0.32	0.72	2.07	1.97	4.72	4.78	5.44	7.56	1.16	0.85	1.13
p-value	*0.58*	*0.66*	*0.75*	*0.80*	*0.69*	*0.69*	*0.95*	*0.85*	*0.70*	*0.36*	*0.37*	*0.09*	*0.09*	*0.07*	*0.02*	*0.56*	*0.66*	*0.57*
BG (4 lags)	0.03	0.18	0.18	1.82	2.02	2.08	1.08	0.76	0.38	0.34	0.90	1.07	0.89	2.07	1.95	2.44	2.09	2.34
p-value	*1.00*	*0.95*	*0.95*	*0.14*	*0.11*	*0.10*	*0.38*	*0.56*	*0.82*	*0.85*	*0.47*	*0.39*	*0.48*	*0.10*	*0.12*	*0.06*	*0.10*	*0.07*
TP in the sample		YES			NO			YES			YES			YES			YES	

	FIN			FRA			GER			GRE			HOL			HUN		
	Cubic	Quad.	Linear	Cubic	Quad.	Linear	Cubic	Quad.	Linear	Cubic	Quad.	Linear	Cubic	Quad.	Linear	Cubic	Quad.	Linear
ADRL	(0,0,0,0)	(0,0,0)	(0,0)	(0,0,0,0)	(0,0,0)	(0,0)	(0,0,0,0)	(0,0,0)	(0,0)	(0,0,0,0)	(0,0,0)	(0,0)	(0,0,0,0)	(0,0,0)	(0,0)	(0,0,0,0)	(0,0,0)	(3,3)
alfa	-0.33	-0.33	-0.09	-0.31	-0.20	-0.06	-0.26	-0.11	-0.04	-0.26	-0.19	-0.14	-0.20	-0.23	-0.02	-0.16	-0.11	0.01
t-statistic	*-3.02*	*-3.02*	*-1.68*	*-2.71*	*-2.47*	*-1.60*	*-2.49*	*-1.75*	*-1.16*	*-2.44*	*-2.41*	*-1.68*	*-2.43*	*-3.10*	*-0.48*	*-2.10*	*-1.90*	*0.26*
C	2.92	-0.90	-7.44	4.10	-3.90	-7.46	-1.64	-2.88	-9.80	-5.28	-4.69	-5.78	-20.04	-1.36	-10.55	21.29	-8.24	6.09
t-statistic	*0.60*	*-0.93*	*-6.48*	*0.72*	*-2.92*	*-7.07*	*-0.20*	*-1.01*	*-7.94*	*-6.94*	*-12.62*	*-15.05*	*-1.86*	*-1.05*	*-1.59*	*0.99*	*-3.43*	*0.12*
GDPPC(-1)	-11.44	-5.84	-0.64	-13.61	-4.34	-0.26	-6.55	-5.14	0.36	-1.73	-2.72	-1.35	14.98	-5.94	0.54	-33.57	-1.10	-9.03
t-statistic	*-1.70*	*-6.94*	*-1.44*	*-1.73*	*-3.81*	*-0.86*	*-0.67*	*-2.44*	*0.67*	*-1.05*	*-4.68*	*-9.18*	*1.16*	*-5.48*	*0.21*	*-1.34*	*-0.42*	*-0.28*
GDPPC^2(-1)	3.65	1.01		4.64	0.91		1.37	1.03		-0.14	0.39		-6.40	1.10		12.07	0.44	
t-statistic	*1.21*	*5.57*		*1.32*	*3.86*		*0.35*	*2.60*		*-0.14*	*2.13*		*-1.26*	*4.96*		*1.26*	*0.60*	
GDPPC^3(-1)	-0.40			-0.53			0.00			0.09			0.87			-1.44		
t-statistic	*-0.92*			*-1.05*			*0.00*			*0.49*			*1.32*			*-1.19*		
Interventions																		
Step														1982	1982			
Impulse																	1956	
Turning Point	imag.	2.90		imag.	2.37		2.40	2.51		3.11	3.45		3.00	2.70		2.61	1.26	
	imag.			imag.			1147.68			-2.08			1.92			2.97		
Schwartz iC	-1.61	-1.67	-1.59	-1.57	-2.83	-3.02	-3.80	-3.85	-3.91	-2.82	-2.92	-2.81	-2.82	-3.09	-2.77	-3.43	-2.98	-2.84
JB	2.01	1.25	1.13	3.36	1.56	0.34	1.47	0.26	0.48	0.48	1.91	0.45	4.96	7.87	9.06	2.07	7.00	0.26
p-value	*0.37*	*0.53*	*0.57*	*0.19*	*0.46*	*0.84*	*0.48*	*0.88*	*0.79*	*0.78*	*0.39*	*0.80*	*0.08*	*0.02*	*0.01*	*0.36*	*0.03*	*0.88*
BG (4 lags)	0.29	0.07	2.34	2.11	0.49	2.37	1.46	1.26	1.37	1.09	2.19	0.36	1.22	0.87	0.88	0.34	2.59	0.28
p-value	*0.88*	*0.99*	*0.07*	*0.09*	*0.74*	*0.07*	*0.23*	*0.30*	*0.26*	*0.37*	*0.08*	*0.84*	*0.32*	*0.49*	*0.48*	*0.85*	*0.05*	*0.89*
TP in the sample		YES			YES			YES			NO			YES			YES	

Table A1.1 - Error Correction Term - ECM cubic, quadratic and linear model

	IRE			ITA			JAP			KOR			MEX			NOR		
	Cubic	Quad.	Linear	Cubic	Quad.	Linear	Cubic	Quad.	Linear	Cubic	Quad.	Linear	Cubic	Quad.	Linear	Cubic	Quad.	Linear
ADRL	(0,1,1,0)	(0,0,0)	(3,2)	(0,0,0,0)	(1,0,0)	(0,0)	(4,3,3,3)	(0,1,0)	(1,1,0)	(3,3,0,0)	(0,0,0)	(2,2)	(2,1,1,1)	(2,0,0)	(2,0)	(0,2,2,2)	(0,0,0)	(0,1)
alfa	-0.70	-0.57	-0.04	-0.15	-0.25	-0.04	-0.37	-0.25	-0.09	0.02	-0.10	-0.08	-0.24	-0.17	-0.12	-0.48	-0.34	-0.11
t-statistic	*-5.56*	*-4.58*	*-0.50*	*-1.96*	*-3.68*	*-1.32*	*-4.33*	*-3.64*	*-2.48*	*0.32*	*-2.54*	*-3.59*	*-3.30*	*-2.83*	*-2.14*	*-4.34*	*-3.19*	*-1.64*
C	-2.84	-5.94	-11.10	0.00	-2.45	-8.63	-6.96	-5.61	-5.58	7.50	-7.18	-7.44	-12.31	-3.87	-5.80	3.11	-3.49	-7.32
t-statistic	*-3.51*	*-28.65*	*-1.52*	*0.00*	*-5.51*	*-3.29*	*-7.82*	*-24.90*	*-10.14*	*0.19*	*-11.31*	*-17.48*	*-4.73*	*-3.28*	*-20.82*	*0.51*	*-3.14*	*-11.98*
GDPPC(-1)	-6.52	-2.06	1.44	-9.33	-4.56	-0.04	-1.21	-2.12	-1.13	-23.64	-1.45	-0.54	13.45	-4.34	-1.34	-12.86	-3.65	-0.66
t-statistic	*-5.52*	*-10.62*	*0.34*	*-1.43*	*-11.70*	*-0.04*	*-0.87*	*-8.50*	*-7.29*	*-0.38*	*-3.16*	*-2.80*	*2.35*	*-2.51*	*-8.18*	*-1.82*	*-4.03*	*-3.09*
GDPPC^2(-1)	2.29	0.31		3.30	0.80		0.20	0.31		13.01	0.24		-11.06	1.05		4.78	0.60	
t-statistic	*4.18*	*6.79*		*1.04*	*9.10*		*0.29*	*4.91*		*0.37*	*1.93*		*-2.72*	*1.77*		*1.76*	*3.32*	
GDPPC^3(-1)	-0.27			-0.40			-0.02			-2.48			2.67			-0.62		
t-statistic	*-3.35*			*-0.81*			*-0.14*			*-0.36*			*2.84*			*-1.80*		
Interventions																		
Step																		
Impulse																		2006
Turning Point	imag. imag.	3.36		imag. imag.	2.85		imag. imag.	3.38		imag. imag.	3.05		1.85 0.91	2.07		imag. imag.	3.06	
Schw artz iC	-2.44	-2.36	-2.15	-3.52	-3.65	-3.66	-3.10	-3.12	-3.59	-2.75	-2.59	-3.16	-2.83	-2.89	-2.98	-1.62	-1.72	-1.69
JB	1.95	4.18	0.18	2.72	1.37	2.05	0.74	0.39	7.21	0.13	1.94	1.09	5.53	6.38	4.27	0.95	7.80	0.59
p-value	*0.38*	*0.12*	*0.92*	*0.26*	*0.50*	*0.36*	*0.69*	*0.82*	*0.03*	*0.94*	*0.38*	*0.58*	*0.06*	*0.04*	*0.12*	*0.62*	*0.02*	*0.75*
BG (4 lags)	0.85	0.76	1.63	0.60	0.53	0.63	3.11	2.32	1.88	1.31	0.89	0.53	1.79	0.49	1.21	0.88	2.69	2.30
p-value	*0.50*	*0.56*	*0.19*	*0.67*	*0.71*	*0.64*	*0.03*	*0.07*	*0.13*	*0.28*	*0.48*	*0.71*	*0.15*	*0.74*	*0.32*	*0.48*	*0.04*	*0.07*
TP in the sample		NO			YES			YES			NO			NO			YES	

	NZL			POL			POR			SPA			SWE			SWI		
	Cubic	Quad.	Linear	Cubic	Quad.	Linear	Cubic	Quad.	Linear	Cubic	Quad.	Linear	Cubic	Quad.	Linear	Cubic	Quad.	Linear
ADRL	(0,0,0,0)	(0,0,0)	(0,0)	(0,0,0,0)	(0,0,0)	(0,0)	(0,0,0,0)	(0,0,0)	(1,0)	(0,0,0,0)	(0,0,0)	(0,0)	(0,0,0,0)	(0,0)	(0,0)	(1,1,1,1)	(0,0,0)	(0,1)
alfa	-0.34	-0.26	-0.25	0.03	0.03	0.00	-0.57	-0.55	-0.31	-0.29	-0.31	-0.16	-0.20	-0.14	-0.06	-0.38	-0.36	-0.04
t-statistic	*-3.40*	*-2.66*	*-2.80*	*0.78*	*0.66*	*0.03*	*-3.82*	*-3.79*	*-3.21*	*-3.48*	*-3.93*	*-2.15*	*-2.62*	*-2.00*	*-1.57*	*-2.51*	*-3.80*	*-0.74*
C	-64.77	-7.07	-6.50	-2.18	-0.31	93.13	-5.58	-5.82	-5.58	-5.54	-5.94	-6.42	44.63	-0.58	-11.72	41.20	14.38	-8.87
t-statistic	*-2.64*	*-2.20*	*-20.50*	*-0.44*	*-0.04*	*0.02*	*-14.23*	*-46.03*	*-61.00*	*-6.34*	*-26.10*	*-34.58*	*2.00*	*-0.14*	*-4.90*	*0.85*	*5.29*	*-1.72*
GDPPC(-1)	70.12	-0.43	-0.87	-6.77	-8.76	-66.08	-1.37	-0.90	-1.20	-2.39	-1.63	-0.95	-61.52	-7.17	1.07	-42.33	-15.80	0.17
t-statistic	*2.33*	*-0.16*	*-6.91*	*-1.41*	*-1.14*	*-0.03*	*-1.77*	*-5.18*	*-30.44*	*-1.48*	*-6.08*	*-12.61*	*-2.26*	*-2.30*	*1.18*	*-0.81*	*-8.00*	*0.09*
GDPPC^2(-1)	-28.66	-0.09		1.63	2.19		0.21	-0.08		0.61	0.19		23.04	1.50		11.32	2.70	
t-statistic	*-2.34*	*-0.17*		*1.23*	*1.14*		*0.45*	*-1.65*		*0.69*	*2.63*		*2.11*	*2.48*		*0.61*	*7.56*	
GDPPC^3(-1)	3.83			0.33			-0.06			-0.07			-2.82			-0.92		
t-statistic	*2.32*			*0.60*			*-0.64*			*-0.48*			*-1.96*			*-0.42*		
Interventions																		
Step					1981, 1990	1981, 1990												
Impulse																		
Turning Point	2.83 2.16	-2.44		1.44 -4.72	2.00		imag. imag.			imag. imag.	4.27		2.33 3.12	2.39		2.87 5.36	2.92	
Schw artz iC	-2.83	-2.81	-2.87	-3.72	-3.80	-3.47	-2.66	-2.72	-2.84	-2.74	-2.81	-2.80	-2.23	-2.23	-2.26	-2.61	-2.74	-2.45
JB	3.94	1.55	0.95	4.60	3.76	1.54	1.30	1.67	0.43	2.40	2.22	0.41	0.72	1.01	0.69	0.64	0.67	0.64
p-value	*0.14*	*0.46*	*0.62*	*0.10*	*0.15*	*0.46*	*0.52*	*0.43*	*0.81*	*0.30*	*0.33*	*0.81*	*0.70*	*0.60*	*0.71*	*0.73*	*0.72*	*0.73*
BG (4 lags)	1.08	0.50	1.04	1.80	1.99	2.17	1.38	1.22	0.49	1.76	1.86	1.01	0.93	0.86	0.82	1.55	3.28	2.26
p-value	*0.38*	*0.74*	*0.40*	*0.15*	*0.11*	*0.09*	*0.25*	*0.31*	*0.74*	*0.15*	*0.13*	*0.41*	*0.45*	*0.50*	*0.52*	*0.21*	*0.02*	*0.08*
TP in the sample		YES			YES			YES			NO			YES			YES	

Table A1.1 - Error Correction Term - ECM cubic, quadratic and linear model

	TUR			UK			USA			USS			BRA			CHN			IND		
	Cubic	Quad.	Linear	Cubic	Quad.	Linear	Cubic	Quad.	Linear	Cubic	Quad.	Linear	Cubic	Quad.	Linear	Cubic	Quad.	Linear	Cubic	Quad.	Linear
ADRL	(0,0,0,0)	(0,0,0)	(0,0)	(0,0,0,0)	(0,0,0)	(0,0)	(0,0,0,0)	(0,0,0)	(0,0)	(1,2,2,2)	(1,0)	(1,0)	(0,0,0,0)	(4,4,0)	(0,0)	(1,1,0,0)	(1,1,1)	(1,1)	(0,0,0,0)	(0,0,0)	(0,0)
alfa	-0.24	-0.45	-0.16	-0.40	-0.22	-0.20	-0.17	-0.14	-0.05	0.03	-0.09	-0.06	-0.04	-0.07	-0.17	-0.16	-0.10	-0.06	-0.15	-0.15	0.01
t-statistic	*-1.51*	*-4.14*	*-1.79*	*-3.59*	*-2.18*	*-2.63*	*-2.37*	*-2.06*	*-1.47*	*0.43*	*-2.09*	*-1.56*	*-0.43*	*-0.77*	*-2.37*	*-4.13*	*-2.91*	*-2.45*	*-2.34*	*-2.38*	*0.24*
C	-5.14	-4.62	-5.52	-0.41	-9.47	-9.76	27.26	-4.31	-9.10	51.12	-7.45	-7.77	-9.85	-5.37	-5.70	-7.24	-6.94	-6.66	-6.57	-6.57	-0.13
t-statistic	*-4.80*	*-31.12*	*-26.46*	*-0.08*	*-7.67*	*-68.43*	*1.26*	*-1.94*	*-19.65*	*0.42*	*-4.35*	*-15.70*	*-0.71*	*-4.61*	*-35.68*	*-71.38*	*-41.36*	*-26.18*	*-55.43*	*-57.39*	*-0.01*
GDPPC(-1)	-1.92	-2.80	-1.42	-10.82	-0.01	0.24	-37.70	-3.85	-0.12	-127.59	-1.26	-0.85	9.15	-3.28	-1.02	-1.11	-1.19	-0.69	-1.90	-1.91	-2.29
t-statistic	*-0.65*	*-11.02*	*-11.40*	*-1.83*	*-0.01*	*3.95*	*-1.64*	*-2.42*	*-0.76*	*-0.48*	*-0.57*	*-2.86*	*0.26*	*-1.12*	*-9.67*	*-7.47*	*-4.23*	*-2.54*	*-15.05*	*-22.94*	*-0.64*
GDPPC^2(-1)	-0.17	0.51		4.27	0.05		12.65	0.66		89.47	0.12		-10.90	1.20		1.45	0.46		1.28	1.25	
t-statistic	*-0.07*	*5.15*		*1.81*	*0.24*		*1.56*	*2.33*		*0.47*	*0.17*		*-0.31*	*0.79*		*5.18*	*1.95*		*4.14*	*6.42*	
GDPPC^3(-1)	0.19			-0.55			-1.40			-20.65			3.75			-0.71			-0.06		
t-statistic	*0.30*			*-1.75*			*-1.49*			*-0.47*			*0.33*			*-3.91*			*-0.13*		
Interventions																					
Step									1970							1958	1958	1958			
Impulse																			1977	1977	1977
Turning Point	2.20	2.72		2.16	0.05		2.74	2.93		1.28	5.07		1.32	1.36		imag.	1.29		0.78	0.76	
	-1.58			3.06			3.26			1.60			0.62			imag.			13.18		
Schwartz iC	-2.44	-2.97	-2.79	-3.91	-4.03	-4.10	-3.91	-3.93	-4.69		-4.05	-4.15	-2.82	-2.88	-3.34	-2.40	-2.26	-2.33	-4.12	-4.19	-4.13
JB	1.32	0.21	0.63	0.02	0.35	0.43	0.68	1.30	1.73	4.12	0.74	0.43	0.46	0.75	1.31	3.41	7.79	3.57	2.44	2.29	1.42
p-value	*0.52*	*0.90*	*0.73*	*0.99*	*0.84*	*0.81*	*0.71*	*0.52*	*0.42*	*0.13*	*0.69*	*0.81*	*0.79*	*0.69*	*0.52*	*0.18*	*0.02*	*0.17*	*0.29*	*0.32*	*0.49*
BG (4 lags)	0.22	0.26	0.61	0.26	0.22	0.23	0.54	1.25	0.47	0.61	0.57	1.37	1.75	1.78	2.29	2.03	0.39	0.62	2.68	2.69	2.32
p-value	*0.93*	*0.90*	*0.66*	*0.90*	*0.93*	*0.92*	*0.71*	*0.30*	*0.75*	*0.66*	*0.69*	*0.26*	*0.16*	*0.15*	*0.07*	*0.11*	*0.82*	*0.65*	*0.04*	*0.04*	*0.07*
TP in the sample		NO			YES			YES			NO			YES			YES			YES	

Part II

Economic structure and the environment: an analysis from a national perspective

Chapter 2

ECONOMIC STRUCTURE AND KEY SECTORS ANALYSIS OF GREENHOUSE GAS EMISSIONS IN URUGUAY

Abstract

This chapter identifies the key sectors in greenhouse gas emissions of the Uruguayan economy through input–output analysis. In order to guide mitigation policy design, we decompose each sector’s responsibility into the pollution generated through its own production process and the pollution indirectly generated in the production processes of other sectors. In addition, the role of external demand is analyzed.

The results show that all the key polluting sectors are important because of their own emissions, except for the Motor vehicles and oil retail trade sector, which has significant CO_2 emissions because of both its pure backward and forward linkages. Moreover, very indirect effects are found through Building, and Hotels and restaurants. Also, Financial intermediation may be relevant for the design of mechanisms to encourage cleaner production. Finally, external demand is the main driver for methane and nitrous oxide emissions, while carbon dioxide emissions are mainly driven by domestic demand.

2.1 Introduction

During the Rio Summit of 1992, the attending countries drew up the United Nations Framework Convention on Climate Change, to cooperatively limit average global temperature increases and the resulting climate change, and to cope with the impacts of these. Five years later the Kyoto Protocol was adopted, legally binding developed countries (Annex B) to emission control targets. The Protocol's first commitment period ended in 2012. At the 17th session of the Conference of the Parties (COP17), in Durban in 2011, governments of the parties to the Kyoto Protocol decided to start a second commitment period, from 2013 onwards, whose length is to be determined. However, in 2007, the Bali Action Plan called for developing countries to implement nationally appropriate mitigation actions (NAMAs) in a measurable, reportable, and verifiable manner. Also, the 2012 Rio+20 Conference final report not only calls on parties to fully implement their commitments, but also "*calls for the widest possible cooperation by all countries and their participation in an effective and appropriate international response, with a view to accelerating the reduction of global greenhouse gas emissions*" (United Nations, 2012, p. 37).

The productive structure plays a salient role in the relationship between the economy and the environment. Input–output (IO) analysis extended to the environmental dimension allows for a more complete understanding of the relationship between the economy and material flows, which is essential for fully understanding environmental problems and designing policies to solve them (Hoekstra, 2005). Rasmussen (1952) proposed IO analysis to measure structural interdependence through backward and forward inter-sectoral linkages. Hirschman (1958) suggested using this concept to identify key sectors in the economy, arguing that economic development and structural change are driven by sectors with above-average linkages. Thus, a relatively small number of sectors, whose first impulse may produce small changes, may ultimately strongly affect the economy as a whole.

Sectors with greater linkages generate greater externalities, meriting government intervention (Jones, 1976). Thus, key sectors analysis extended to the environmental dimension makes it possible to allocate sector responsibility regarding resource depletion and environmental degradation. This would be useful for mitigation policy design, and identifying which sectors would be involved and how they are related to other sectors.

Methane emissions and nitrous oxide represent 83% of total Uruguayan greenhouse gases (GHGs), with Cattle farming being the main direct polluting sector. Carbon dioxide emissions represent 16.6% of total GHG emissions, and the main direct polluters are the transport-related sectors (43.2%). In this context, it is relevant to analyze whether these sectors pollute just to satisfy their final demand, or because other sectors need their production. Key sectors analysis in GHG emissions in Uruguay—both in terms of demand and supply and taking into account the weight of the sectors in the economy—will help to allocate emissions' responsibility to productive sectors.

It would also be important to analyze the emissions embodied in Uruguayan international trade. The analysis above is a production-based approach (domestic production including exports), based on the Intergovernmental Panel on Climate Change (IPCC) methodology for computing GHG emission inventories. This is a definition from a territorial perspective that allows domestic mitigation analysis and national policy design to be developed. Many critiques suggest including imports and leaving out exports-related emissions (consumption-based approach). This would help to determine the country's consumer responsibility, and would be useful, for example, for correctly allocating tradable permits to stabilize GHGs on a global scale (Kondo et al., 1998; Munksgraad and Pedersen, 2001; Lenzen et al., 2004; and Peters, 2008). Also, a shared responsibility approach, balancing both extreme points of view, has been developed by Lenzen et al. (2007). A consumption-based approach requires complex information that is not available for Uruguay for recent years. To alleviate this requirement, the domestic technology structure assumption for computing factors embodied in imported commodities has been widely employed in the literature. However, this has been demonstrated to be an implausible assumption for determining the emissions balance (Lenzen et al., 2004). It is particularly very implausible in the case of Uruguay, a small economy based on agro-industrial exports, because it is not possible to produce its imports domestically. Also, Andrew et al. (2009), with data for 2001 (based in an IO matrix for 1997), show that Uruguay is one of the countries for which the domestic technology structure assumption gives more biased results for carbon dioxide multipliers. This is a consequence of the high weight of clean energy sources in its structure, not coincident with the technology generally employed to produce its imports. Because of all this, a consumption-based approach is neither realistic nor useful for this case study. However, total national emissions from a production-based approach can be decomposed into those produced to satisfy external demand, and those embodied in domestic consumption. This allows the role of external demand on national emissions to be benchmarked.

The general objective of this chapter is to identify key polluting sectors of the Uruguayan economy in order to orientate mitigation policy design. To this end, two specific objectives are defined: i) organizing detailed data for carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) from productive activities and relating these to the national accounts structure, to come up with a tentative proposal for environmental accounts for Uruguay; and ii) determining the productive sectors' responsibility, either own and pure, through both their forward and backward linkages in relation to GHG emissions. Further analysis of the relationship between the Uruguayan productive structure and the environment helps to provide guidelines about specific policy design and government intervention for each problem, according to the role of each of the sectors. Sectors with different levels and types of linkages deserve different kinds of policies.

The next section details the methodology and data employed. Section 2.3 shows and discusses the empirical results. Section 2.4 discusses policy implications and reaches conclusions.

2.2 Methodology

There has been great debate around the key sectors' concept since Rasmussen/Hirschman's traditional approach that still continues today.[1] Alternative perspectives on economic interdependence should not be regarded as exclusive, but as complementing each other (Sonis et al., 2000). Environmental extensions have been widely applied in the literature (Hoekstra, 2010). As regards GHGs, key sectors applications have been developed for CO_2 emissions in Spain (Alcántara and Padilla, 2006), and Brazil (Imori and Guilhoto, 2010).

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[1] Hewings (1982), Lenzen (2003) and Miller and Blair (2009) present comprehensive surveys on key sector analysis evolution. Sánchez-Chóliz and Duarte (2003) provide a general definition covering almost all definitions of linkage indicators.

In addition to key sectors analysis, it is important to decompose linkage multipliers to distinguish a sector's own emissions from those that are purely indirect. It is not only important to see if a sector is significant, but also if it is important because it involves many other sectors or because it draws heavily on itself, or a few other sectors. Relevant policies will vary depending on the nature of sector linkages (Alcántara et al., 2010). The next two subsections describe the methodology employed in the empirical analysis

2.2.1 Key sectors analysis

Leontief (1936) model defines matrix $\boldsymbol{L} = (\boldsymbol{I} - \boldsymbol{A})^{-\mathbf{1}}$ where $\boldsymbol{A}$ is a technological coefficient matrix whose elements a_{ij} denote the interindustry flows from sector i to sector j.[2] The increase in the level of gross output required to hold a unit increase in final demand is defined by the sum of the columns of matrix $\boldsymbol{L}$. This analysis can be generalized to any relevant dimension. We define vector $\boldsymbol{c}_{1xn}$ as a row vector of coefficients that relates every sector to a specific pollutant. Hence $\boldsymbol{cx'} = e$, where $\boldsymbol{x}$ is the sector production vector and e is a scalar that denotes total emissions. In this way $\boldsymbol{e'}_{n\times 1} = \hat{\boldsymbol{c}}(\boldsymbol{I} - \boldsymbol{A})^{-\mathbf{1}}\boldsymbol{y'}$ is defined, where $\boldsymbol{e}$ is a vector representing the direct sector emissions, $\boldsymbol{y}$ is the row vector of final demand, and matrix $\boldsymbol{F_y} = \hat{\boldsymbol{c}}(\boldsymbol{I} - \boldsymbol{A})^{-\mathbf{1}}$ is a linear operator that converts final demand variations into variations in the emission vector. In this way demand-driven unweighted backward linkages extended to GHG emissions are defined as:

$$(1) \qquad \boldsymbol{\mu}^{uw}_{\boldsymbol{y}_{1\times n}} = \boldsymbol{u}\hat{\boldsymbol{c}}(\boldsymbol{I} - \boldsymbol{A})^{-1}$$

where $\boldsymbol{u}$ is a row summation vector[3]. In order to avoid biased conclusions, multipliers can be weighted by final demand. This avoids giving much importance to small sectors that take an important part of their input from other sectors, while in fact their weight in total production is not very significant. In the case of emissions analysis, even though

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[2] In this chapter, elements in **bold** denote vectors and matrices (lowercase and uppercase, respectively), while the scalars will be expressed in plain text. In turn, the ^ symbol over a vector element refers to a diagonal matrix composed of the specified vector.

[3] The demand driven multiplier of sector *i* in traditional IO analysis depicts the total output required per unit worth increase of its final demand. Different than this, in an IO model extended to GHG emissions, the demand driven multiplier of sector *i* represents the total pollution impact when its final demand increases by one unit worth.

those sectors are the ones whose final demand variations have greater impact in pollution terms, their contribution to total emissions is less significant. Both perspectives together are useful to distinguish those sectors that are important because of their technology from those where mitigation policies would be more effective. So, if $\tilde{y}_i = \frac{y_i}{\sum_i y_i}$ and $\sum_i \tilde{y}_i = 1$. Then equation (2) is obtained:

$$(2) \qquad \boldsymbol{\mu}^{w}_{\boldsymbol{y}_{1\times n}} = \boldsymbol{u}\hat{\boldsymbol{c}}(\boldsymbol{I}-\boldsymbol{A})^{-1}\hat{\tilde{\boldsymbol{y}}}$$

Total sectoral embodied emissions (direct plus indirect) can be computed as $\boldsymbol{e}^{\boldsymbol{total}}_{n\times 1}{}' = \boldsymbol{uc'}(\boldsymbol{I}-\boldsymbol{A})^{-\boldsymbol{1}}\hat{\boldsymbol{y}} = \boldsymbol{uc'}(\boldsymbol{I}-\boldsymbol{A})^{-\boldsymbol{1}}\hat{\boldsymbol{y}}^{\boldsymbol{exp}} + \boldsymbol{uc'}(\boldsymbol{I}-\boldsymbol{A})^{-\boldsymbol{1}}\hat{\boldsymbol{y}}^{\boldsymbol{dom}}$**,** where $\boldsymbol{y}^{\boldsymbol{exp}}$ is the sectoral exports vector, while $\boldsymbol{y}^{\boldsymbol{dom}}$ is a vector of final domestic demand. This allows total sectoral embodied emissions for satisfying exports and domestic demand to be computed.

Jones (1976) argues that supply-side multipliers (forward linkages) cannot be measured as the row sum of the Leontief inverse matrix. $\boldsymbol{L}$ traces the backward effects through the system of a final demand increase, but it biases the forward effect of an increase in primary inputs. The row sum of $\boldsymbol{L}$ can indicate that a sector shows significant forward linkages just because it is the main input of several small sectors, although its production can be mainly directed to final demand. As a consequence, forward linkages must be measured by departing from the Ghosh (1958) model.[4] In this way, departing from $\boldsymbol{G} = (\boldsymbol{I}-\boldsymbol{D})^{-1}$, the Ghosh inverse matrix, $\boldsymbol{F_v} = (\boldsymbol{I}-\boldsymbol{D})^{-\boldsymbol{1}}\hat{\boldsymbol{c}}$ is a linear operator that converts primary input variations into variations in the emissions vector. Supply-driven forward unweighted multipliers can be defined as:

$$(3) \qquad \boldsymbol{\mu}^{uw}_{\boldsymbol{v}_{1\times n}}{}' = (\boldsymbol{I}-\boldsymbol{D})^{-1}\hat{\boldsymbol{c}}\boldsymbol{u}'$$

In this case, multipliers of weighted forward linkages are defined by reference to their weight in total primary inputs plus imports, $\tilde{v}_j = \frac{v_j}{\sum_j v_j}$ such that $\sum_j \tilde{v}_j = 1$. Equation (3) can be rewritten as:

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[4] Symmetrically to the Leontief inverse: $(\boldsymbol{I}-\boldsymbol{D})^{-\boldsymbol{1}} = \hat{\boldsymbol{x}}^{-\boldsymbol{1}}(\boldsymbol{I}-\boldsymbol{A})^{-\boldsymbol{1}}\hat{\boldsymbol{x}}$, where $\boldsymbol{x}$ is the total output levels vector.

$$(4) \qquad \boldsymbol{\mu}^{w}_{\boldsymbol{v}_{1\times n}}{}' = \widehat{\tilde{\boldsymbol{v}}}(\boldsymbol{I}-\boldsymbol{D})^{-1}\hat{\boldsymbol{c}}\boldsymbol{u}'$$

In this way, it is possible to identify the vector of total emissions generated per final demand unit from the demand-driven model, and the total emissions generated as a consequence of the extra primary inputs that are needed to increase the supply of sector i, from a supply-driven model. Unweighted and weighted multipliers are classified in relation to their average multiplier, $\mu^{uw} = \frac{\boldsymbol{\mu}_{y}^{uw}\boldsymbol{u}'}{n} = \frac{\boldsymbol{\mu}_{v}^{uw}\boldsymbol{u}'}{n}$ and $\mu^{w} = \frac{\boldsymbol{\mu}_{y}^{w}\boldsymbol{u}'}{n} = \frac{\boldsymbol{\mu}_{v}^{w}\boldsymbol{u}'}{n}$. Key sectors are defined as those with both their backward and forward linkages above the average multiplier. Sectors that only satisfy the first or second condition are classified as demand- or supply-driven significant sectors, respectively. Alternatively, in order to avoid classification biases because of outliers, the threshold could be defined by reference to the median multiplier.

The Leontief and Ghosh models together can only be used as descriptive tools for comparative studies and for linkages and key sectors analysis, but not for impact studies (Oosterhaven, 1988; 2012). When the demand-driven model is used for impact analysis, a crucial assumption is that the direct input-coefficients matrix, $\boldsymbol{A}$, is constant. So, and as a consequence of the straight relation between $\boldsymbol{A}$ and $\boldsymbol{D}$, this means that the coefficients of $\boldsymbol{D}$ cannot remain constant. This problem is known as the "*joint stability problem*" (Chen and Rose, 1986). Dietzenbacher (1997) argues that the Ghosh model can be useful if it is interpreted as a price model, where forward linkages are understood as transfers of the costs increase of a sector's primary inputs (value added or imports) to the rest of the economy's output value. Also, the Ghosh model cannot be interpreted in a physical, causal sense because $\boldsymbol{D}$ does not quantify the amount of output generated by an injection of primary inputs, but instead indicates how primary inputs depend on further processing (Lenzen, 2003).

Although multipliers are weighted to avoid biased results, it may be the case that an increase in the final demand for the product of a particular sector with high multipliers does not affect many other sectors. This would happen in sectors that draw heavily on only one or a few sectors. Rasmussen (1952) proposes measuring multiplier variability by the coefficient of variation (*CV*) indices as a complementary approach to control for sensitivity to extreme values. From a demand perspective, the *CV* of sector j is defined as $CV_j^y = \frac{\sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(l_{ij}-\frac{1}{n}\sum_{i=1}^{n} l_{ij}\right)^2}}{\frac{1}{n}\sum_{i=1}^{n} l_{ij}}$, while from a supply perspective it can be defined as $CV_i^v = \frac{\sqrt{\frac{1}{n-1}\sum_{j=1}^{n}\left(g_{ij}-\frac{1}{n}\sum_{j=1}^{n} g_{ij}\right)^2}}{\frac{1}{n}\sum_{j=1}^{n} g_{ij}}$. A sector that shows a high value of the *CV* from a demand perspective can be interpreted as a sector that draws heavily on only one or a few sectors, while if its value is low, it depicts a sector that buys inputs evenly from other sectors. *CV* from a supply perspective can be interpreted analogously.

2.2.2 Own and pure components decomposition

It is important to distinguish if sectors pollute through their own production processes or whether they are polluting indirectly through the production processes of other sectors. This task is very important for policy design, because different polluting natures will require different policy measures. This analysis refers only to weighted multipliers, because policy measures should tackle those sectors with higher impact.

Following Alcántara et al. (2010), mitigation policies will be more effective in those sectors with either a high own backward, own forward or pure forward component. Targeting these would reduce pollution either from the sector itself or from other sectors. When only one sector with a high own component is involved, technological improvements and better practices would be effective in diminishing this sector’s emissions. In contrast, in sectors with a high pure forward component, policies should aim to reduce emissions associated with their supplies, that is, to focus on where their production is destined, or supply policies for avoiding the polluting process of this input. When more than one sector is involved in the polluting process, policies that are specific to one sector are not enough, and cross-sectoral policies should be encouraged.

Finally, sectoral measures to reduce emissions would not be effective in sectors with a high pure backward component because these sectors are not directly responsible for GHG emissions. In this case, other sectors demand products from directly-polluting sectors and, thus, these other sectors are responsible for these GHG emissions. In this case, technological or better practice measures are effective if they reduce intermediate demand to directly-polluting sectors. Also, final demand measures can be adopted, but, as this means reducing final demand for several sectors, it may not be very attractive for policymakers.

Following Alcántara et al. (2010), the decomposition of the own and pure components of backward and forward linkages can be made by subtracting the diagonal elements of matrix $\boldsymbol{F}_y$ or $\boldsymbol{F}_v$ respectively from each multiplier. Departing from (2), total GHG emissions from any sector per unit of total demand of sector j can be defined as $\mu_{y_j} = \sum_i \boldsymbol{F}_{\boldsymbol{y}_{ij}} \tilde{y}_j = \boldsymbol{F}_{\boldsymbol{y}_{jj}} \tilde{y}_j + \sum_{i \neq j} \boldsymbol{F}_{\boldsymbol{y}_{ij}} \tilde{y}_j$. Thus, the “own weighted backward component” can be written as:

(5) $$\mu_{\boldsymbol{y}_j}^{w-own} = \boldsymbol{F}_{\boldsymbol{y}_{jj}} \tilde{y}_j$$

and the “pure weighted backward component” as:

(6) $$\mu_{\boldsymbol{y}_j}^{w-pure} = \sum_{i \neq j} \boldsymbol{F}_{\boldsymbol{y}_{ij}} \tilde{y}_j$$

The own weighted backward component indicates how variations in the final demand for the products of a sector affect GHG emissions from the sector itself, while the pure weighted backward component denotes how variations in the final demand for the products of a sector affect GHG emissions from other sectors.

In the same way, it is possible to decompose forward linkages. Departing from (4), total GHG emissions per unit of product for any good can be defined as $\mu_{v_i} = \sum_j \boldsymbol{F}_{\boldsymbol{v}_{ij}} \tilde{v}_i = \boldsymbol{F}_{v_{ii}} \tilde{v}_i + \sum_{j \neq i} \boldsymbol{F}_{\boldsymbol{v}_{ij}} \tilde{v}_i$. Analogously, the “own weighted forward component” can be defined as:

(7) $$\mu_{v_i}^{w-own} = \boldsymbol{F}_{v_{ii}} \tilde{v}_i$$

and the “pure forward component” as:

(8) $$\mu_{\boldsymbol{v}_i}^{w-pure} = \sum_{j \neq i} \boldsymbol{F}_{v_{ij}} \tilde{v}_i$$

Similarly to the above, the own weighted forward component tells how variations in the production of a sector as a consequence of an increase in its primary inputs affect GHG emissions in the sector itself. The pure weighted forward component depicts how variations in the production of a sector as a consequence of the increase in its primary inputs affect emissions of other sectors when processing this production as inputs.

Own and pure components decomposition is complementary to the *CV*. Sectors that show high own components are also expected to show a high *CV*. Moreover, a high pure component depicts the importance of a sector because it makes others pollute. Along with the *CV*, this is useful to show whether it makes only one or a few sectors pollute, or whether it makes many of them pollute. It is relevant to note whether the production of a sector showing a significant pure component is spread among many sectors, or is concentrated only in one, or a few. Given this, the *CV* helps to characterize linkages in this aspect. If a sector shows both own and pure significant components, the *CV* omitting the main diagonal elements must be computed to avoid biases produced by the own component.

2.2.3 Data

There is no official IO matrix for Uruguay. However, in the benchmark of a Red Mercosur – Food and Agricultural Organization agreement for technical assistance to the Agriculture, Livestock and Fishing Ministry, an IO table for the year 2005 was constructed under direct supervision of the Central Bank of Uruguay (BCU), the institution that publishes the national accounts information (Terra et al., 2009). There is a consensus on its validity, and it is the main reference for both public and private analysis. It is split into 56 activities at basic prices.

Table 2.1: Productive sectors, output and GHG emissions

Sector	Name	Output US$:	% Output	CO_2 Ktons	$\%CO_2$	CH_4 Ktons	$\%CH_4$	N_2O Ktons	$\%N_2O$	CO_2e Ktons	$\%CO_2e$
1	Rice growing	176.62	0.6%	91.0	1.5%	743.7	4.0%	0.9	0.0%	835.6	2.3%
2	Other cereals and crops	447.55	1.5%	112.9	1.9%	1.3	0.0%	1.6	0.0%	115.9	0.3%
3	Vegetables and horticultural growing	108.68	0.4%	12.2	0.2%	0.0	0.0%	0.1	0.0%	12.3	0.0%
4	Fruits growing	146.38	0.5%	19.3	0.3%	0.1	0.0%	0.2	0.0%	19.5	0.1%
5	Raw milk and milk products prepared in	235.49	0.8%	65.4	1.1%	1328.3	7.1%	0.6	0.0%	1394.3	3.8%
6	Cattle farming	987.90	3.4%	63.1	1.0%	15161.7	81.5%	12039	99.8%	27264.3	74.1%
7	Other animal farming	112.72	0.4%	6.4	0.1%	18.3	0.1%	0.1	0.0%	24.8	0.1%
8	Forestry and logging	138.67	0.5%	5.3	0.1%	0.0	0.0%	0.0	0.0%	5.4	0.0%
9	Fishing	65.67	0.2%	169.3	2.8%	0.2	0.0%	1.1	0.0%	170.6	0.5%
10	Mining and quarrying	64.39	0.2%	11.4	0.2%	0.0	0.0%	0.0	0.0%	11.5	0.0%
11	Meat production	1,426.40	4.9%	114.4	1.9%	108.8	0.6%	0.0	0.0%	223.2	0.6%
12	Fish processing and fish products	172.15	0.6%	0.0	0.0%	0.7	0.0%	0.0	0.0%	0.7	0.0%
13	Fruit and vegetables processing and preserving	32.41	0.1%	0.0	0.0%	22.3	0.1%	0.0	0.0%	22.3	0.1%
14	Manufacture of vegetable and animal oils and fats	29.45	0.1%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%
15	Dairy products	479.76	1.6%	134.8	2.2%	29.4	0.2%	0.0	0.0%	164.1	0.4%
16	Rice mill products	227.34	0.8%	56.7	0.9%	0.0	0.0%	0.0	0.0%	56.7	0.2%
17	Flour and other grain mill	74.37	0.3%	0.8	0.0%	0.0	0.0%	0.0	0.0%	0.8	0.0%
18	Prepared animal feeds	64.96	0.2%	48.0	0.8%	0.0	0.0%	0.0	0.0%	48.0	0.1%
19	Bakery and similar farinaceous products	276.49	0.9%	66.3	1.1%	0.1	0.0%	0.0	0.0%	66.4	0.2%
20	Sugar and other food products	336.91	1.2%	41.4	0.7%	0.0	0.0%	0.0	0.0%	41.5	0.1%
21	Wines	63.56	0.2%	35.2	0.6%	0.1	0.0%	0.0	0.0%	35.3	0.1%
22	Manufacture of malt liquors and malt	97.75	0.3%	3.8	0.1%	0.1	0.0%	0.0	0.0%	3.9	0.0%
23	Distilling, rectifying and blending of spirits;	151.05	0.5%	32.7	0.5%	0.2	0.0%	0.0	0.0%	32.9	0.1%
24	Tobacco	61.54	0.2%	0.8	0.0%	0.0	0.0%	0.0	0.0%	0.8	0.0%
25	Spinning, weaving and finishing of textiles	252.86	0.9%	69.9	1.1%	38.1	0.2%	0.0	0.0%	108.0	0.3%
26	Knitted and crocheted fabrics and articles	59.01	0.2%	12.5	0.2%	0.0	0.0%	0.0	0.0%	12.5	0.0%
27	Dressing and dyeing of fur; manufacture of articles of fur	274.03	0.9%	12.6	0.2%	0.0	0.0%	0.0	0.0%	12.6	0.0%
28	Tanning and dressing and manufacture of leather	282.97	1.0%	23.0	0.4%	2.0	0.0%	0.0	0.0%	24.9	0.1%
29	Footwear	37.89	0.1%	2.6	0.0%	0.0	0.0%	0.0	0.0%	2.6	0.0%
30	Wood products	178.22	0.6%	74.9	1.2%	0.0	0.0%	0.0	0.0%	75.0	0.2%
31	Paper and paper products	149.15	0.5%	162.4	2.7%	0.1	0.0%	0.0	0.0%	162.5	0.4%
32	Publishing, printing and reproduction of recorded media	186.69	0.6%	16.9	0.3%	0.0	0.0%	0.0	0.0%	17.0	0.0%
33	Refined petroleum	1,026.82	3.5%	416.2	6.8%	3.9	0.0%	0.5	0.0%	420.6	1.1%
34	Pesticides and other agro-chemical products	117.51	0.4%	0.5	0.0%	0.0	0.0%	0.0	0.0%	0.5	0.0%
35	Pharmaceuticals	180.87	0.6%	5.3	0.1%	0.0	0.0%	0.0	0.0%	5.3	0.0%
36	Basic chemicals	363.65	1.2%	21.1	0.3%	0.1	0.0%	0.0	0.0%	21.2	0.1%
37	Rubber and plastics products	305.95	1.0%	1.5	0.0%	0.0	0.0%	0.0	0.0%	1.5	0.0%
38	Other non-metallic mineral products	206.59	0.7%	475.2	7.8%	0.3	0.0%	0.0	0.0%	475.6	1.3%
39	Basic metals	620.06	2.1%	24.3	0.4%	0.1	0.0%	0.0	0.0%	24.3	0.1%
40	Motor vehicles	171.69	0.6%	0.2	0.0%	0.0	0.0%	0.0	0.0%	0.2	0.0%
41	Furniture	189.84	0.6%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%
42	Electricity, gas and water supply	837.07	2.9%	895.8	14.7%	16.2	0.1%	1.2	0.0%	913.2	2.5%
43	Building	2,473.46	8.5%	7.1	0.1%	0.0	0.0%	0.0	0.0%	7.1	0.0%
44	Motor vehicles and oil retail trade	3,096.67	10.6%	14.8	0.2%	0.0	0.0%	0.0	0.0%	14.9	0.0%
45	Hotels and restaurants	867.28	3.0%	26.3	0.4%	0.0	0.0%	0.1	0.0%	26.4	0.1%
46	Land transport; transport via pipelines	957.48	3.3%	1261.2	20.7%	2.4	0.0%	17.5	0.1%	1281.1	3.5%
47	Water and air transport	875.27	3.0%	1371.5	22.5%	0.4	0.0%	1.4	0.0%	1373.3	3.7%
48	Post and telecommunications	777.83	2.7%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%
49	Financial intermediation	1,243.68	4.3%	1.5	0.0%	0.0	0.0%	0.0	0.0%	1.5	0.0%
50	Real estate activities	2,164.56	7.4%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%
51	Renting of machinery and equipment	941.08	3.2%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%
52	Public administration and defence; compulsory social security	1,238.21	4.2%	44.7	0.7%	0.0	0.0%	0.1	0.0%	44.8	0.1%
53	Education	722.02	2.5%	5.8	0.1%	0.0	0.0%	0.0	0.0%	5.9	0.0%
54	Health and social work	1,465.63	5.0%	16.9	0.3%	0.0	0.0%	0.1	0.0%	17.0	0.0%
55	Sewage and refuse disposal	794.97	2.7%	40.9	0.7%	1132.1	6.1%	0.1	0.0%	1173.1	3.2%
56	Private households with employed persons	192.25	0.7%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%
Total		**29,229**	**100.0%**	**6,097**	**100%**	**18,611**	**100%**	**12,065**	**100%**	**36,773**	**100%**
% Total emissions				**16.6%**		**50.6%**		**32.8%**		**100%**	

Source: prepared by the authors based on Terra et al. (2009), MVOTMA (2010a) and DNTEN (2008)

In reference to GHG emissions, a sectoral vector is constructed. The Ministry of Housing, Land Use Planning, and Environment details the 2004 GHG inventory classified by processes (MVOTMA, 2010a). We have constructed GHG emissions accounts following the Eurostat (2009) methodology. Secondary sources, like the reports of the National Energy and Nuclear Technology Direction (DNETN, 2008), which detail the structure of net and used energy consumption for the year 2006 are used.[5]

Table 2.1 depicts the productive sectors' total output (in millions of US dollars) and total GHG emissions (carbon dioxide, C_2O, methane, CH_4, nitrous oxide, N_2O, and total GHGs, CO_2e, all of them in ktons of CO_2-equivalent).

The Uruguayan productive structure in 2005 shows a high weight of service sectors (44 to 55), jointly with Building (43), as well as Cattle farming (6) and Meat production (11). For the analysis below, it is important to note that, on average, 60% of productive inputs are primary inputs or imports, while 61% of the production goes from the productive system straight to final demand.

Methane emissions represent half of the total emissions of the Uruguayan productive sectors, while nitrous oxide represents one third, and carbon dioxide the remaining 16%. The Cattle farming sector (6) emits almost all the methane and nitrogen oxide, while carbon dioxide emissions mainly come from the Transport sectors (46 and 47).

2.3 Empirical results

The key sectors analysis of total GHG emissions is carried out first. This analysis is useful for constructing a general view of sectoral responsibilities for the problem as a whole, as well as for a better understanding of the divergence between unweighted and weighted multipliers. The decomposition of linkages, relevant for policy guidelines, is only developed for the three specific pollutants with reference to weighted multipliers analysis. This is because policy guidelines are only relevant for specific gases, considering their weight in total emissions.

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[5] Methodology for sectoral allocation of emissions is show in Appendix II.

Table 2.2: Total GHG (CO_2e) linkages Uruguay 2004

	unweighted										weighted									
	$\mu_v>\mu$					$\mu_v<\mu$					$\mu_v>\mu$					$\mu_v<\mu$				
	Sector	**BL Ranking**	**CV^y**	**FL Ranking**	**CV^v**	**Sector**	**BL Ranking**	**CV^y**	**FL Ranking**	**CV^v**	**Sector**	**BL Ranking**	**CV^y**	**FL Ranking**	**CV^v**	**Sector**	**BL Ranking**	**CV^y**	**FL Ranking**	**CV^v**
$\mu_y>\mu$	**6**	1	7.5	1	7.4	**11**	2	7.3	42	6.7	**6**	2	7.5	1	7.4	**11**	1	7.3	31	6.7
	5	3	7.2	2	7.1	**25**	5	6.6	27	6.9	**55**	6	6.9	8	7.0	**15**	3	6.1	27	6.5
	1	4	7.3	3	6.8	**28**	6	7.0	47	6.8	**47**	7	7.1	3	6.7	**45**	4	6.1	35	3.3
	9	9	6.8	7	7.3	**16**	7	6.3	22	4.8	**46**	9	6.8	6	6.2	**28**	5	7.0	46	6.8
	38	10	6.7	6	6.6	**15**	8	6.1	30	6.5						**25**	8	6.6	26	6.9
						14	11	6.6	44	2.3						**16**	10	6.3	40	4.8
$\mu_y<\mu$	**18**	12	4.3	8	4.1						**42**	11	7.0	7	6.2					
	55	14	6.9	12	7.0						**44**	12	3.0	4	5.2					
	47	15	7.1	10	6.7						**5**	15	7.2	5	7.1					
	46	17	6.8	11	6.2						**33**	21	7.1	2	3.7					
	2	28	5.0	13	5.1						**49**	43	2.8	9	4.9					
	33	30	7.1	9	3.7															
	35	38	2.9	5	7.3															
	34	48	3.2	4	5.6															

mean CV^y = 4.8
mean CV^v = 5.2

Expressions (1) to (4) have been computed in order to analyze sectors' responsibility in relation to total GHG emissions. Five key sectors are identified when unweighted multipliers are considered: Cattle farming (6), Raw milk and milk products prepared on the premises (5), Rice growing (1), Fishing (9), and Other non-metallic mineral products (38). Only sector 6 remains as key when weights are considered. Also three services sectors, that were only important from a supply perspective in the unweighted case, emerge as key in this case: two Transport-related services (46 and 47) and Sewage and refuse disposal (55). Sector 5 is only important because of its forward linkages in this case (Table 2.2).[6]

Changes in sector classification when the weight in final demand and value added is considered depict those sectors that are significant as a consequence of their technological structure, but that are not very effective for mitigating emissions when their scale is considered (Table 2.2). The block of sectors that are only important from a demand perspective is almost the same in both cases, while the block important from a supply perspective denotes several changes. First, this means that those sectors that, due to their technology requirements, increase their own emissions or pull others to pollute when their final demand increases, also have significant weight in the total final

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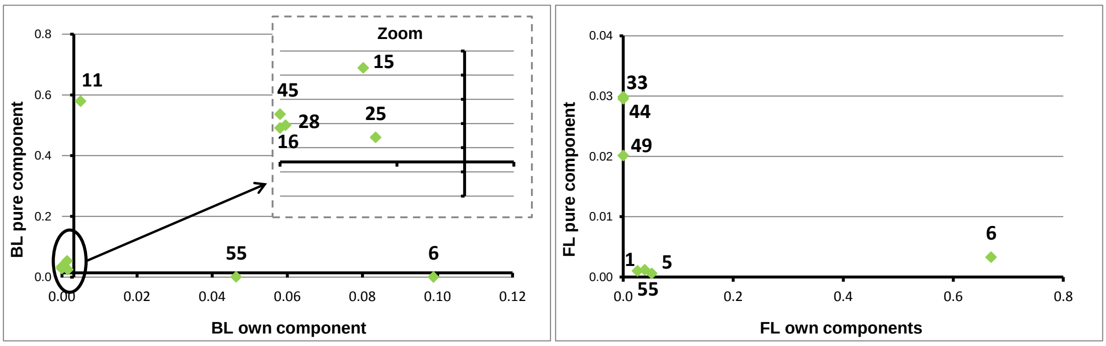
[6] When taking the median as a classification reference, the results change slightly, but this information does not add much to the analysis. The median implies, by definition, that half of the sectors are considered as key, from a demand perspective, a supply perspective, or both. Changing classification criteria to the median multiplier has two main effects on the results: it highlights the whole significance of sectors that were already important from only one perspective, and it atomizes the number of sectors to be considered when some may be not very significant. In this way, this analysis could be useful as a complementary one when intervention in the most important sectors is not feasible.

demand. Second, while three sectors that are only important from a supply perspective become key, there are several others with a very low share in total emissions or that are minor inputs of the polluting sectors.

Figure 2.1: CH_4 – Backward and forward linkages own and pure components



When looking only at methane emissions, the results are similar, except for the fact that the sectors whose emissions come mainly from energy combustion are not significant in this case (Table A2.1 in Appendix I). Methane key sectors are the main direct polluters, and their weighted backward and forward linkages are driven entirely through their own components (Figure 1). But also, pure indirect emissions represent 82% of total methane emissions (Table 2.3). Direct polluters provide inputs mainly to agro-industrial sectors. Also a significant part of them is generated due to the demand of other sectors that take a large share of their inputs from them.[7] This is the case for Tanning and dressing and manufacture of leather (28) and Hotels and restaurants (45).[8] Almost all of the sectors with a significant pure weighted backward component do not show an important own weighted component and a high *CV* value. This means that when these sector demand increases they pull only one or a few sectors to pollute (except Rice mill products (16), with a *CV* of its backward linkages of a little over the mean, but still high, $CV^{y}_{16} = 5$).

Both the significance of some of the primary sector's production, like Cattle farming (6), Rice growing (1), and Raw milk and milk products prepared in premises (5), as input to other sectors and its great weight in total emissions explain the importance of its own weighted forward component. They sell almost all their production inside the productive system, and are the main inputs of Meat production (11), Rice mill products

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[7] By a power series approximation of the Leontief inverse matrix, we computed that around 15.5% of total methane pure indirect emissions are of a higher order than one.

[8] Sector 45 includes commercial retail trade.

(16) and Dairy products (15) respectively, which do not directly emit methane. In this way, increasing their production only increases their own emissions. The own forward weighted linkages component of Sewage and refuse disposal (55) is explained mainly because it is a direct polluting sector: 75% of its production goes straight to final demand, while 4.5% is sold to itself.

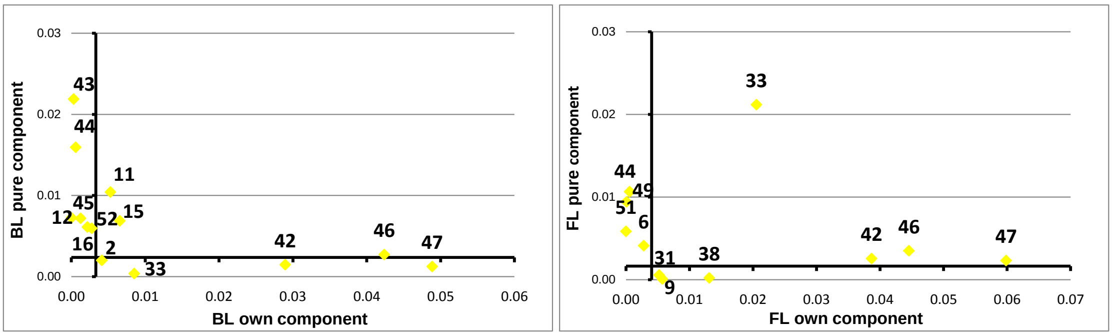
Finally, Motor vehicles and oil retail trade (44) and Financial intermediation (49) show significant pure forward weighted linkages. Both sectors' production variations can indirectly impact on emissions from Cattle farming (6), the main directly-polluting sector. Also, all the sectors with important pure forward weighted linkages show coefficients of variation over the mean of them. This means that when their production increases, they pull only one or a few sectors to pollute. This confirms the impact of the expansion in these sectors on Cattle farming (6) emissions.

Results for nitrous oxide emissions have many similarities with the ones for methane emissions. This is because the distribution of nitrous oxide direct emissions is almost equal, except for Sewage and refuse disposal (55), which is not significant in this case (Table A2.3 in Appendix I).

When looking only at carbon dioxide emissions, direct emissions are more scattered among sectors than in the previous cases, because they mainly come from fossil fuel combustion. When using weighted linkages, we identify five key sectors: Land transport and transport via pipelines (46), Water and air transport (47), Electricity, gas and water supply (42), Refined petroleum (33), and Motor vehicles and oil retail trade (44) (Table A2.2 in Appendix I).

Sectors 46, 47 and 42 are the main direct carbon dioxide polluters (57.9%). Their weighted backward and forward linkages are driven mainly by their own components (Figure 2). Looking at the IO matrix, it can be seen that this is because only a small part of their inputs comes from other sectors, while their production is destined mainly to final demand or they sell to themselves.

Figure 2.2: C_2O – Backward and forward linkages own and pure components



Sector 33 directly emits 6.8% of total carbon dioxide emissions. Its weighted backward linkages are mainly explained by its own component. This is because of two facts. First, 61.5% of its production stays inside the productive system, and is required mainly by other direct CO_2 polluting sectors, like Rice growing (1), Raw milk and milk products prepared on the premises (5), Fishing (9), Transport-related sectors (46 and 47), and by sector 33 itself. Second, 93% of its inputs are primary inputs or imports. Therefore, sector 33 does not pull other sectors so much when its demand increases. Also, sector 33's weighted forward linkage components are both important, because a significant part of its production goes to other sectors, while increasing its production also pushes its own pollution.

Pure weighted backward linkages play a very important role (42% of total carbon dioxide emissions are of this kind, Table 2.3).[9] This component explains the importance of the Motor vehicles and oil retail trade (44) sector. Its *CV* is lower than the average, meaning that increasing this sector's final demand leads many other sectors to pollute. This is because it does not pollute itself but demands inputs from polluting sectors, like Refined petroleum (33), Electricity, gas and water supply (42), Land transport and transport via pipelines (46), and Water and air transport (47). Its weighted forward linkages are significant because of the pure component, as increases in its production also increase the emissions of transport-related sectors (46 and 47).

There are some other sectors that explain the pure indirect pollution caused when they demand inputs from direct polluters' sectors. In particular, Building (43) pulls Other non-metallic mineral products (38) to pollute, by the time that this later demands inputs

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[9] Around 34% of total carbon dioxide pure indirect emissions are of a higher order than one (see footnote 7).

also from direct polluter sectors. This makes sector 43's pure emissions highly indirect. Similar is the case of Hotels and restaurants (45), which not only demand inputs from direct polluter sectors, but also from sectors that make others pollute. Also, the weighted forward linkages of Fishing (9), Paper and paper products (31), and Other non-metallic mineral products (38) are explained mainly by their own components, while those of the other sectors that are important only from a supply perspective are explained through their pure weighted forward components. When taking into account the *CV*, all those sectors with significant pure weighted forward linkages show low values. This means that when they expand their production, the pollution that they induce in other sectors is not concentrated in only one or a few sectors.

Finally, while almost all GHG emissions from primary sectors are own (96.8%), and they are produced to satisfy internal demand (76.6%), they only represent 11.3% of total emissions. The case of the industrial sectors is different, as they have the greatest responsibility in total emissions (74%), generated mainly indirectly in producing the agro-industrial sectors' exports (Table 2.3). This pattern is explained by the high weight of methane and nitrous oxide in total emissions. Unlike the above, CO_2 emissions are produced mainly to satisfy domestic final demand. This is not surprising because, while methane emissions are embodied in products that rapidly leave the productive system, and are generally exported, carbon dioxide emissions are mainly related to fuel combustion, embodied in products that are mainly employed as inputs by other sectors, or by domestic consumption.

Table 2.3: Own, pure and total GHGs, CH_4, CO_2, and N_2O emissions (CO_2 equivalent) in Uruguay (2004)

Total GHGs emissions (CO_2 eq.)										
	Own		Pure		Total					
Sector	Own Ktons	% Total GHGs by sector	Pure Ktons	% Total GHGs by sector	Total Ktons	%Total GHGs	Exports Ktons	% Total GHGs by sector	Dom. Cons. Ktons	% Total GHGs by sector
Primary	4023,2	96,8%	133,8	3,2%	4157,0	11,3%	972,3	23,4%	3184,7	76,6%
Industrial	1666,8	6,1%	25501,5	93,9%	27168,2	73,9%	17869,8	65,8%	9298,4	34,2%
Services	2793,1	51,3%	2655,1	48,7%	5448,2	14,8%	1074,1	19,7%	4374,1	80,3%
Total	8483,0	23%	28290,4	77%	36773,4	100%	19916,2	54%	16857,2	46%

CH_4 (CO_2 eq.)										
	Own		Pure		Total					
Sector	Own Ktons	% Total CH_4 by sector	Pure Ktons	% Total CH_4 by sector	Total Ktons	%Total CH_4	Exports Ktons	% Total CH_4 by sector	Dom. Cons. Ktons	% Total CH_4 by sector
Primary	2320,9	99,2%	19,17	0,8%	2340,1	12,6%	490,4	21,0%	1849,7	79,0%
Industrial	183,8	1,3%	14140,59	98,7%	14324,3	77,0%	9791,9	68,4%	4532,4	31,6%
Services	894,9	46,0%	1051,81	54,0%	1946,7	10,5%	47,6	2,4%	1899,1	97,6%
Total	3399,6	18%	15211,6	82%	18611,1	100%	10329,9	56%	8281,2	44%

N_2O (CO_2 eq.)										
	Own		Pure		Total					
Sector	Own Ktons	% Total N_2O by sector	Pure Ktons	% Total N_2O by sector	Total Ktons	%Total N_2O	Exports Ktons	% Total N_2O by sector	Dom. Cons. Ktons	% Total N_2O by sector
Primary	1512,7	99,4%	9,4	0,6%	1522,1	12,6%	381,7	25,1%	1140,4	74,9%
Industrial	0,9	0,0%	9902,9	100,0%	9903,8	82,1%	6786,1	68,5%	3117,7	31,5%
Services	12,6	2,0%	626,5	98,0%	639,1	5,3%	21,8	3,4%	617,3	96,6%
Total	1526,3	13%	10538,7	87%	12065,0	100%	7189,7	60%	4875,3	40%

CO_2 (CO_2 eq.)										
	Own		Pure		Total					
Sector	Own Ktons	% Total CO_2 by sector	Pure Ktons	% Total CO_2 by sector	Total Ktons	%Total CO_2	Exports Ktons	% Total CO_2 by sector	Dom. Cons. Ktons	% Total CO_2 by sector
Primary	189,6	64,3%	105,3	35,7%	294,8	4,8%	100,1	34,0%	194,7	66,0%
Industrial	1482,1	50,4%	1458,0	49,6%	2940,1	48,2%	1291,7	43,9%	1648,4	56,1%
Services	1885,5	65,9%	976,8	34,1%	2862,4	46,9%	1004,7	35,1%	1857,7	64,9%
Total	3557,2	58%	2540,1	42%	6097,3	100%	2396,5	39%	3700,7	61%

Source: prepared by the authors based on Terra et al. (2009), MVOTMA (2010a) and DNTEN (2008).

2.4 Policy implications and conclusions

The present chapter shows the key sectors for GHG emissions in the Uruguayan economy in 2004. Sectoral linkages have been decomposed in terms of own and pure indirect components. This analysis is relevant because policy design for mitigating emissions will be different if a sector pollutes through its own production process or if it makes other sectors pollute. Also, total emissions have been split between those produced to satisfy external and domestic demand. In this sense, the present chapter's main contributions are twofold: i) it constructs a sectoral GHG emissions vector, linking, for the first time in Uruguay, national accounts and the environment,; ii) it helps to distinguish those sectors where focusing the Climate Change Response Plan (NCCRP) lines of action for mitigation policies would be more effective, as well as those sectors not considered in it and that pull polluters through their pure indirect emissions.

Table 2.4 summarizes the above results, linking the weighted linkages decomposition and the corresponding policy implications. Technological improvements and better practices are only feasible in directly-polluting sectors. In the case of methane and nitrous oxide the NCCRP (MVOTMA, 2010b) already identifies Cattle farming (6) and Sewage and refuse disposal (55) in their priority lines, because of their significance as direct polluters (their joint direct emissions reach 87.5% of total emissions, Table 2.1 and Table A2.4 in Appendix I). Also, because the majority of pollution comes from the primary sectors, improving productivity in sectors that demand inputs from them will mainly increase final demand of these sectors, pulled by external demand, rather than diminish emissions (when considering total weighted demand multipliers, 68.9% of total methane emissions is produced by meat production (11), dairy products (15), and rice mill products (16)).

Moreover, a very interesting point that IO analysis allows is the identification of those sectors that pollute through indirect channels, and that are not obvious on first inspection. It is of special interest to look for the indirect emissions of a higher order than one. Despite these emissions representing 12.6% of total methane emissions, they are less obvious to policy makers. This is the case for Hotels and restaurants (45); a sector whose methane emissions are almost null, but whose demand indirectly pulls both the primary and agro-industrial sectors to pollute (it amounts to 3.5% of total methane emissions). This opens an opportunity to develop demand policies, like labeling or product process certifications. However, given the extensive cattle farming production technique employed in Uruguay, the scope of this kind of measure is limited. Also, an important aspect of the analysis above is the availability of complementary measures through Motor vehicles and oil retail trade (44), and Financial intermediation (49) because of their pure weighted forward linkages. This allows mitigation policy measures through both sectors to be developed. Credit access is key for pushing production. In this sense, facilitating credit access to non-polluting sectors, or credit incentives for cattle farms that apply best practices for improving their environmental performance would be a policy option. Also, the oil retail trade plays an important role in the production of intermediate products. This allows tax or subsidies to be implemented to encourage cleaner energies through this sector.

Technical improvements and better practice measures for carbon dioxide mitigation should focus on Refined petroleum (33), Electricity, gas and water supply (42), Land transport and transport via pipelines (46), and Water and air transport (47). These sectors show significant own weighted forward and backward, pure weighted forward linkages, and a high magnitude of their multipliers. They are the main direct polluters (64.7% of total direct emissions), while their contribution when considering both the own and pure components slightly decreases (42.4% of total emissions). These facts make them the most relevant in terms of policymaking, and the NCCRP properly distinguishes transport sectors in its priority lines for carbon dioxide mitigation.

Table 2.4: Weighted linkages CH_4, N_2O and CO_2 decomposition and policy measures

If sector show important	CH_4	N_2O	CO_2	Policy implications
	Sector	Sector	Sector	
Own backward or forward components	6 Cattle farming 1 Rice growing 5 Raw milk and milk products prepared on premises 55 Sewage and refuse disposal 11 Meat production	6 Cattle farming	33 Refined petroleum 42 Electricity, gas and water supply 46 Land transport; transport via pipelines 47 Water and air transport	Sectoral measures directly reduce resource use or environmental degradation: Technological improvement and best practices
Pure forward components, and many sectors involved	33 Refined petroleum 44 Motor vehicles and oil retail trade 49 Financial intermediation	33 Refined petroleum 44 Motor vehicles and oil retail trade 49 Financial intermediation	2 Other cereals and crops 11 Meat production 15 Dairy products 9 Fishing 31 Paper and paper products 38 Other non-metallic mineral products 44 Motor vehicles and oil retail trade 49 Financial intermediation	Inter-sectoral policies
Pure backward	11 Meat production 15 Dairy products 16 Rice mill products 25 Spinning, weaving and finishing of textiles 28 Tanning and dressing and manufacture of leather 45 Hotels and restaurants	11 Meat production 25 Spinning, weaving and finishing of textiles 28 Tanning and dressing and manufacture of leather	11 Meat production 12 Fish processing and fish products 15 Dairy products 16 Rice mill products 43 Building 44 Motor vehicles and oil retail trade 45 Hotels and restaurants 52 Public administration and defence; compulsory social security	Sectoral policies are not effective, intermediate or final demand policies are needed

But key sectors analysis and weighted linkages decomposition are particularly relevant in the carbon dioxide case, because emission sources are more disperse. In this case, energy efficiency improvements are also feasible in intermediate demand sectors. Despite this, rebound effects can also appear in this case, if the demand or the supply of the sectors that improve their energy efficiency increases as a consequence of this improvement. In this sense, energy efficiency measures oriented to reduce emissions should focus on Hotels and restaurants (45), and Motor vehicles and oil retail trade (44) (these sectors are responsible of 5.2% and 2.7% of total carbon dioxide emissions respectively, and almost all are produced through their pure components). Sector 45 directly demands land transport services and electricity, but also demands inputs from the agro-industrial and distillery sectors. These sectors both demand transport and electricity inputs, as well as inputs from primary sectors, that also need energy from different sources, as well as processed inputs. In this way, demand policies in sector 45 reduce emissions in many other sectors, because its highly indirect emissions are spread among many different sectors. Similar are the cases of Meat production (11), and Dairy products (15), which show high pure weighted backward linkages (responsible for 5% and 4.2% of total carbon dioxide emissions respectively). But these sectors are the main exporters, and demand policies are less feasible in this case.

Also important are the weighted indirect emissions of the Building (43) sector (7% of total carbon dioxide emissions). They are purely generated through its demand for Other non-metallic mineral products (38), but this sector pollutes both through its own productive process and its demand for transport services and electricity. A similar path is depicted by Real estate activities (50), but its share in total emissions is much lower (1.1% of the total carbon dioxide emissions). The highly indirect emissions of these sectors depict the relevance of the housing market and building for mitigation policies. Housing market measures for purchasing and improving second hand houses, instead of building new, can be an interesting channel for diminishing this pure indirect pollution. Also, emissions information provided by suppliers on incentives for low-emissions materials substitution would be an effective alternative (Acquaye and Duffy, 2010).

Finally, policy measures can again be complemented through supplies to the polluting sectors from the Motor vehicles and oil retail trade (44) and Financial intermediation (49). In particular, sector 49's pure weighted forward linkages depict the relevance of financial services as a tool for reducing emissions. This result is particularly interesting because of the significance of financial services on the Building (43) sector.

Looking further ahead, the technical and cost viability of interventions should be included in the policymaking process. Deciding on which sectors to focus on and the kind of policy mechanisms to apply is a first step towards mitigating the GHG emissions of the Uruguayan economic system.

Finally, methane and nitrous oxide emissions are mainly produced by primary sectors when providing inputs to industrial sectors to satisfy their external demand. Carbon dioxide emissions are more spread between industrial and services sectors, because they mainly come from fuel combustion. Unlike the cases of the other gases, although CO_2 emitted to meet external demand is significant, these emissions are mainly generated to satisfy domestic demand. It is noteworthy that more than half (56%) of total GHG emissions are made in order to satisfy external demand. Further studies should overcome data availability limitations in order to develop a consumption-based approach for correctly determining Uruguay's responsibility in GHG emissions, and help in the design of complementary GHG mitigation measures.

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Appendix I

Table A2.1: CH_4 linkages Uruguay 2004

	unweighted										weighted									
	$\mu_v>\mu$					$\mu_v<\mu$					$\mu_v>\mu$					$\mu_v<\mu$				
	Sector	BL Ranking	CV^y	FL Ranking	CV^v	**Sector**	BL Ranking	CV^y	FL Ranking	CV^v	**Sector**	BL Ranking	CV^y	FL Ranking	CV^v	**Sector**	BL Ranking	CV^y	FL Ranking	CV^v
$\mu_y>\mu$	**6**	1	7.5	1	7.4	**11**	2	7.5	34	7.0	**6**	2	7.5	1	7.4	**11**	1	7.5	25	6.9
	5	3	7.5	2	7.4	**16**	5	5.0	17	6.2	**55**	4	7.5	3	7.3	**15**	3	7.3	27	5.2
	1	4	4.7	3	7.2	**25**	6	7.1	24	6.9						**45**	5	6.9	38	4.6
	55	9	7.5	6	7.3	**15**	7	7.3	32	5.2						**28**	6	7.4	48	5.7
						28	8	7.4	51	5.7						**16**	7	5	35	6.2
						14	10	7.5	36	3.2						**25**	8	7.1	24	6.9
$\mu_y<\mu$	**13**	13	6.9	8	7.2						**5**	9	7.5	2	7.4					
	18	15	7.3	7	5.9						**1**	10	4.7	6	7.2					
	35	24	5.3	5	7.4						**44**	12	5.0	5	5.8					
	34	46	5.1	4	5.5						**49**	31	5.6	7	5.7					
											33	43	5.5	4	5.3					

mean CV^y = 5.7
mean CV^v = 5.4

Table A2.2: CO_2 linkages Uruguay 2004

	unweighted										weighted									
	$\mu_v>\mu$					$\mu_v<\mu$					$\mu_v>\mu$					$\mu_v<\mu$				
	Sector	BL Ranking	CV^y	FL Ranking	CV^v	**Sector**	BL Ranking	CV^y	FL Ranking	CV^v	**Sector**	BL Ranking	CV^y	FL Ranking	CV^v	**Sector**	BL Ranking	CV^y	FL Ranking	CV^v
$\mu_y>\mu$	**9**	1	7.2	1	7.4	**12**	8	6.3	52	4.4	**47**	1	7.3	1	7.2	**43**	4	5.2	22	1.8
	38	2	6.9	2	7.4	**16**	10	3.8	20	7.1	**46**	2	7	2	6.9	**11**	6	3.1	29	6.5
	47	3	7.3	3	7.2	**15**	12	4	16	7.2	**42**	3	7.1	4	7	**15**	7	4	18	7.2
	46	4	7.0	4	6.9	**7**	14	3.9	34	4.4	**44**	5	3.8	6	2.6	**16**	9	3.8	42	7.1
	31	5	6.4	6	6.8						**33**	8	7.2	3	4	**45**	10	2.1	33	4.1
	42	6	7.1	5	7.0											**52**	11	3.5	23	5.7
	18	7	5.5	8	5.9											**12**	12	6.3	51	4.4
	21	9	5.1	11	7.2											**2**	13	5.2	14	5.8
	1	11	6.3	10	5.7															
	30	13	5.9	13	6.4															
$\mu_y<\mu$	**5**	16	5	12	5.1						**31**	17	6.4	11	6.8					
	33	17	7.2	9	4						**38**	18	6.9	5	7.4					
	10	20	4	7	6						**9**	27	7.2	10	7.4					
											51	35	2.9	9	2.7					
											49	41	3.2	7	2.5					
											6	46	4.8	8	4.4					

mean CV^y = 4.4
mean CV^v = 5.1

Table A2.3: N_2O linkages Uruguay 2004

	unweighted										weighted									
	$\mu_v>\mu$					$\mu_v<\mu$					$\mu_v>\mu$					$\mu_v<\mu$				
	Sector	BL Ranking	CV^y	FL Ranking	CV^v	**Sector**	BL Ranking	CV^y	FL Ranking	CV^v	**Sector**	BL Ranking	CV^y	FL Ranking	CV^v	**Sector**	BL Ranking	CV^y	FL Ranking	CV^v
$\mu_y>\mu$	**6**	1	7,5	1	7,5	**11**	2	7,5	50	7,4	**6**	2	7,5	1	7,5	**11**	1	7,5	41	7,4
						14	5	7,5	33	7,4						**45**	3	7,5	32	7,3
						25	3	7,5	39	7,4						**28**	4	7,5	50	7,4
						28	4	7,5	53	7,4						**25**	5	7,5	40	7,4
						29	6	7,5	54	7,2										
						45	7	7,5	37	7,3										
$\mu_y<\mu$	**2**	34	5,0	4	7,4						**44**	8	7,3	2	7,5					
	33	55	4,6	5	7,4						**49**	33	7,1	4	7,5					
	34	39	7,1	3	7,5						**33**	46	4,6	3	7,4					
	35	17	7,4	2	7,5															

mean CV^y = 6.7
mean CV^v = 7.2

Table A2.4: National Climate Change Response Plan lines of action for GHGs emission mitigation

Primary Sectors	Cattle farming and dairy products	Best practices in dairy and cattle closures manure management for reducing methane emissions
		Improving animal diets with prairie planting
		Soil carbon sequestration through productivity of pastures promotion
	Agriculture	Soil carbon sequestration through reduced tillage methods, direct seeding and proper selection of crop sequences or pastures rotations
		Promoting innovative management of irrigation and fertilization practices for reducing methane emissions from flooded rice cultivation
		Encourage fossil fuels substitution by agricultural and agroindustrial waste biomass
		Increase fossil energy and nitrogen fertilizer use efficiency
	Forests and Forestry	Encourage efficient forest plantations as carbon sink development
		Encourage use of wood residues from forests and forest industry as alternative energy sources
		Promote native forests protection and enhance their protection through a more efficient application of existing legislation
Energy	Energy matrix diversification	Support specific initiatives of the Strategic Energy Development guidelines for 2015 goals
	Energy efficiency	Ensure continuity of energy efficiency policies developed in the Energy Efficiency Project of the DNE-Uruguay
	Emissions reduction	Identify GHGs mitigation measures for the energy sector, and consider it application in different industries.
		Define and apply energy efficiency standards and norms, in reference to building materials thermal properties and building characteristics
		Residential and services lighting systems efficiency improvement
Transport	Energy consumption reduction	Define plans and policies that would help reduce energy consumption, diversifying the energy matrix and defining actions to improve transport energy use efficiency
		Improve public transport systems for passengers and cargo transport efficiency through alternative transportation and energy sources
		Promote more energy efficient transportation and to continue replacing fossil fuels with biofuels
		Evaluate the potential of the Uruguay river navigation development
Waste	Emissions reduction	New urban biogas capture landfill for reducing methane emissions from decomposition of solid waste
		Promote industrial processes wastewater treatment plants anaerobic lagoons replacement by anaerobic intensive processes
CDM		Public strategy design for taking advantage of opportunities for supporting sustainable developing that can exist

Source: MVOTMA (2010a) and MVOTMA (2010b)

Appendix II. Data and sectoral allocation of environmental degradation indicators

Appendix II is structured in two parts. In the first one data from different sources employed for the analysis is described. In the second, the sectoral allocation of environmental degradation indicators process is described.

AII.1 – Data

Data from different sources is going to be used. On one side, the Input-Output matrix for 2005 constructed by Terra et al. (2009) is employed. It is in tune with most of all the environmental data Greenhouse gases emissions (GHG), collected from the 2004 Greenhouse Gases National Inventory (GGNI04), the most updated source published by the Environmental National Direction (DINAMA) (MVOTMA, 2010). GHG emissions from fuel combustion are allocated between productive sectors employing detailed energy consumption surveys for 2006 by the Energy and Nuclear Technology Direction (DNETN, 2008).

AII.1.1 - Input–Output matrix 2005

Terra et al. (2009) constructs an Input-Output matrix as a result of a technical assistance project to the Agricultural Planning and Policy Office of the Livestock, Agriculture and Fisheries Ministry (MGAP), suited for analyzing in detail the agricultural sector and in its impact through the study of linkages and a computable general equilibrium model.

The matrix is divided in 56 sectors (8 primary sectors, 33 secondary, and 15 tertiary) in basic prices (Table A2.5) employing the National Classification of the Central Bank (CNBCU), that can be straight related to the International Standard Industrial Classification of All Economic Activities, Rev.3 (ISIC Rev. 3). Data is based in System National Accounts (SNA) published by the Central Bank of Uruguay (BCU). BCU has recently completed the review of these accounts based on the Supply and Use Table (SUT) 1997, previously published, and presented the SUT series for the period 1997-2005. Reference year is 2005, which had been a year without shocks for the Uruguayan economy (BCU, 2009). Supplementary data sources from the National Institute of Statistics (INE), the National General Accounting Office (CGN) and the Social Bank (BPS) was employed in it construction.

Looking for technological homogeneity of the production function of each sector, secondary products had been assigned to those productive sectors where the product is manufactured as a principal activity. When the secondary products represent more than 5% of the origin activity, it is reallocated to the destiny activity taking into account it cost structure. When it represent less than the 5% of the origin activity, the reallocation procedure is made automatically, keeping it cost structure at the origin activity, because there are lot of these kind of products, and its impact is really low.

AII.1.2 - Greenhouse Gases National Inventory 2004

The 2004 Greenhouse Gases National Inventory (GGNI04) (MVOTMA, 2010) published by the Environmental National Direction (DINAMA) shows six direct (carbon dioxide, CO2, Methane, CH4, nitrous oxide, N2O, hydrofluorocarbons, HFC, perfluorocarbons, PFC, and sulfur hexafluoride, SF6), and four indirect (nitrogen oxides, NOx, carbon monoxide, CO, Non-methane volatile organic compounds, NMVOC, and sulfur dioxide, SO2) greenhouse gases emissions from six sources: 1. energy, 2. industrial processes, 3. solvents and other products use, 4. agriculture, 5. changes in land use and forestry, and 6. waste (we do not take into account emissions from changes in land use and forestry). Because of it relevance, this chapter only considers CO2, CH4, and N2O emissions (Table A2.6).

AII.1.3 – Energy consumption (DNETN, 2008)

DNTEN (2008) shows the result of a survey of energy consumption by source and use for 42 sectors (14 of agriculture, 18 industries and 10 commerce and services) in 2006. The survey collects energy consumption of 18 sources, in tonne of oil equivalent (TOE): natural gas, supergas (butane), propane, kerosene, petrol, gas oil, diesel oil, fuel oil - heating, fuel oil - heavy, fuel oil, firewood, mineral coke, residual coal oil, coke, waste biomass, solar energy, eolic, electricity (Table A2.7).

AII.2 - Sectoral allocation of environmental degradation indicators

While data from water and solid waste indicators are collected straight from the productive sectors that produce them, GHG emissions becomes from the national inventory, classified by processes. This means that while the first can be straight allocated to the respective productive sector, the second has to take into consideration the different processes that take place in each sector for matching GGNI04 data with the National Accounts structure of the Input Output matrix.

This section describes how GGNI04 data is allocated to economic activities. Eurostat´s Manual for Air Emissions Account (Eurostat, 2009) describes precisely how to assign process based inventory emissions to economic activities. It allows for a straight allocation of the 1996 IPCC classification (IPCC, 2006) used in the GGNI04 to the 1997 Selected Activities for Air Pollution (SNAP) nomenclature employed by the Core Inventory of Air emissions (CORINAIR) developed by the European Topic Centre on Air Emissions, by the time that it describes how to assign SNAP97 process oriented data to the Statistical Classification of Economic Activities in the European Community (NACE). Air pollution accounts in NACE nomenclature is easily converted to ISIC Rev. 3, and hence, to COBCU.

Emissions of five categories (category 5 is not going to be taken into account, because is not straight related to emissions related to productive structure) are allocated in relation to the 2005 Input Output matrix for Uruguay.

1A: Energy

1A1: Energy industry fuel combustion emissions

Following Eurostat (2009) energy industries fuel combustion emissions are allocated as follows: 1A1a, Thermal and power plants to sector E.TTTT.0 Electric Energy, 1A1b, Refinery to D.23TT.0 Refined petroleum products and nuclear fuel, and 1A1c, from gas plants to C.TTTT.0 Crude oil and natural gas, services related to the removal of such products.

1A2 Manufacturing industries and construction fuel combustion emissions

Manufacturing industries emissions straight allocation is not possible. In that way, secondary sources data from DNETN (2008) is needed. The GGNI04 work sheets provides full descriptive information about which kind of source produces the GHG emissions (Table A2.8 to A2.10). In that way, crossing data from the GNNI04 and DNETN (2008) by emission source it is possible to disentangle almost all fuel combustion emissions from manufacturing industries and construction.

Because the aggregation level of the energy use by productive sectors is higher than the one of the IO matrix, this process do not allows to disentangle fuel combustion emissions between: Mills (D.1531.1, Manufacture of rice mill products + D.1531.9, Manufacture of flour and other grain mill products except rice), Other food industries (D.153R.0, Prepared animal feeds, corn oil and starch products + D.154R.0, Bakery and noodles industry + D.154S.0, Refined, crude and impalpable sugar), Beverages and tobacco (D.1552.0, Regular and sparkling wines + D.1553.0, Malt liquors and malt + D.155S.0, Distilling, rectifying and blending of spirits; ethyl alcohol production from fermented materials + D.1600.0, Manufacture of tobacco products), Textiles (D.171T.0, Spinning, weaving and finishing of textiles, and manufacture of other textiles + D.17RT.0, Manufacture of knitted and crocheted fabrics and articles), Leather (D.18TT.0, Dressing and dyeing of fur; manufacture of articles of fur + D.191T.0, Tanning and dressing of leather; manufacture of luggage, handbags, saddlery and harness + D.1920.0, Manufacture of footwear), Paper (D.210T.0, Manufacture of paper and paper products + D.22TT.0, Publishing, printing and reproduction of recorded media), and Chemicals (D.24RT.0, Manufacture of pesticides and other agro-chemical products, fertilizers and nitrogen compounds + D.24ST.0, Manufacture of pharmaceuticals, medicinal chemicals and botanical products + D.24UT.0, Manufacture of basic chemicals, except of pesticides and other agro-chemical products, fertilizers and nitrogen compounds).

This would imply to work with a higher level of aggregation than the 56 sectors available at the IO matrix. While the level of aggregation is still low, and would allow a good performance of the analysis, a final effort can be done for disentangling the emissions from these sectors. This is relevant in particular for disentangling the behavior of the rice mill sector from other mill products, because the high weight of this sector in the Uruguayan economy, and it difference in the technological structure, food manufactures from beverage and tobacco, as consequence of the high weight of this sector in the economy, leather and footwear manufactures from other textile industry, as well as pharmaceutical industry from basic chemicals, as consequence of it heterogeneity in the technological structure and linkages with the rest of the economy.

For split them, the suggested procedure of allocating emissions in function of each sector energy´s demand is employed (Eurostat, 2009).

Biomass burning CO2 emissions

Biomass includes wood and waste biomass, bagasse, rice hulls, black liquor and sunflower husk. While 69.5% of this emissions is produced by private households, the others are allocated between Manufacturing industries and Commercial / institutional (29.8% and 0.7% respectively).

These emissions can be split between productive sectors using DNETN (2008). A greater disaggregation is reached with the same strategy than before, but in this time in reference to the demand of each sector from sector D.20TT.0, Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials.

1A3: Transport fuel combustion emissions

Transport fuel combustion emissions assignation is not an easy task. A territory system boundaries to the residence principle is required. That is, emissions of residents in domestic and international journeys, as well as those international journeys leaving from abroad. This means to adjust transport fuel combustion emissions, adding those made by residents leaving from abroad the country, and substracting those made by no residents in the country in domestic and international journeys (Eurostat, 2009). GNNI04 provides emissions from transport fuel combustion estimations based in fuel sold in the country. In this way, this adjustment is necessary, but there exist not secondary sources to approach it. In this way, the assumption that total emissions from transport fuel combustion are produced by residents is going to be done, and this fact must be taken into account when interpreting results.

In this way, transport emissions from fuel combustion by 1A3a, domestic aviation and 1A3d, domestic navigation are straight allocated to sector I.RRTT.0, Passenger services and freight cabotage vessels, oceangoing and inland, while those from 1A3c, railway are assigned to I.60TT.0, Freight services by land and pipeline transportation service. It must be noted that.

However, 1A3b, road transport emissions is not an easy task. GNNI04 accounts emissions from both, economic activities and particular households. A first split between private households and productive sectors transport has to be done. In a second step, those emissions belonging to industries has to be disentangled between productive sectors, because GNNI04 accounts for both, those emissions from sector for which transport is their primary product and for those that it is a secondary product (Eurostat ,2009).

There is not a straight way for the first step, because any statistical source allows to disentangle between private households and industries fuel consumption. However, it is possible to distinguish it between types of vehicles (cars, motorcycles, trucks, taxis and buses). The assumption that the first two are employed exclusively by private households, while the last three are only used by productive sectors is going to be made. This is the best approach, despite it do not account emissions from those sectors that employ cars and motorcycles, and includes extra emissions from those trucks, taxis and buses that are not being used for productive activities. This means that 61.6%, 33.8% and 72.1% of total CO_2, CH_4, N_2O road transport emissions respectively are produced by productive sectors.

The IO matrix employed reallocates road transport activities developed as a secondary activity into sector I.60TT.0 Freight services by land and pipeline transportation service. In this way, the second split must not be done, and all the road transport emissions are allocated at it.

International Bunkers

Finally, under the first assumption previously done, emissions from fuel combustion related to aviation and marine international bunkers, that the GNNI04 records separately, are allocated to sector I.RRTT.0 Water transport, air transport, supporting and auxiliary transport activities; activities of travel agencies.

Because of data availability problems, it was not possible to split Internationl Bunkers emissions both, through emissions from households and productive systems, and by the residential criteria. In this way, that the whole International Bunkers emissions became from Uruguayan productive sectors is assumed.

1A4: Other sectors fuel combustion emissions

While fuel combustion emissions from category 1A4b, residential are not taken into account, those from 1A4a, Commercial / Institutional and 1A4c, Agriculture/ Forestry / Fishing are disentangled employing DNETN (2008) data source, as before (Table A2.8 to A2.10).

In that way, fuel combustion emissions from 1A4a, Commercial / Institutional are split in 10 economic activities, while the once from 1A4c, Agriculture/ Forestry / Fishing can disentangled in 14 economic activities, that can be aggregated to the 8 agricultural economic sector from the IO matrix.

1A5 Others (not accounted anywhere else) from fuel combustion

This emission category is not allocated anywhere, because is not possible to know it source. By the time, it represents only 0.085% of total CO_2 emissions.

1B Fugitive emissions from fuel

GNNI04 worksheets allows to allocate fugitive emissions from 1B1, Solid fuels are entirely allocated in sector D.23TT.0 Manufacture of coke, refined petroleum products and nuclear fuel, while those from 1B2, Petrol and natural gas are split between this sector (16.5%), because of those coming from petrol refinery, and E.TTTT.0 Electric Energy, because of those emitted during natural gas distribution (83.5%).

2 Industrial processes

Emissions from industrial processes can be straight assigned, one to one, between economic activities, based in Eurostat (2009). There is only one exception that is not possible to split straight, because emissions becoming from 2A4, Sodium carbonate production use are produced both by sector D.24UT.0, Manufacture of basic chemicals, except of pesticides and other agro-chemical products, fertilizers and nitrogen compounds and D.26TT.0 Manufacture of other non-metallic mineral products.

Emissions from this category in Uruguay only becomes from the sodium carbonate imported for the production of soap and glass. In this way, seeking a similar strategy than the one proposed by Eurostat (2009), this emissions are allocated between this two productive sectors proportionally to the imported inputs in total product of these (79.4% and 20.6% respectively).

4 Agriculture

Emissions of methane from agriculture can be straight allocated to the corresponding productive sector, one to one, based in Eurostat (2009). Split between milk and meat cattle is possible with GNNI04 worksheets.

6 Waste

On the one hand, category 6A, Solid waste disposal are estimated in reference to waste that is disposed in municipal landfills. In that way, all this category is straight allocated to sector O.TTTT.0, Sewage and refuse disposal, sanitation and similar activities, activities of membership organizations n.e.c., recreational, cultural and sporting activities, and other service activities.

On other hand, 98.3% of category 6B1, Industrial wastewater can be split between productive sectors employing GNNI04 worksheets. The complement is referred to “Other industries” that cannot be split.

Finally, emissions from 6B2 Domestic and comercial wastewater reaches 7.3% of total wastewater treatment emissions, and they cannot be split between them. Because of both this factors, they are not taken into account.

Table A2.5 - Input-Output 2005 matrix sector description (Terra et al., 2009)

Nº	Cod BCU	Sector
1	A.0111.1	Rice growing and related services activities
2	A.0111.9	Other cereals and crops n.e.c. growing and related services activities
3	A.0112.0	Vegetables, horticultural specialties and nursery products growing and related services activities
4	A.0113.0	Fruit, nuts, beverage and spice crops growing and related services activities
5	A.0121.1	Raw milk and milk products prepared in premises, and related services activities
6	A.0121.9	Cattle, sheep, goats, horses, asses, mules and hinnies farming and related services activities
7	A.0122.0	Other animal farming; production of animal products n.e.c.
8	A.0200.0	Forestry, logging and related service activities
9	B.0500.0	Fishing, operation of fish hatcheries and fish farms; service activities incidental to fishing
10	C.TTTT.0	Mining and quarrying
11	D.1511.0	Production, processing and preserving of meat and meat products
12	D.1512.0	Processing and preserving of fish and fish products
13	D.1513.0	Processing and preserving of fruit and vegetables
14	D.1514.0	Manufacture of vegetable and animal oils and fats
15	D.1520.0	Manufacture of dairy products
16	D.1531.1	Manufacture of rice mill products
17	D.1531.9	Manufacture of flour and other grain mill products except rice
18	D.153R.0	Manufacture of prepared animal feeds
19	D.154R.0	Manufacture of bakery, macaroni, noodles, couscous and similar farinaceous products
20	D.154S.0	Manufacture of sugar, cocoa, chocolate and sugar confectionery, and other food products n.e.c.
21	D.1552.0	Manufacture of wines
22	D.1553.0	Manufacture of malt liquors and malt
23	D.155S.0	Distilling, rectifying and blending of spirits; ethyl alcohol production from fermented materials
24	D.1600.0	Manufacture of tobacco products
25	D.171T.0	Spinning, weaving and finishing of textiles, and manufacture of other textiles
26	D.17RT.0	Manufacture of knitted and crocheted fabrics and articles
27	D.18TT.0	Dressing and dyeing of fur; manufacture of articles of fur
28	D.191T.0	Tanning and dressing of leather; manufacture of luggage, handbags, saddlery and harness
29	D.1920.0	Manufacture of footwear
30	D.20TT.0	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
31	D.210T.0	Manufacture of paper and paper products
32	D.22TT.0	Publishing, printing and reproduction of recorded media
33	D.23TT.0	Manufacture of coke, refined petroleum products and nuclear fuel
34	D.24RT.0	Manufacture of pesticides and other agro-chemical products, fertilizers and nitrogen compounds
35	D.24ST.0	Manufacture of pharmaceuticals, medicinal chemicals and botanical products
36	D.24UT.0	Manufacture of basic chemicals, except of pesticides and other agro-chemical products, fertilizers and nitrogen compounds
37	D.25TT.0	Manufacture of rubber and plastics products
38	D.26TT.0	Manufacture of other non-metallic mineral products
39	D.RRTT.0	Manufacture of basic metals, fabricated metal products, except machinery and equipment, machinery and equipment n.e.c., office, accounting and computing machinery, electrical machinery and apparatus n.e.c., radio, television and communication equipment and apparatus, medical, precision and optical instruments, watches and clocks
40	D.SSTT.0	Manufacture of motor vehicles, trailers and semi-trailers, and other transport equipment
41	D.UUTT.0	Manufacture of furniture; manufacturing n.e.c., and recycling
42	E.TTTT.0	Electricity, gas and water supply
43	F.45TT.0	Construction
44	G.TTTT.0	Wholesale and retail trade; repair of motor vehicles, motorcycles and personal and household goods
45	H.55TT.0	Hotels and restaurants
46	I.60TT.0	Land transport; transport via pipelines
47	I.RRTT.0	Water transport, air transport, supporting and auxiliary transport activities; activities of travel agencies
48	I.64TT.0	Post and telecommunications
49	J.TTTT.0	Financial intermediation
50	K.70TT.0	Real estate activities
51	K.RRTT.0	Renting of machinery and equipment without operator and of personal and household goods, computer and related activities, research and development, and other business activities
52	L.75TT.0	Public administration and defence; compulsory social security
53	M.80TT.0	Education
54	N.85TT.0	Health and social work
55	O.TTTT.0	Sewage and refuse disposal, sanitation and similar activities, activities of membership organizations n.e.c., recreational, cultural and sporting activities, and other service activities
56	P.9500.0	Private households with employed persons

Table A2.6: Greenhouse Gase emissions by source - 2004 (in CO_2 equivalente units*)

Source	Emisions		
	CO2 (Gg)	CH4 (Gg)	N2O (Gg)
Total Nationa Emitions	**5.439,8**	**18.634,4**	**12.183,0**
1 Energy	**5.122,6**	**29,4**	**34,1**
1A Fuel combustion	5.122,6	10,3	34,1
1A1 Energy industries	1.311,3	0,9	1,6
1A1a Thermal pow er plants	894,5	0,7	1,2
1A1b Refinery	416,2	0,1	0,5
1A1c Other energy industries (Gas Plant)	0,6	0,0	0,0
1A2 Manufacturing industries and construction	538,5	1,5	0,5
1A3 Transport	2.211,2	7,4	25,7
1A3a Domestic aviation	11,2	0,1	0,0
1A3b Road	2.024,4	6,9	24,2
1A3c Railw ay	13,9	0,0	0,1
1A3d Domestic navigations	161,7	0,2	1,4
1A4 Other sectors	1.056,9	0,5	5,0
1A4a Commercial / Institutional	137,8	0,0	0,4
1A4b Residential	374,1	0,1	0,0
1A4c Agriculture/ Forestry / Fishing	545,0	0,3	4,7
1A5 Others (not accounted anyw here else)	4,6		NA
1B Fugitive emissions from fuel		19,3	0,0
1B1 Solid fuels		0,7	0,0
1B2 Petrol and natural gas		18,5	0,0
2 Industrial processes	**317,2**		**NH**
2A Mineral products	317,2		0,0
2A1 Cement production	291,2		0,0
2A2 Lime production	24,6		0,0
2A4 Sodium carbonate production and use	1,4		0,0
2A5 Asphalt paving			0,0
2B Chemistry industry	NH		NH
2C Metal production	NH		NH
2D Others´ production (paper, pulp, food and	NA		0,0
2D1 Paper and pulp			0,0
2D2 Food and beverages			0,0
2E Halocarbons and sulfur hexafluoride			0,0
2F Halocarbons and sulfur hexafluoride			0,0
2F1 Air conditioning and refrigeration			0,0
2F2 Foams			0,0
2F3 Fire extinguishers			0,0
2F4 Aerosols			0,0
2F6 Others (high voltage electrical insulation)			0,0
2G Others (specify)	NH		NH
3 Solvents and other products use	**NE**		**NE**

Table A2.6 (cont.): Greenhouse Gase emissions by source - 2004 (in CO_2 equivalente units*)

Source	Emisions		
	CO2	CH4	N2O
	(Gg)	(Gg)	(Gg)
4 Agriculture		**17.251,9**	**12.071,4**
4A Enteric fermentation		16.170,0	0,0
4A1 Cattle		14.980,6	0,0
4A2 Buffalos			0,0
4A3 Sheeps		1.025,4	0,0
4A4 Goats		1,6	0,0
4A5 Camels and llamas			0,0
4A6 Horses		157,3	0,0
4A7 Mules and donkeys		0,2	0,0
4A8 Pigs		5,0	0,0
4A9 Poultry			0,0
4B Manure management		333,3	31,0
4B1 Cattle		265,4	0,0
4B2 Buffalos			0,0
4B3 Sheeps		37,0	0,0
4B4 Goats		0,1	0,0
4B5 Camels and llamas			0,0
4B6 Horses		17,4	0,0
4B7 Mules and donkeys		0,0	0,0
4B8 Pigs		8,8	0,0
4B9 Poultry		4,4	0,0
4C Rice		743,4	0,0
4D Agricultural soils		0,0	12.034,2
4E Prescribed burning of savannas		4,6	4,7
4F Agriculture waste burning in the countryside		0,9	0,5
4G Others (specify)			NH
5 Changes in land use and forestry			**NA/NH**
5A Changes in forest biomass and other woody vegetation	8.493,1		0,0
5A2 Temperate	8.493,1		0,0
5B Forest and grassland conversion	NH		NH
5C Abandonment of managed lands			0,0
5D Soil emissions			0,0
5E Others (specify)	NA		NA
6 Waste		**1.352,8**	**77,5**
6A Solid waste disposal		1.132,1	0,0
6B Wastewater treatment		220,7	NE
6B1 Industrial wastewater		204,5	0,0
6B2 Domestic and comercial		16,2	0,0
6C Waste inciniration		0,0	0,0
6D Others (human excrement)			77,5
7 Others (specify)	**NA**	**NA**	**NA**
Memorandum items			**0,0**
International Bunkers	1.198,6	0,1	NE
Aviation	130,2	0,1	NE
Marine	1.068,4		NE
Biomass burning CO2 emissions	2.039,0	0,0	0,0
Total	**26.338,7**	**18.731,4**	**12.316,4**

***equivalent units employing Global-warming Potencial (GWP) in a 100 years term**

Note: NH, not happens; NE, not estimated; NA, not applies

Source: MVOTMA (2010)

Table A2.7: Energy consumption by sources and subsectors (TEP - 2006)

Subsectors	NG	SG	Prop	KE	Pet	GO	DO	FO Hea	FO Het	FO	FW	MC	RC	CQ	WB	SO	EO	EE	Total
Agriculture																			
Fishing		18			1,392	41,327												8,955	51,693
Minery		4			19	10,405					1,089							5,522	17,039
Fruits		6			63	3,235					22							841	4,167
Viticulture		14			33	1,590					580							472	2,688
Horticulture		23		4	41	3,088					166							528	3,851
Cereals and industrials		41		1	150	29,066					587					1,607	2,701	681	34,836
Rice		116			149	23,372					115						35	5,061	28,848
Milk cattle		163			227	16,563					1,898						226	8,198	27,275
Meat cattle		82		0	162	11,304					686					51	126	943	13,355
Sheeps		575		308	504	3,826					3,675						189	321	9,398
Pigs		14		37	34	278					77						33	156	630
Poultry		1,085			32	1,266					17,066						97	2,319	21,864
Forest		44		3	76	1,235					314				5		18	114	1,808
Agricultural cooperatives											4,346								4,346
SubT Agropecuary	**0**	**2,186**	**0**	**353**	**2,882**	**146,555**	**0**	**0**	**0**	**0**	**30,621**	**0**	**0**	**0**	**5**	**1,658**	**3,425**	**34,111**	**221,797**
Manufacturing industries and construction																			
Cold stores	5,681	19	206		9	201	14			10,605	20,295							20,400	57,432
Dairy industry	7,946	19			4	118				17,127	15,971							11,494	52,679
Mills		4	61		2	505				89	18,876				1,560			9,517	30,613
Other food industries	8,831	266	669		42	2,259				7,124	22,784				14,533			16,787	73,295
Beverages and tobacco	2,673	845	10		4	525				2,197	19,557				783			8,305	34,900
Textil	2,598	1,540			3	478				7,544	15,443							11,784	39,391
Leather	1,311	9	82			422				4,459	5,694							5,598	17,573
Wood		7			8	2,009				300	1,957				24,055			4,331	32,667
Paper	12,596	42	699		0	456	60			6,829	28,801				15,241			16,253	80,977
Chemical (exept. Oil)	159	76	1		2	669	118			4,742	1,444				143			11,946	19,300
Rubber and plastic	58	207	29		12	541	4			119	78							7,777	8,825
Glass		44	14			9				16								396	480
Ceramic	7,506	6	781			277				2,904	1,329							1,699	14,502
Cement	15,577	3				95				16,101			28,179		9,170			8,154	77,280
Basic metals	1,096	96	1,751			392	19			2,624		1,231		836				7,117	15,161
Machinery and equipment	158	266	68		12	833				319	494			54				7,675	9,881
Other manuf.		5				295												817	1,117
Construction		36			50	9,236	38											2,019	11,380
SubT Industries and const.	**66,190**	**3,490**	**4,371**	**0**	**148**	**19,320**	**253**	**0**	**0**	**83,099**	**152,723**	**1,231**	**28,179**	**890**	**65,485**	**0**	**0**	**152,069**	**577,453**

Table A2.7 (cont.): Energy consumption by sources and subsectors (TEP - 2006)

Subsectors	NG	SG	Prop	KE	Pet	GO	DO	FO Hea	FO Het	FO	FW	MC	RC	CQ	WB	SO	EO	EE	Total
Commercial and institutional																			
Wholesale and retali trade	456	1,808	24	91	2	651		139			4,130							45,777	53,078
Education	144	521			237	320		255	82		317							5,119	6,995
Health	1,463	83	36		1	223	23	7,888	76		424							9,234	19,451
Hotels	948	222	1,855		24	57		1,156	1,233		1,080							7,531	14,105
Restaurants	1,614	1,283	238	4	4	10					8,080							5,705	16,937
Financial and assurance establishm	16	30				72		431			36							6,356	6,941
Public admin. and military	11	350	115	0	33	2,870	12	925			1,463							11,741	17,519
Water supply	27	22			5	10	66				122							22,627	22,879
Other services	417	1,153	72	293	115	1,588	13	5,104	8,421		3,774							63,810	84,759
Street lighting																		18,593	18,593
SubT Com. And SS.	**5,096**	**5,472**	**2,340**	**388**	**421**	**5,801**	**114**	**15,898**	**9,812**	**0**	**19,426**	**0**	**0**	**0**	**0**	**0**	**0**	**196,493**	**261,257**
Total	**71,288**	**11,089**	**6,711**	**742**	**1,989**	**110,708**	**329**	**15,898**	**9,811**	**83,100**	**201,681**	**1,231**	**28,179**	**890**	**65,490**	**1,659**	**3,426**	**366,179**	**980,399**

Natural Gas (NG), Supergas (butane) (SG), Propane (Prop), Kerosene (KE), Petrol (Pet), Gas Oil (GO), Diesel Oil (DO), Fuel Oil - Heating (FO Hea), Fuel Oil - Heavy (FO Hev), Fuel Oil (FO), Firewood (FW), Mineral Coke (MC), Residual Coal Oil (RC), Coke (CQ), Waste Biomass (WB), Solar Energy (SO), Eolic (EO), Electricity (EE)

Source: DNETN (2008)

Table A2.8 CO_2 emissions by energy type

Source	Natural Gas	Supergas (butane)	Propane	Kerosene	Petrol	Gas Oil	Diesel Oil	Fuel Oil (heat)	Fuel Oil (heavy)	Fuel Oil	Coal	Total GNNI
1A Fuel combustion												
1A2 Manufacturing industries and construction	25.57%	0.54%	1.32%		0.11%	4.11%	0.03%			66.52%	0.63%	98.84%*
1A4 Other sectors												
1A4a Comercial / Institutional	14.08%	0.38%	5.17%	0.22%		61.78%	1.21%	10.61%	6.55%			100%
1A4c Agriculture/ Forestry / Fishing					3.89%	96.11%						100%

* The 1.16% of emissions not allocated are produced from kerosene, anthracite and peat, that could not be allocated between sectors.
Source: MVOTMA (2010)

Table A2.9: CH_4 emissions by energy type

Source	Natural Gas	Supergas (butane)	Propane	Kerosene	Petrol	Gas Oil	Diesel Oil	Fuel Oil (heat)	Fuel Oil (heavy)	Fuel Oil	Coal	Coke	Total GNNI
1A Fuel combustion													
1A2 Manufacturing industries and	2.08%			0.06%	0.01%	0.69%	0.01%			96.26%	0.21%	0.69%	100%
1A4 Other sectors													
1A4a Comercial / Institutional	19.96%			0.19%		52.20%	1.03%	16.46%	10.16%				100%
1A4c Agriculture/ Forestry / Fishing						100%							100%

Source: MVOTMA (2010)

Table A2.10: N_2O emissions by energy type

Source	Natural Gas	Supergas (butane)	Propane	Kerosene	Petrol	Gas Oil	Diesel Oil	Fuel Oil (heat)	Fuel Oil (heavy)	Fuel Oil	Coal	Petrol Coal	Total GNNI
1A Fuel combustion													
1A2 Manufacturing industries and					0.20%	6.47%	0.06%			91.32%		0.65%	98.7%*
1A4 Other sectors													
1A4a Comercial / Institutional	49.93%			0.14%		40.81%	0.80%	5.15%	3.18%				100%
1A4c Agriculture/ Forestry / Fishing						100%							100%

* The 1.3% of emissions not allocated are produced from kerosene that could not be allocated between sectors.
Source: MVOTMA (2010)

Chapter 3

INPUT–OUTPUT SUBSYSTEMS: AGRO INDUSTRIAL CH_4 AND SERVICES CO_2 EMISSIONS IN URUGUAY

Abstract

This chapter analyzes methane emissions of the agro industrial subsystem and carbon dioxide emissions of the services sectors subsystem in Uruguay in 2004. The relationship of these subsystems with the rest of the economy is analyzed through input–output methodology employing a multiplicative decomposition. This is combined with an additive decomposition for the study of the linkages within them. This approach allows to study the importance of these subsystems as units in the economic structure as well as to analyze in detail the relationship between the different branches in each of the subsystems. The results depict in which sectors mitigation policies are more effective, and if they would be better tackled through technical improvements and better practices, or through demand policies.

3.1 Introduction

Greenhouse gas (GHG) emissions from the Uruguayan productive structure reached 36,773 ktons. (in carbon dioxide equivalent units) in 2004[1]. The Uruguayan National Climate Change Response Plan (NCCRP) (MVOTMA, 2010a) exposes the strategic lines of action for GHGs mitigation. These make reference, in general terms, to improve practices in primary sectors and waste management, and to improve energy efficiency and reduce energy consumption. Input–output analysis (IOA) extended to GHGs emissions would help to determine which kind of policy measures are better and in which sectors are interventions more effective to mitigate GHGs emissions.

Since Hirschman (1958), IOA has been a widely used tool for measuring the structural interdependence and for key sectors analysis. IOA extended to the environmental dimension allows for a more complete understanding of the relationship between the economy and material flows, which is essential for fully understanding environmental problems and the policy design to solve them (Hoekstra, 2005).

Key sectors analysis provides an overview about the relationship between the productive structure and the environment. However, sometimes it is more important to focus on the most relevant sectors, and not to analyze the environmental impact of the whole economic system, studying their relationship with the environment with greater complexity, and paying attention to their relationships with the entire production system (Alcántara, 1995). If we consider a system of industries in which each produces a different commodity, as defined in IOA, *"such a system can be subdivided into as many parts as there are commodities in its net product, in such a way that each part forms a smaller self-replacing system, the net product of which consists of only one kind of commodity. These parts we shall call 'subsystems"* (Sraffa, 1960, p. 89).

Harcourt and Massaro (1964) made the first proposal for the construction of subsystems, but this idea was first formalized by Pasinetti (1977), calling Sraffa's subsystem concept as vertically integrated sector. This approach considers the economic

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[1] Accounts for CO_2, CH_4 and N_2O. Sectoral allocation of emissions is elaborated by the authors based on MVOTMA (2010b) and DNETEN (2008), following the Eurostat (2009) methodology. An appendix detailing this process is available upon request.

subsystem as an analytical unit drawn from the economic system that can be studied keeping the characteristics of the economic system. Thus, subsystems analysis allows studying the structure of each of the industries involved in the economic system, while it increases the explanatory power of the traditional approach of key sectors analysis, providing a greater level of disaggregation of the linkages between those branches within the subsystem, and between the subsystem branches and the rest of the economy (Alcántara and Padilla, 2009; and Navarro and Alcántara, 2010).

Subsystems analysis of the relationship between the productive structure and the environment was first proposed by Alcántara (1995), who applied it to sulfur dioxide (SO_2), nitrogen oxides (NO_X) and volatile organic compounds emissions in Spain in 1985, through an additive decomposition of the emissions generated by each industry into five components: i) scale; ii) feedback; iii) own; iv) spillover; and v) the spillover of the rest of the economy.

Alternative additive decompositions are employed to analyze the environmental impact in water resources pollution in Aragon, Spain, in 1995 by Sánchez-Chóliz and Duarte (2003), carbon dioxide emissions (CO_2) in the services subsystem in Spain in 2000 by Alcántara and Padilla (2009), and methane (CH_4) emissions in the agricultural and food industry in Catalonia, Spain, in 2001, by Navarro and Alcántara (2010). A multiplicative decomposition derived from the Miyazawa multipliers is employed by Firtz et al. (1998) to analyze how the subsystem of non-polluting sectors influence in the emissions of air polluting sectors in the Chicago region.

Methane represents half of total GHGs emissions of the Uruguayan productive structure in 2004. Direct pollution of this gas is clearly concentrated in primary sectors (92.7% of total methane emissions). In this way, the subsystem benchmark is an ideal framework for decomposing in detail those sector emissions, helping for a better methane mitigation policies design.

Historically the idea that services are non-material because they are lower capital intensive sectors has been developed. This concept has been taken as if the services activities have low impact on the environment and that they consume less energy.[2] As Fourcroy et al. (2012) remarks, services provision is developed through interactions with customers, that are reached through the combination of operations, conditioning, and travel. Each of these elements requires direct energy consumption (and hence pollution), but also requires other sectors to pollute when taking part of these interactions. This goes against the false perception that services sectors are non-materialized as shown by several authors (Suh, 2006; Nansai et al., 2007; Alcántara and Padilla, 2009; and Fourcroy et al., 2012). Despite carbon dioxide emissions only represent 16.6% of total Uruguayan GHGs in 2004, half of them are directly related to services sectors. The NCCRP only tackles transport sector emissions in its lines of action, giving priority to the reduction of energy consumption emissions, while energy efficiency is addressed in general terms. In this sense, the decomposition of services subsystem multipliers would allow to orientate the design of mitigation policies.

The present chapter analyzes methane emissions of the agro industrial subsystem and carbon dioxide emissions of services sectors subsystem in Uruguay in 2004. We propose to combine two decomposition methodologies. First, we apply the multiplicative decomposition developed by Pyatt and Round (1979) and latter applied to interregional multipliers by Miller (1969), Sonis and Hewings (1993), and Dietzenbacher (2002) to analyze the relation between each subsystem with the rest of the economy. This methodology captures the full circular flow of transactions for production in the economy. Second, we apply an additive decomposition, combining different subsystems approaches, for analyzing the relationship inside the subsystem itself. This allows for a more intuitive and easier interpretation of the relationships between the sectors of the subsystem. Multipliers decomposition can be interpreted as systems that produce *pollution by means of pollution* (Alcántara, 1995), as an environmentally extended application of Sraffa’s (1972) *production of commodities by means of commodities*.

The methodology is presented in next section. Section 3.3 shows the case of methane emissions in the agro industrial subsystem, while section 3.4 presents the results in

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[2] Fourcroy et al. (2012) shows an excellent review of the evolution of the concept of non-materiality of services.

reference to carbon dioxide emissions in the services subsystem. Conclusions are presented in last section.

3.2 Methodology

The Leontief model identity, $\boldsymbol{x'} = (\boldsymbol{I} - \boldsymbol{A})^{-\mathbf{1}}\boldsymbol{y'} = \boldsymbol{L}\boldsymbol{y}'$, denotes the relationship between total output levels (***x'***) required in an economy to hold a final demand column vector (***y'***) through the inverse Leontief matrix (or matrix of coefficients of direct and indirect requirements per unit of final demand)[3]. Matrix $\boldsymbol{A}$ is the Leontief technical coefficients matrix, whose elements, a_{ij}, depict the weight of how much sector *j* purchases to sector *i* in relation to total sector *j* production. To isolate the effects of subsystem *s* this model can be rewritten in a partitioned way as:

$$(1) \qquad \begin{pmatrix} \boldsymbol{x}^{s\prime} \\ \boldsymbol{x}^{r\prime} \end{pmatrix} = \left(\begin{bmatrix} \boldsymbol{I}_{s\times s} & \mathbf{0} \\ \mathbf{0} & \boldsymbol{I}_{r\times r} \end{bmatrix} - \begin{bmatrix} \boldsymbol{A}_{ss} & \boldsymbol{A}_{sr} \\ \boldsymbol{A}_{rs} & \boldsymbol{A}_{rr} \end{bmatrix} \right)^{-\mathbf{1}} \begin{pmatrix} \boldsymbol{y}^{s\prime} \\ \boldsymbol{y}^{r\prime} \end{pmatrix} = \begin{bmatrix} \boldsymbol{L}_{ss} & \boldsymbol{L}_{sr} \\ \boldsymbol{L}_{rs} & \boldsymbol{L}_{rr} \end{bmatrix} \begin{pmatrix} \boldsymbol{y}^{s\prime} \\ \boldsymbol{y}^{r\prime} \end{pmatrix}$$

and following Pyatt and Round (1979), Round (1985, 2001) and Dietzenbacher (2002) the inverse Leontief matrix, $\boldsymbol{L}$, can be decomposed as follows:

$$(2) \qquad \begin{pmatrix} \boldsymbol{x}^{s\prime} \\ \boldsymbol{x}^{r\prime} \end{pmatrix} = \begin{bmatrix} \boldsymbol{F}_s & \mathbf{0} \\ \mathbf{0} & \boldsymbol{F}_r \end{bmatrix} \times \begin{bmatrix} \boldsymbol{I}_{s\times s} & \boldsymbol{S}_{sr} \\ \boldsymbol{S}_{rs} & \boldsymbol{I}_{r\times r} \end{bmatrix} \times \begin{bmatrix} \boldsymbol{M}_s & \mathbf{0} \\ \mathbf{0} & \boldsymbol{M}_r \end{bmatrix} \begin{pmatrix} \boldsymbol{y}^{s\prime} \\ \boldsymbol{y}^{r\prime} \end{pmatrix}$$

$$= \begin{bmatrix} \boldsymbol{F}_s\boldsymbol{M}_s & \boldsymbol{F}_s\boldsymbol{S}_{sr}\boldsymbol{M}_r \\ \boldsymbol{F}_r\boldsymbol{S}_{rs}\boldsymbol{M}_s & \boldsymbol{F}_r\boldsymbol{M}_r \end{bmatrix} \begin{pmatrix} \boldsymbol{y}^{s\prime} \\ \boldsymbol{y}^{r\prime} \end{pmatrix}$$

where:

$\boldsymbol{M}_s = (\boldsymbol{I} - \boldsymbol{A}_{ss})^{-1}$ and $\boldsymbol{M}_r = (\boldsymbol{I} - \boldsymbol{A}_{rr})^{-1}$;

$\boldsymbol{S}_{sr} = (\boldsymbol{I} - \boldsymbol{A}_{ss})^{-1}\boldsymbol{A}_{sr}$ and $\boldsymbol{S}_{rs} = (\boldsymbol{I} - \boldsymbol{A}_{rr})^{-1}\boldsymbol{A}_{rs}$; and

$\boldsymbol{F}_s = [\boldsymbol{I} - (\boldsymbol{I} - \boldsymbol{A}_{ss})^{-1}\boldsymbol{A}_{sr}(\boldsymbol{I} - \boldsymbol{A}_{rr})^{-1}\boldsymbol{A}_{rs}]^{-1} = [\boldsymbol{I} - \boldsymbol{S}_{sr}\boldsymbol{S}_{rs}]^{-1}$ and

$\boldsymbol{F}_r = [\boldsymbol{I} - (\boldsymbol{I} - \boldsymbol{A}_{rr})^{-1}\boldsymbol{A}_{rs}(\boldsymbol{I} - \boldsymbol{A}_{ss})^{-1}\boldsymbol{A}_{sr}]^{-1} = [\boldsymbol{I} - \boldsymbol{S}_{rs}\boldsymbol{S}_{sr}]^{-1}$

The production needed to obtain total output of subsystem *s* can be isolated assuming $\boldsymbol{y}^r = \mathbf{0}$, such that:

---

[3] In this chapter, elements in **bold** denote vectors and matrices (lowercase and uppercase, respectively), while the scalars will be expressed in plain text. In turn, the ^ symbol over a vector element refers to a diagonal matrix composed of the specified vector.

(3) $$\begin{pmatrix} \boldsymbol{x}_s^{s\prime} \\ \boldsymbol{x}_s^{r\prime} \end{pmatrix} = \begin{bmatrix} \boldsymbol{L}_{ss} & \boldsymbol{L}_{sr} \\ \boldsymbol{L}_{rs} & \boldsymbol{L}_{rr} \end{bmatrix} \begin{pmatrix} \boldsymbol{y}^{s\prime} \\ \boldsymbol{0} \end{pmatrix} = \begin{bmatrix} \boldsymbol{F}_s\boldsymbol{M}_s & \boldsymbol{F}_s\boldsymbol{S}_{sr}\boldsymbol{M}_r \\ \boldsymbol{F}_r\boldsymbol{S}_{rs}\boldsymbol{M}_s & \boldsymbol{F}_r\boldsymbol{M}_r \end{bmatrix} \begin{pmatrix} \boldsymbol{y}^{s\prime} \\ \boldsymbol{0} \end{pmatrix}$$

where $\boldsymbol{x}_s^s$ is the production of subsystem *s* for attending its final demand, and $\boldsymbol{x}_s^r$ is the production of the rest of the economy to be employed as input by subsystem *s*. Pre multiplying (3) by $\boldsymbol{u}$, a summation row vector, the total production of the economy that is needed for the final demand of subsystem *s* is reached:

(4) $$\boldsymbol{u}_{1\times n} \begin{pmatrix} \boldsymbol{x}_s^{s\prime} \\ \boldsymbol{x}_s^{r\prime} \end{pmatrix} = \boldsymbol{u}_{1\times s}\boldsymbol{L}_{ss}\boldsymbol{y}^{s\prime} + \boldsymbol{u}_{1\times r}\boldsymbol{L}_{rs}\boldsymbol{y}^{s\prime} = \boldsymbol{u}_{1\times s}\boldsymbol{F}_s\boldsymbol{M}_s\boldsymbol{y}^{s\prime} + \boldsymbol{u}_{1\times r}\boldsymbol{F}_r\boldsymbol{S}_{rs}\boldsymbol{M}_s\boldsymbol{y}^{s\prime}$$

where the first term accounts both, subsystem *s* internal transactions for satisfying its final demand and a *feedback* component, which accounts the sales of subsystem *s* to the rest of the economy that are employed for providing inputs to subsystem *s* sectors. The second term accounts for those sales from the rest of the economy employed by subsystem *s* as inputs for satisfying its final demand. The first component can be decomposed adding and subtracting $\boldsymbol{M}_s\boldsymbol{y}^{s\prime}$ such that:

(5) $$\boldsymbol{u}_{1\times n} \begin{pmatrix} \boldsymbol{x}_s^{s\prime} \\ \boldsymbol{x}_s^{r\prime} \end{pmatrix} = \boldsymbol{u}_{1\times s}\boldsymbol{F}_s\boldsymbol{M}_s\boldsymbol{y}^{s\prime} + \boldsymbol{u}_{1\times s}\boldsymbol{M}_s\boldsymbol{y}^{s\prime} - \boldsymbol{u}_{1\times s}\boldsymbol{M}_s\boldsymbol{y}^{s\prime} + \boldsymbol{u}_{r\times 1}\boldsymbol{F}_r\boldsymbol{S}_{rs}\boldsymbol{M}_s\boldsymbol{y}^{s\prime}$$
$$= \underbrace{\boldsymbol{u}_{1\times s}\boldsymbol{M}_s\boldsymbol{y}^{s\prime}}_{internal\ component} + \underbrace{\boldsymbol{u}_{1\times s}[\boldsymbol{F}_s - \boldsymbol{I}]\boldsymbol{M}_s\boldsymbol{y}^{s\prime}}_{feedback\ component} + \underbrace{\boldsymbol{u}_{1\times r}\boldsymbol{F}_r\boldsymbol{S}_{rs}\boldsymbol{M}_s\boldsymbol{y}^{s}}_{spillover\ component}{}'$$

The expression above decomposes the total production that is needed for providing the total final demand of subsystem *s*. It is also relevant to split those components between the sectors of subsystem *s*. For this purpose, each component can be rewritten diagonalizing the last vector, such that:

Internal component:

(6) $$\boldsymbol{u}_{1\times s}\boldsymbol{M}_s\widehat{\boldsymbol{y}}^{s}$$

where $\boldsymbol{M}_s\widehat{\boldsymbol{y}}^{s}$ depicts the total production of subsystem *s* for attending its final demand (both final output and intermediate inputs). However, it is relevant to split the internal component to shed light on the relationships inside the subsystem. For this purpose, it is useful to decompose the internal component following an additive decomposition. This would allow to distinguish between: a) the production of a sector of subsystem *s* for satisfying its own final demand (*internal scale component*); b) the production of a sector of *s* that is purchased as input by itself for satisfying its final demand (*internal own component*); c) the production of a sector of subsystem *s* purchased as inputs by other sectors of the same subsystem and employed to produce inputs bought by this sector for attending its final demand (*internal feedback component*); and d) inputs that a sector of subsystem *s* demands to other sectors of the same subsystem for satisfying its final demand (*internal spillover component*).

For this, matrix $\boldsymbol{M}_s$ can be written as $\boldsymbol{M}_s = \boldsymbol{M}_s^D + \boldsymbol{M}_s^O$, where $\boldsymbol{M}_s^D$ is a diagonal $s_x s$ matrix that contains the main diagonal of matrix $\boldsymbol{M}_s$while matrix $\boldsymbol{M}_s^O$ is equal to matrix $\boldsymbol{M}_s$, but with null values in its main diagonal. The technical coefficients matrix of subsystem *s* can be rewritten in the same way, such that $\boldsymbol{A}_{ss} = \boldsymbol{A}_{ss}^D + \boldsymbol{A}_{ss}^O$. From above, $\boldsymbol{M}_s$ can be rewritten such that $\boldsymbol{M}_s = \boldsymbol{A}_{ss}^D \boldsymbol{M}_s^D + \boldsymbol{A}_{ss}^O \boldsymbol{M}_s + \boldsymbol{A}_{ss}^D \boldsymbol{M}_s^O + \boldsymbol{I}$.[4] Eq. (6) can be rewritten such that:

(6a) $$\boldsymbol{u}_{s\times1}\boldsymbol{M}_s\widehat{\boldsymbol{y}^s} = \underbrace{\boldsymbol{u}_{s\times1}\boldsymbol{A}_{ss}^D\boldsymbol{M}_s^D\widehat{\boldsymbol{y}}^s}_{\substack{internal\ own\\ component}} + \underbrace{\boldsymbol{u}_{s\times1}\boldsymbol{A}_{ss}^D\boldsymbol{M}_s^O\widehat{\boldsymbol{y}}^s}_{\substack{internal\ feedback\\ component}} + \underbrace{\boldsymbol{u}_{s\times1}\boldsymbol{A}_{ss}\boldsymbol{M}_s^{\boldsymbol{O}}\widehat{\boldsymbol{y}}^s}_{\substack{internal\ spillover\\ component}} + \underbrace{\boldsymbol{u'}_{s\times1}\widehat{\boldsymbol{y}}^s}_{\substack{internal\ scale\\ component}}$$

Feedback component:

(7) $$\boldsymbol{u}_{s\times1}[\boldsymbol{F}_s - \boldsymbol{I}]\boldsymbol{M}_s\widehat{\boldsymbol{y}}^s$$

is the production of the sectors of subsystem *s* used as inputs by sectors from outside the subsystem, but that are used by them to provide inputs to the subsystem sectors.

Spillover component:

(8) $$\boldsymbol{u}_{r\times1}\boldsymbol{F}_r\boldsymbol{S}_{rs}\boldsymbol{M}_s\widehat{\boldsymbol{y}}^s$$

depicts the production from sectors that do not belong to subsystem *s* for providing inputs for attending its final demand.

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[4] $\boldsymbol{M}_s = [\boldsymbol{M}_s - \boldsymbol{I}] + \boldsymbol{I} = \boldsymbol{A}_{ss}\boldsymbol{M}_s + \boldsymbol{I} = (\boldsymbol{A}_{ss}^D + \boldsymbol{A}_{ss}^O)(\boldsymbol{M}_s^D + \boldsymbol{M}_s^O) + \boldsymbol{I} = \boldsymbol{A}_{ss}^D\boldsymbol{M}_s^D + \boldsymbol{A}_{ss}^O\boldsymbol{M}_s^D + \boldsymbol{A}_{ss}\boldsymbol{M}_s^O + \boldsymbol{I}$

The model above can be easily extended to any environmental dimension for taking into account the environmental impact. We define $\boldsymbol{c}_{nx1}{}' = \begin{pmatrix} c_1 \\ \vdots \\ c_n \end{pmatrix}$, a vector of coefficients that relates every sector with a particular environmental dimension (either resource use or pollution), such that $\boldsymbol{c'x} = E$, where $\boldsymbol{x}$ is the sector production vector and E is a scalar that denotes the total resource use or pollution generation. Henceforth, $\boldsymbol{c}$ is going to be defined as the GHGs emissions intensity vector. In this way, the direct emissions coefficient of sector j can be defined as $c_j = {}^{e_j}/_{x_j}$,where e_j indicates sector j direct emissions. Rewriting the emissions coefficients vector in a partitioned way, as before, such that $\boldsymbol{c}_{nx1}{}' = \begin{pmatrix} \boldsymbol{c^s}' \\ \boldsymbol{c^r}' \end{pmatrix}$, where $\boldsymbol{c^s}$are the direct emission coefficients of the sectors of subsystem s. Pre multiplying (1) by a diagonal matrix constructed from vector $\boldsymbol{c}$, the model can be transformed as:

$$(9)\qquad \begin{aligned} \boldsymbol{e}' &= \boldsymbol{\hat{c}x} = \boldsymbol{\hat{c}Ly}' \\ &= \begin{pmatrix} \boldsymbol{\hat{c}^s} & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{\hat{c}^r} \end{pmatrix} \begin{bmatrix} \boldsymbol{L}_{ss} & \boldsymbol{L}_{sr} \\ \boldsymbol{L}_{rs} & \boldsymbol{L}_{rr} \end{bmatrix} \begin{pmatrix} \boldsymbol{y^s}' \\ \boldsymbol{y^r}' \end{pmatrix} \\ &= \begin{pmatrix} \boldsymbol{\hat{c}^s} & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{\hat{c}^r} \end{pmatrix} \begin{bmatrix} \boldsymbol{F}_s & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{F}_r \end{bmatrix} \times \begin{bmatrix} \boldsymbol{I} & \boldsymbol{S}_{sr} \\ \boldsymbol{S}_{rs} & \boldsymbol{I} \end{bmatrix} \times \begin{bmatrix} \boldsymbol{M}_s & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{M}_r \end{bmatrix} \begin{pmatrix} \boldsymbol{y^s}' \\ \boldsymbol{y^r}' \end{pmatrix} \\ &= \begin{pmatrix} \boldsymbol{\hat{c}^s} & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{\hat{c}^r} \end{pmatrix} \begin{bmatrix} \boldsymbol{F}_s\boldsymbol{M}_s & \boldsymbol{F}_s\boldsymbol{S}_{sr}\boldsymbol{M}_r \\ \boldsymbol{F}_r\boldsymbol{S}_{rs}\boldsymbol{M}_s & \boldsymbol{F}_r\boldsymbol{M}_r \end{bmatrix} \begin{pmatrix} \boldsymbol{y^s}' \\ \boldsymbol{y^r}' \end{pmatrix} \end{aligned}$$

where $\boldsymbol{e}_{n\times 1}{}'$ is a columnd vector whose elements are $e_j\ \forall\, j = 1, \dots, n$. Again, for analyzing subsystem s role on pollution impact or total emissions, $\boldsymbol{y}^r = 0$ is assumed such that:

$$(10)\qquad \begin{bmatrix} \boldsymbol{e^{s}_{s}}' \\ \boldsymbol{e^{s}_{r}}' \end{bmatrix} = \begin{bmatrix} \boldsymbol{\hat{c}^s} & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{\hat{c}^r} \end{bmatrix} \begin{bmatrix} \boldsymbol{F}_s\boldsymbol{M}_s & \boldsymbol{F}_s\boldsymbol{S}_{sr}\boldsymbol{M}_r \\ \boldsymbol{F}_r\boldsymbol{S}_{rs}\boldsymbol{M}_s & \boldsymbol{F}_r\boldsymbol{M}_r \end{bmatrix} \begin{pmatrix} \boldsymbol{y^s}' \\ \boldsymbol{0} \end{pmatrix}$$

where $\boldsymbol{e^s_s}$ are those emissions coming from subsystem s itself during the production processes for attending its final demand, and $\boldsymbol{e^s_r}$ is the pollution from the rest of the sectors during their production processes for providing subsystem s the inputs needed for satisfying its final demand. Similar to equation (5), pre multiplying (1) by a unitary vector $\boldsymbol{u}$ nx1 we get subsystem s total emissions (E^s):

(11) $$E^s = \boldsymbol{c}^s\boldsymbol{F}_s\boldsymbol{M}_s\boldsymbol{y}^{s\,\prime} + \boldsymbol{c}^r\boldsymbol{F}_r\boldsymbol{S}_{rs}\boldsymbol{M}_s\boldsymbol{y}^{s\prime} = \underbrace{\boldsymbol{c}^s\boldsymbol{M}_s\boldsymbol{y}^{s\,\prime}}_{internal\ component} + \underbrace{\boldsymbol{c}^s[\boldsymbol{F}_s - \boldsymbol{I}]\boldsymbol{M}_s\boldsymbol{y}^{s\,\prime}}_{feedback\ component} + \underbrace{\boldsymbol{c}^r\boldsymbol{F}_r\boldsymbol{S}_{rs}\boldsymbol{M}_s\boldsymbol{y}^{s\,\prime}}_{spillover\ component}$$

In the same way as in equations (6) to (8), each component can be split for each sector of subsystem *s*.

(11) $\boldsymbol{\mu}_s^{internal} = \boldsymbol{c}^s\boldsymbol{M}_s\widehat{\boldsymbol{y}}^s$

depicts each subsystem sector contribution to the subsystem internal component. The internal component shows the emissions produced by the subsystem *s* both, when producing products for satisfying its own final demand directly, and when producing inputs demanded by it also for attending its own final demand.

Again, following eq. (6a), eq. (11) can be split to distinguish between: a) those emissions that a sector of subsystem *s* directly produces for attending its final demand (*internal scale component*); b) the pollution of a sector of subsystem *s* when producing inputs bought by itself (*internal own component*); c) the pollution generated by a sector of subsystem *s* when producing inputs that are used by other sectors of the same subsystem for providing inputs to it (*internal feedback component*); and d) the emissions that a sector from subsystem *s* makes other sectors of the same subsystem produce in their productive processes to provide inputs for satisfying its final demand (*internal spillover component*).

(11a) $\boldsymbol{\mu}_s^{internal-scale} = \boldsymbol{c}^s\widehat{\boldsymbol{y}}^s$
(11b) $\boldsymbol{\mu}_s^{internal-own} = \boldsymbol{c}^s\boldsymbol{A}_{ss}^D\boldsymbol{M}_s^D\widehat{\boldsymbol{y}}^s$
(11c) $\boldsymbol{\mu}_s^{internal-feedback} = \boldsymbol{c}^s\boldsymbol{A}_{ss}^D\boldsymbol{M}_s^O\widehat{\boldsymbol{y}}^s$
(11d) $\boldsymbol{\mu}_s^{internal-spillover} = \boldsymbol{c}^s\boldsymbol{A}_{ss}\boldsymbol{M}_s^O\widehat{\boldsymbol{y}}^s$

Also,

(12) $\boldsymbol{\mu}_s^{feedback} = \boldsymbol{c}^s(\boldsymbol{F}_s - \boldsymbol{I})\ \boldsymbol{M}_s\widehat{\boldsymbol{y}}^s$

shows the contribution of each subsystem sector to the subsystem feedback component. It depicts those emissions produced by the sectors of subsystem s for providing inputs to sectors outside the subsystem, but that are used by them for providing inputs to subsystem sectors. Finally,

$$(13) \quad \boldsymbol{\mu}_s^{spillover} = \boldsymbol{c}^{\boldsymbol{r}} \boldsymbol{F}_r \boldsymbol{S}_{rs} \boldsymbol{M}_s \widehat{\boldsymbol{y}}^{\boldsymbol{s}}$$

depicts the contribution of each subsystem sector to the subsystem spillover component. The spillover component accounts those emissions produced by sectors not belonging to subsystem s for providing inputs to sectors of subsystem s for attending their final demand.

3.3 Agro industrial subsector and methane emissions in Uruguay

Input–output matrix for Uruguay 2005 is split into 56 sectors at basic prices (10 primary, 33 industrial, and 13 service sectors)[5]. Following Terra et al. (2009), we define agro industrial subsystem consisting of 24 sectors (8 primary and 16 industrial based in agricultural inputs), that represent 21.3% of total Uruguayan output in 2005 (Table 3.1). Uruguayan methane emissions in 2004 reached 18,634 ktons (CO_2 equivalent units) almost all coming from the productive sectors (MVOTMA, 2010b). Agro industrial subsystem was responsible of 93.8% of direct and 88.9% of total (direct and indirect) methane emissions[6].

Despite direct and total emissions of agro industrial subsystem are similar, there are salient differences at branch level. As an example, Cattle farming (6); the main direct polluter, is only responsible of 10% of its total methane emissions. Similar cases are Raw milk and milk products prepared in premises (5); and Rice growing (1). This shows that the pollution coming from primary sectors is to a great degree consequence

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[5] There is not an official input–output matrix for Uruguay. However, in the benchmark of an agreement between RED Mercosur – FAO for technical assistance to the Agriculture, Livestock and Fishing ministry, it was constructed under direct supervision of the Central Bank of Uruguay (BCU), institution that publishes the national account information (Terra et al., 2009). There is a consensus on its validity, and it is the main reference for both public and private analysis. The Uruguayan productive structure is not very dynamic between 2004 and 2005, so similar productive structures are assumed.

[6] See Appendix II of Chapter 2 for the methodology of sectoral allocation of emissions, based on MVOTMA (2010b) and DNETEN (2008), and following the Eurostat (2009) methodology, is available upon request.

of other sectors pulling them when demanding their products as inputs. This is the case of Meat production (9); that is responsible of 60% of total emissions but only of 0.6% of direct emissions.

Table 3.1: Agro industrial subsystem sectors, Output and CH_4 direct and indirect emissions

Sector	BCU code	Name	Output U$S :	% Output	Direct CH_4 Ktons	% Direct CH_4	Total CH_4 Ktons	% Total CH_4
1	A.0111.1	Rice growing	176,6	0,6%	743,7	4,0%	167,2	0,9%
2	A.0111.9	Other cereals and crops	447,6	1,5%	1,3	0,0%	4,9	0,0%
3	A.0112.0	Vegetables and horticultural growing	108,7	0,4%	0,0	0,0%	0,8	0,0%
4	A.0113.0	Fruits growing	146,4	0,5%	0,1	0,0%	0,9	0,0%
5	A.0121.1	Raw milk and milk products prepared in premises	235,5	0,8%	1328,3	7,1%	245,7	1,3%
6	A.0121.9	Cattle farming	987,9	3,4%	15161,7	81,5%	1903,9	10,2%
7	A.0122.0	Other animal farming	112,7	0,4%	18,3	0,1%	14,7	0,1%
8	A.0200.0	Forestry and logging	138,7	0,5%	0,0	0,0%	0,6	0,0%
9	D.1511.0	Meat production	1.426,4	4,9%	108,8	0,6%	11228,9	60,3%
10	D.1513.0	Fruit and vegetables processing and preserving	32,4	0,1%	22,3	0,1%	14,8	0,1%
11	D.1514.0	Manufacture of vegetable and animal oils and fats	29,4	0,1%	0,0	0,0%	22,6	0,1%
12	D.1520.0	Dairy products	479,8	1,6%	29,4	0,2%	1045,9	5,6%
13	D.1531.1	Rice mill products	227,3	0,8%	0,0	0,0%	541,0	2,9%
14	D.1531.9	Flour and other grain mill	74,4	0,3%	0,0	0,0%	0,7	0,0%
15	D.153R.0	Prepared animal feeds	65,0	0,2%	0,0	0,0%	4,3	0,0%
16	D.154R.0	Bakery and similar farinaceous products	276,5	0,9%	0,1	0,0%	136,1	0,7%
17	D.1552.0	Wines	63,6	0,2%	0,1	0,0%	1,1	0,0%
18	D.1553.0	Manufacture of malt liquors and malt	97,7	0,3%	0,1	0,0%	6,1	0,0%
19	D.171T.0	Spinning, weaving and finishing of textiles	252,9	0,9%	38,1	0,2%	498,0	2,7%
20	D.17RT.0	Knitted and crocheted fabrics and articles	59,0	0,2%	0,0	0,0%	9,0	0,0%
21	D.18TT.0	Dressing and dyeing of fur; manufacture of articles of fur	274,0	0,9%	0,0	0,0%	99,4	0,5%
22	D.191T.0	Tanning and dressing and manufacture of leather	283,0	1,0%	2,0	0,0%	564,9	3,0%
23	D.1920.0	Footwear	37,9	0,1%	0,0	0,0%	29,6	0,2%
24	D.20TT.0	Wood products	178,2	0,6%	0,0	0,0%	1,3	0,0%
Total agroindustrial subsystem			**6.211**	**21,3%**	**17.454**	**93,8%**	**16.543**	**88,9%**
Total			**29.229**	**100%**	**18.611**	**100%**	**18.611**	**100%**

Source: own elaboration based in Terra et al. (2009), MVOTMA (2010a) and DNTEN (2008)

From the above, we would expect that those sectors that pull direct polluters to be sectors that also belong to the agro industrial subsector. But if we only considered the agro industrial subsectors, we could lose the general perspective of the economy. This trade-off between direct and total emissions among sectors of the agro industrial subsystem can hide some intermediate transactions that are not clarified by the analysis above. For this purpose, we compute equations (11a-d) to (13), as defined before.

Table 3.2 shows the results of multipliers decompositions. The internal component accounts for 99.6% of the agro industrial methane emissions. This result is similar to the one found by Navarro and Alcántara (2010) for the internal component of agricultural and food industry subsystem for methane emissions in the Spanish case. But different to their results, the relation between internal scale and other internal components is lower in the Uruguayan case. Almost all methane emissions are computed by the internal spillover component (84.1% of total subsystem methane emissions). This depicts the importance of the internal subsystem transactions in its total emissions. Moreover, the internal scale component accounts for 15% of total subsystem emissions, while the internal own and feedback components are almost null. Finally, the spillover and the feedback components of the agro industrial subsystem to the rest of the economy are also non relevant. This means that the agro industrial subsystem does not pull the rest of the economy to produce methane emissions either when providing inputs for satisfying its own final demand, nor as consequence of its own production sold to the rest of the economy that is employed for providing inputs to it. Two facts explain this. First, almost all the direct and total methane emissions came from the agro industrial subsystem. In consequence, any of the inputs produced outside this subsystem pollutes much less during its production process in relation to the pollution generated by the subsystem itself. Second, the sectors of the agro industrial subsystem and the rest of the economy are weakly linked. The sectors of the rest of the economy do not demand many inputs to the agro industrial subsystem sectors. These facts make clear that the power of the agro industrial subsystem to pull the rest of the economy to produce methane emissions is almost null and so attention must focus in the subsystem internal transactions.

Back to the internal spillover component, Meat production (9) is responsible of 79.9% of these emissions. This is straight related with the inputs it demands to Cattle farming (6), which is responsible of 81.5% of direct methane emissions, but only of 10% of total emissions. Also the share in the internal spillover component of the agro industrial subsystem of Spinning, weaving and finishing of textiles (19) (3.3%); and Tanning and dressing and manufacture of leather (22) (4%); are straight related with Cattle farming (6) direct emissions. In this sense, demand policies on these sectors would be effective for methane emissions mitigation.

Table 3.2: Agroindustrial subsystem - CH_4 emissions

Sector	Internal scale component	%	Internal own component	%	Internal feedback component	%	Internal spillover component	%	Feedback component	%	Spillover component	%	Total CH_4 Ktons	% Total CH_4 agroind.
1	155,5	6,3%	11,4	45,2%	0,0	0,0%	0,0	0,0%	0,1	0,6%	0,2	0,5%	167,2	1,0%
2	0,8	0,0%	0,1	0,4%	0,0	0,0%	0,0	0,0%	1,9	7,5%	2,0	4,9%	4,9	0,0%
3	0,0	0,0%	0,0	0,0%	0,0	0,0%	0,0	0,0%	0,3	1,1%	0,5	1,1%	0,8	0,0%
4	0,0	0,0%	0,0	0,0%	0,0	0,0%	0,0	0,0%	0,4	1,5%	0,4	1,1%	0,9	0,0%
5	235,0	9,5%	7,4	29,4%	0,1	0,1%	3,0	0,0%	0,1	0,5%	0,2	0,5%	245,7	1,5%
6	1.902,2	77,2%	0,0	0,0%	0,1	0,1%	0,9	0,0%	0,4	1,4%	0,3	0,8%	1903,9	11,5%
7	6,7	0,3%	0,0	0,0%	0,1	0,1%	7,3	0,1%	0,3	1,3%	0,3	0,8%	14,7	0,1%
8	0,0	0,0%	0,0	0,0%	0,0	0,0%	0,0	0,0%	0,2	0,8%	0,4	0,9%	0,6	0,0%
9	92,5	3,8%	4,1	16,2%	0,4	0,6%	11.115,5	79,9%	7,0	27,2%	9,4	22,8%	11228,9	67,9%
10	13,5	0,5%	0,0	0,0%	0,0	0,0%	0,6	0,0%	0,2	0,9%	0,5	1,2%	14,8	0,1%
11	0,0	0,0%	0,0	0,0%	0,0	0,0%	22,2	0,2%	0,2	0,6%	0,2	0,5%	22,6	0,1%
12	26,2	1,1%	1,0	4,0%	30,6	44,3%	979,8	7,0%	2,0	7,7%	6,3	15,4%	1045,9	6,3%
13	0,0	0,0%	0,0	0,0%	36,5	52,9%	499,1	3,6%	2,0	7,8%	3,3	8,1%	541,0	3,3%
14	0,0	0,0%	0,0	0,0%	0,0	0,0%	0,2	0,0%	0,2	0,8%	0,3	0,7%	0,7	0,0%
15	0,0	0,0%	0,0	0,0%	0,0	0,0%	4,1	0,0%	0,1	0,5%	0,1	0,2%	4,3	0,0%
16	0,1	0,0%	0,0	0,0%	0,7	1,0%	128,5	0,9%	1,9	7,5%	4,9	11,9%	136,1	0,8%
17	0,1	0,0%	0,0	0,0%	0,0	0,0%	0,0	0,0%	0,3	1,2%	0,7	1,7%	1,1	0,0%
18	0,1	0,0%	0,0	0,0%	0,2	0,3%	2,3	0,0%	0,8	2,9%	2,7	6,6%	6,1	0,0%
19	30,3	1,2%	1,2	4,7%	0,0	0,0%	464,0	3,3%	1,2	4,8%	1,3	3,1%	498,0	3,0%
20	0,0	0,0%	0,0	0,0%	0,0	0,0%	8,1	0,1%	0,4	1,4%	0,5	1,2%	9,0	0,1%
21	0,0	0,0%	0,0	0,0%	0,2	0,3%	94,2	0,7%	2,0	7,7%	2,9	7,1%	99,4	0,6%
22	1,8	0,1%	0,0	0,1%	0,2	0,3%	557,5	4,0%	2,6	10,2%	2,7	6,6%	564,9	3,4%
23	0,0	0,0%	0,0	0,0%	0,0	0,0%	28,8	0,2%	0,4	1,5%	0,4	1,0%	29,6	0,2%
24	0,0	0,0%	0,0	0,0%	0,0	0,0%	0,1	0,0%	0,7	2,5%	0,5	1,3%	1,3	0,0%
Total agroindustrial subsystem	**2.465,0**	**14,9%**	**25,2**	**0,2%**	**69,0**	**0,4%**	**13.916,6**	**84,1%**	**25,8**	**0,2%**	**41,1**	**0,2%**	**16.543**	**100%**
% of total CH_4 emissions	**13,2%**		**0,1%**		**0,4%**		**74,8%**		**0,14%**		**0,22%**		**88,9%**	

Source: own elaboration based in Terra et al. (2009), MVOTMA (2010a) and DNTEN (2008)

There are other less relevant sectors in the share of total internal spillover component, which can be tackled in the same way. Dairy products (12); represents 7% of the emissions of this component, and are straight related to direct methane emissions from Raw milk and milk products prepared in premises (5). Also relevant is the share of sector Rice mill products (13) (3.6%), related to direct emissions of Rice growing (1).

Finally, as expected, the main contributors to agro industrial subsystem internal scale component are also the main direct polluter sectors (sectors 1, 5 and 6). Different than above, sectoral measures, like technological improvement and better practices, directly reduce resource use or environmental degradation.

The NCCRP presents in its priority lines of action many sectoral technical measures to be adopted in the primary sectors for methane mitigation. The analysis above helps to determine in which sectors those measures are going to be more effective. Also, as shown above, we identified several indirect polluter sectors that can be tackled for complementing the intervention in primary sectors through demand policies.

3.4 Services subsystem and carbon dioxide emissions in Uruguay

Total carbon dioxide emissions in Uruguay in 2004 reached 8,675 ktons., and 70% of them came from the productive sectors (MVOTMA, 2010b)[7]. Services subsystem consists of 13 sectors that represent 52.5% of Uruguayan output in 2005.[8] Its direct emissions reached 2,783.7 ktons., while the total emissions where 2,862 ktons in 2004 (45.7% and 46.9% of total CO_2 emissions, respectively) (Table 3.3).

Direct and total subsystem emissions are quite similar in absolute terms. On the one hand, despite Land transport; transport via pipelines (46); and Water and air transport (47); are the two main contributors to subsystem direct emissions, their contribution to subsystem total emissions is significantly smaller. On the other hand, contribution to total emissions significantly raises in relation to direct emissions for Motor vehicles and oil retail trade (44); Hotels and restaurants (45); and Public administration and defense;

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[7] It considers international bunkers and biomass burning CO_2 emissions.

[8] The literature defines services activities both through a positive and a residual definition. For the residual definition services are all the activities that are not manufacturing or agricultural activities, while for the positive definition services are branches that meet specific characteristics that distinguish them from other economic activities (Fourcroy et al., 2012). For the Uruguayan case, and the level of aggregation of the input–output matrix employed, both perspectives are highly coincident.

compulsory social security (52); while for the other sectors variation is very small. Because of the trade-off between direct and indirect emissions of the contribution of these sectors it is worth to decompose total emissions in a way to better distinguish the best channels for mitigation policies design.

Table 3.3: Services subsystem sectors, Output and CO_2 direct and indirect emissions

Sector	BCU code	Name	Output U$S :	% Output	Direct CO_2 Ktons	% Direct CO_2	Total CO_2 Ktons	% Total CO_2
44	G.TTTT.0	Motor vehicles and oil retail trade	3.096,7	10,6%	14,8	0,2%	317,6	5,2%
45	H.55TT.0	Hotels and restaurants	867,3	3,0%	26,3	0,4%	161,9	2,7%
46	I.60TT.0	Land transport; transport via pipelines	957,5	3,3%	1261,2	20,7%	866,3	14,2%
47	I.RRTT.0	Water and air transport	875,3	3,0%	1371,5	22,5%	962,9	15,8%
48	I.64TT.0	Post and telecommunications	777,8	2,7%	0,0	0,0%	35,4	0,6%
49	J.TTTT.0	Financial intermediation	1.243,7	4,3%	1,5	0,0%	16,3	0,3%
50	K.70TT.0	Real estate activities	2.164,6	7,4%	0,0	0,0%	65,5	1,1%
51	K.RRTT.0	Renting of machinery and equipment	941,1	3,2%	0,0	0,0%	22,6	0,4%
52	L.75TT.0	Public administration and defense; compulsory social security	1.238,2	4,2%	44,7	0,7%	159,2	2,6%
53	M.80TT.0	Education	722,0	2,5%	5,8	0,1%	51,5	0,8%
54	N.85TT.0	Health and social work	1.465,6	5,0%	16,9	0,3%	107,1	1,8%
55	O.TTTT.0	Sewage and refuse disposal	795,0	2,7%	40,9	0,7%	96,0	1,6%
56	P.9500.0	Private households with employed persons	192,3	0,7%	0,0	0,0%	0,0	0,0%
Total services subsystem			**15.337**	**52,5%**	**2783,7**	**45,7%**	**2.862**	**46,9%**
Total			**29.229**	**100%**	**6.097**	**100%**	**6.097**	**100%**

Source: own elaboration based in Terra et al. (2009), MVOTMA (2010a) and DNTEN (2008)

Table 3.4 shows the decomposition of services subsystem multipliers. The internal component explains most of carbon dioxide emissions of this subsystem (77.8%). However, the spillover component, that depicts the emissions the subsystem makes the rest of the economy to produce for providing its final demand, also explains a significant part of total emissions (19.7%). This last result is in line with Alcántara and Padilla (2009) for their analysis of the Spanish economy. Finally, the feedback component is almost null.

Table 3.4: Services subsystem: CO_2 emissions

Sector	Internal scale component	%	Internal own component	%	Internal feedback component	%	Internal spillover component	%	Feedback component	%	Spillover component	%	Total CO_2 Ktons	% Total CO_2 serv.
44	10,5	0,6%	0,5	0,7%	5,7	46,7%	194,0	58,2%	11,4	16,0%	95,5	16,9%	317,6	11,1%
45	23,9	1,3%	0,0	0,1%	1,2	9,9%	23,8	7,1%	17,1	23,9%	95,8	17,0%	161,9	5,7%
46	766,4	42,2%	44,5	69,1%	0,1	0,9%	7,2	2,2%	3,1	4,4%	45,0	8,0%	866,3	30,3%
47	921,9	50,8%	15,7	24,4%	0,4	3,7%	8,5	2,6%	1,9	2,7%	14,4	2,6%	962,9	33,6%
48	0,0	0,0%	0,0	0,0%	0,9	7,2%	20,2	6,0%	1,6	2,2%	12,8	2,3%	35,4	1,2%
49	0,6	0,0%	0,1	0,1%	0,3	2,4%	5,6	1,7%	1,0	1,4%	8,7	1,5%	16,3	0,6%
50	0,0	0,0%	0,0	0,0%	0,3	2,5%	5,9	1,8%	7,8	10,8%	51,5	9,1%	65,5	2,3%
51	0,0	0,0%	0,0	0,0%	0,3	2,8%	7,4	2,2%	1,6	2,3%	13,3	2,4%	22,6	0,8%
52	41,7	2,3%	0,0	0,0%	1,1	8,8%	21,8	6,5%	6,0	8,4%	88,6	15,7%	159,2	5,6%
53	5,7	0,3%	0,0	0,0%	0,2	1,9%	5,0	1,5%	2,9	4,0%	37,6	6,7%	51,5	1,8%
54	14,4	0,8%	2,1	3,3%	0,9	7,5%	18,6	5,6%	11,3	15,8%	59,8	10,6%	107,1	3,7%
55	30,7	1,7%	1,5	2,3%	0,7	5,7%	15,5	4,6%	5,8	8,1%	41,9	7,4%	96,0	3,4%
56	0,0	0,0%	0,0	0,0%	0,0	0,0%	0,0	0,0%	0,0	0,0%	0,0	0,0%	0,0	0,0%
Total services subsystem	**1.815,8**	**63,4%**	**64,4**	**2,2%**	**12,2**	**0,4%**	**333,5**	**11,7%**	**71,6**	**2,5%**	**564,9**	**19,7%**	**2.862**	**100%**
% of total CO_2 emissions	**29,8%**		**1,1%**		**0,2%**		**5,5%**		**1,2%**		**9,3%**		**46,9%**	

Source: own elaboration based in Terra et al. (2009), MVOTMA (2010a) and DNTEN (2008)

The significance of the internal component is mainly explained by the internal scale component (63.4% of total services subsystem emissions). These emissions are mainly produced by Land transport; transport via pipelines (46); and Water and air transport (47), which are also, as exposed above, the main direct polluters. Both sectors allocate more than 60% of their production to final demand. In this way, technological improvement and best practices are effective for mitigating carbon dioxide emissions of these sectors. This point shows the importance of the energy consumption reduction in transport sectors, which is identified as a priority line of action in the NCCRP.

Less relevant, but still significant, is the weight of the internal spillover component (11.7% of total emissions of services subsystem). The main contributor to this component is sector Motor vehicles and oil retail trade (44); (58.2%), while the rest of emissions are spread among the other sectors. This is explained because it pulls Land transport; transport via pipelines (46); and Water and air transport (47) to pollute as consequence of the inputs that sector 44 demands to them. In this way, demand policies in this sector can be useful for mitigating carbon dioxide emissions.

Finally, the spillover component depicts the importance of services subsystem in pulling other sectors of the rest of the economy to pollute. This is important to show the relevance of the subsystems approach, because it allows to distinguish between the pulling effects on the own subsystem, and on the rest of the economy. Spillover emissions are spread among many sectors. It must be highlighted the role of sectors Motor vehicles and oil retail trade (44); Hotels and restaurants (45); Public administration and defense; compulsory social security (52); and Health and social work (54). The significance of these sectors on the spillover component is explained because of their demand to Electricity, gas and water supply (42). In this way, this analysis helps to identify where energy efficiency measures, as identified in the NCCRP priority action lines, are more effective.

3.5 Conclusion

The present chapter analyzes methane emissions of the agro industrial subsystem and carbon dioxide emissions of the services sectors subsystem of Uruguay in 2004. We combine a multiplicative decomposition to analyze the relationship of the subsystems with the rest of the economy with an additive decomposition for the study of the linkages within it. This approach allows to study the significance of the subsystem as a whole in the economic structure as well as to analyze in detail the relationship of each of the subsystem branches between them.

The results show that almost all of total methane emissions from the agro industrial subsystem are produced inside itself. Moreover, the internal spillover component explains almost all these internal emissions. In particular, those emissions that Meat production (9); makes other sectors to pollute. Particularly, it pulls Cattle growing (6) to pollute, a sector that is the main direct polluter by the time that it also is the main contributor to the internal scale effect. Other less relevant sectors that pull sector 6 to pollute are sectors Spinning, weaving and finishing of textiles (19); and Tanning and dressing and manufacture of leather (22).

Similar conclusions, but with a lower impact, can be applied to sector Dairy products (12); that pulls Raw milk and milk products prepared in premises (5) to pollute, and Rice mill products (13); because it pulls Rice growing (1). As in the previously considered sectors, technical improvements and better practices would be effective for methane emission mitigation in those sectors that are pulled, but the impact would be lower.

Different than before, not only the internal component is relevant in reference to the multipliers decomposition of services subsystem carbon dioxide emissions, but also the spillover to the rest of the economy is relevant. This means that this subsystem is relevant not only because of its internal transactions, but also because it pulls other sectors of the rest of the economy to pollute. This refutes the non-material perception of services sectors, as exposed by Suh (2006), Nansai et al. (2007), Alcántara and Padilla (2009) and Fourcroy et al. (2012).

The emissions of the internal component are mainly explained by the internal scale component that is mainly produced Land transport; transport via pipelines (46); and Water and air transport (47) (which are also the main direct polluters). But also relevant is internal spillover component of the services subsystem, mainly because Motor vehicles and oil retail trade (44) pulls the sectors above to pollute.

Finally, the spillover component of services subsystem over the rest of the economy is spread among many subsystem's sectors. But the role of Motor vehicles and oil retail trade (44); Hotels and restaurants (45); Public administration and defense; compulsory social security (52); and Health and social work (54); can be highlighted. In particular, these sectors pulls Electricity, gas and water supply (42), that do not belong to the subsystem, to pollute.

It is worth to note that technical improvements and best practices in reference to energy consumption are plausible ways of implementing demand policies in the services subsystem. This is particularly relevant in Uruguay, where energy production and petrol refinery is in public hands, and demand decrease policies are less unpopular. But still, a rebound effect of increasing energy efficiency consumption on indirect polluter sectors has to be taken into account. This is less plausible in the agro industrial subsector, because, as an example, increasing Meat production (9) inputs productivity would hardly decrease their demand of cows to Cattle farming (6). In this case, technical improvements and best practices should be better (but also difficult to develop) on direct polluters.

The analysis above is a useful guideline for the efficient design of specific measures aligned with the NCCRP priority lines of action. It allows to determine both, in which sectors mitigation policies are more effective, and which kind of measure is more appropriate in each case.

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Part III

Social preferences and the conservation of a common pool resource: a local based perspective

Chapter 4

THE PERILS OF PEER PUNISHMENT

EVIDENCE FROM A COMMON POOL RESOURCE

FRAMED FIELD EXPERIMENT

Abstract

We provide experimental evidence on the effects of non-monetary punishment (NMP) by peers among communities of Uruguayan fishers exploiting a common pool resource (CPR). We find that: a) groups composed of fishers from different communities (out-groups) reduced their exploitation of the resource in response to the threat of punishment; unlike experimental groups from a single community (in-groups), b) NMP effectiveness is diminished because of the presence of antisocial punishment and because individuals correctly anticipate that the likelihood of being punished is increasing in extraction levels. Those who would experience disutility by being punished reduce their extraction levels beforehand while those that do not care about social disapproval maintain their extraction at high levels. Finally, c) individuals adjust their period-by-period decisions in order to converge with their peers' average in a previous period, showing strong conformity effects.

4.1 Introduction

The exploitation of a common pool resource (CPR) poses a typical social dilemma. Hardin (1968) proposed to establish either private or state property rights as a solution to avoid the *tragedy of the commons*. However, market contracts and governments are often unable to prevent overexploitation due to informational asymmetries. Communal property regimes have become an attractive alternative for the conservation and sustainable use of common pool resources (CPR). It has been argued that by enforcing social norms communal property can fill the gaps of incomplete contracts (Ostrom, 1990; Feeny et al. 1990; Baland and Platteau, 1996; Ostrom et al., 1999 and Ostrom, 2000; Bowles and Gintis, 2002).

Several studies have concentrated on the determinants of successful experiences based on communal property regimes but the issue is far from settled.[1] In this study, we assess whether non-monetary punishment (NMP) is effective in promoting cooperation via social preferences in a CPR dilemma.[2] We are particularly interested in determining whether behavior regarding NMP differs in a context in which individuals exploiting a common pool resource belong to different communities relative to the case in which only individuals from the same community are allowed to exploit the resource. Assessing the relevance of non-monetary punishment as a tool to enhance cooperation is of particular importance regarding community management of common pool resources, because informal sanctions typically take place in that setting. Besides, due to the absence of monetary incentives, non-monetary punishment allows better isolation of the presence of

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[1] For a description of successful cases see Ostrom (1990), Feeney et al. (1990), Ostrom et al. (1999) and Baland et al. (2007).

[2] In line with Bowles and Gintis (2011) we understand by social preferences as a wide range of motives such as reciprocity, altruism, conformism and also emotions such as shame, guilt and anger. For the purpose of this study we define cooperation in a narrow sense as the behavior through which one agent internalizes some of the externalities he imposes on other users, and maintains his own use below what would maximize his individual profits. Cooperation often requires coordination. That is, the creation of institutions is needed in order to regulate the use of the resource (Baland et al., 2007). In this study we concentrate on the simplest form of cooperation, as the experiment does not allow for communication or the introduction of any institutional form.

pro-social emotions when an individual reacts to being punished relative to costly punishment.

While van Soest and Vyrastekova (2006) find that costly punishment is effective in increasing cooperation in a CPR dilemma, Noussair et al. (2011) do not observe significant changes in cooperation. Janssen et al. (2010) conclude that costly punishment is not effective in reducing extraction unless combined with communication. There is also evidence that non-monetary punishment (Masclet, 2003; Noussair and Tucker, 2005, and Dugar, 2010), social approval (Gächter and Fehr, 1999) and public observability (Barr, 2001; Denant-Boemont, 2011; and López, 2012) can be effective for increasing contributions in public good games. In turn, Rege and Telle (2004) and Noussair and Tucker (2007) show that an initial increase in cooperation as a consequence of public observability tend to fade away in a repeated game context. To our knowledge, in the context of a CPR dilemma there is so far no evidence of the effectiveness of non-monetary punishment in promoting cooperation.

Several studies show that individuals may achieve greater levels of cooperation when interacting with members of their own group rather than with outsiders.[3] This behavior has been observed both in groups induced artificially (Charness et al., 2007; Hargreaves Heap and Zizzo, 2009; Chen and Xin, 2009, and Harris et al., 2012) and in naturally occurring groups (Bandiera et al., 2005; Miguel and Gugerty, 2005; Ruffle and Sosis, 2006; Goette et al. 2012; and Bernhard, et al., 2006). Natural occurring groups provide an ideal environment for the study of how group affiliation affects social norms. Natural occurring groups allow researchers to observe how individuals' prejudices, expectations and knowledge about the others in the group influence decisions during the experiment (Cárdenas, 2003).

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[3] In a broader sense, Akerlof and Kranton (2000; 2005) and Bowles and Gintis (2002) have highlighted the relevance that social identity and group affiliation have on individuals' behavior in most economic organizations.

We perform a framed field experiment (Harrison and List, 2004) where the subject pool is fishers from the Uruguayan sea coast who fish in two coastal lagoons and live in nearby villages.[4] Our study employs natural-occurring groups in a field setting. We explore whether fishermen that live in different communities exhibit greater sensitivity to NMP when they interact among themselves, than when interacting with fishers who do not belong to their community, and also test whether their propensity to cooperate differs in these two scenarios. Fishermen from different communities do not interact during their daily life, but they are used to encountering each other while fishing, as they tend to move from one lagoon to the other depending on fish availability. We implement both a NMP and an in-group/out-group treatment. Individuals start playing a CPR game, and after five periods the NMP is implemented. The NMP implied that by facing a monetary cost, individuals could express their disapproval of others' extraction decisions. Disapproval was reflected by receiving flags that vary in color in accordance with the level of disapproval achieved among the rest of the group members. During the in-group treatment subjects played the stages described before only with members of their own community, while during the out-group treatment we required that they play the game with members of another community.

The study combines three innovative features that have not been implemented at the same time before. First, instead of inducing artificial in-group/out-group differences we enable individuals from different communities meeting each other. Second, groups are reshuffled after each period in order to avoid repeated game effects that could lead to a self-sustaining cooperative equilibrium. Third, individuals are charged a monetary cost for punishing others even if those socially punished do not face any monetary cost. This step was implemented in order to avoid subjects punishing the others carelessly.

Our framework assumes individuals may not only care about their own payoffs but also value (either positively or negatively) the material payoffs of their peers. Individuals

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[4] We concentrate on coastal lagoons because, unlike the open sea where large-scale fishing is widespread, in coastal lagoons the only agents who develop fishing activities are artisanal fishermen.

share a social norm regarding how much extraction is admitted and may experience shame if they are publically sanctioned for violating it. Besides, even if punishing others is costly (as it can deteriorate the relationship with ones' peers), individuals face motives for punishing others socially when the others deviate from the social norm.

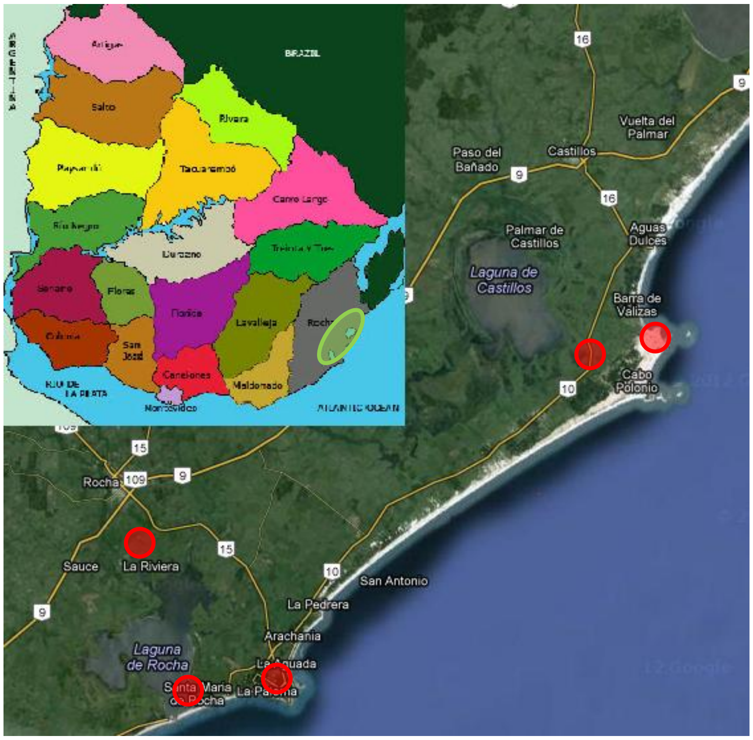
We find that NMP has a positive effect on cooperation when individuals are interacting with fishers from other communities. That is, during the out-group treatment, individuals reduce their extraction level when NMP is available irrespective of whether they are effectively punished. The effectiveness of informal sanctions deteriorates by the fact that not all individuals are sensitive to NMP, and that these types of sanctions can be used to punish both free riders and cooperators. Hence, for peer punishment to be effective it should require coordination to prevent anti-social targeting and to enhance the social signal conveyed by the punishment. We observe that individuals adjust their extraction levels period by period according to their deviation with respect to the group's average in a previous period, as if following an implicit social norm. Also, when subjects observe that their partners were punished in the previous period, they prefer to behave non-cooperatively than running the risk of being disadvantaged by others' decisions. This enhances the idea that social preferences are context dependent. The chapter is organized as follows: Section 4.2 describes the experimental design; Section 4.3 reports results; and finally Section 4.4 concludes.

4.2 Experimental design

4.2.1 Subject pool

Fishermen from five communities that fish either in the Laguna de Rocha or in Laguna de Castillos (two coastal lagoons 50 kilometers away from each other on the Uruguayan sea coast) or in both were recruited (Figure 4.1). We consider a community to be a group of people that live in the same settlement and constantly interact among each other. Individuals from different communities do not differ in terms of ethnicity, while they show some differences in socioeconomic characteristics. These communities differ in terms of how connected they are to the rest of society and the exit options they face. While some live very isolated and fishing is their main source of income (Laguna de Rocha, Puerto los Botes and to less extent El Puente), others are more connected to more densely populated areas and can exploit other exit options (Valizas and Barrio Parque). Facing other exit options as therefore reflected in their income and wealth (see Table A4.1 in the Appendix).

Figure 4.1: Location of field experiment (the five communities marked by red dots)



Fishermen from different communities are not used to meeting each other in their daily lives, but they do so when they move across lagoons during fishing high seasons. This is particularly important during the shrimp high season, which usually takes place once a year in the Laguna de Castillos, but rarely in the Laguna de Rocha, because of geographical reasons. PROBIDES (2002) reports that fishermen complained about fishermen from other communities coming in the high season to fish in the lagoon where they, the complainants, fish all year round. We believe that the place of residence is one of the main dividing factors among fishermen from different communities.

4.2.2 The experiment

The experiment consisted of a CPR game of 20 periods, structured in two stages of 10 periods each. In each stage, players interacted either only with members of their own community (in-group treatment) or in groups mixed with fishermen from another community (out-group treatment). This was not explained to the subjects. By this we mean that we did not mention during the in-group stage that all members from the same community were going to play together. Individuals were simply told in which group they would play based on their identifier.

The CPR game was framed around the decision of how many nets to use when fishing. Subjects made their decision in subgroups of four subjects. During the first five periods of each stage subjects played a regular CPR game, in which they consider a common pool resource exploited by individuals who have the same maximum endowment (eight nets) to fish. Individual benefits increase in the number of nets one uses and decrease with the aggregate level of nets used (see Table A4.2 in the Appendix). Player-i's earnings in each period during the first five periods of each stage were given by the payoff function $\pi_i = 18a_i + 12\sum_{j=1}^{4}(8 - a_j)$. If individuals are selfish, they should always choose $a_i = 8$ to maximize their material payoff. If they deviate from this choice, we assume that/ interpret it as if social preferences are present.

During the last five periods of each stage a NMP treatment was conducted. In this treatment subjects were allowed to express disapproval of others' fishnet choices. As a consequence, subjects who were punished by other players were assigned a flag, and its color (yellow, orange, or red) indicated how much their peers disapproved of the number of nets they had decided to throw. After making the usual decision on how many nets to use and being informed of the total number of nets used by the subgroup (and therefore being able to determine the others' average extraction), they were able to allocate 0 to 10 disapproval points to each possible choice of fishnets the others may have made (see Table A4.3 in Appendix).[5]

Punishment points implied no monetary cost to the punished but did imply a monetary cost to the punisher. The cost of each punishment point for the punisher was equivalent to one point in his earnings account. The subject was charged for the total number of disapproval points he used to punish others, irrespective of whether someone had actually chosen the number of nets the punisher decided to punish.[6] In this way, player i's payoff function during the last five periods of each stage is $\pi_i = 18a_i + 12\sum_{j=1}^{4}(8 - a_j) - \sum_{k=1}^{8}\mu_{ij,k}$.

The cost of punishing was set quite low compared to the points a subject could earn during one period. For instance, in one period if all subjects played the Nash equilibrium, each would earn 144 points, whereas if the social optimum was achieved each would earn 354 points. If during the NMP treatment the subject decided to disapprove of all possible fishnet choices with the maximum number of disapproval points, his cost would amount to 80 points (0.5 US dollars). The aim of this treatment was to recreate the state of being socially punished in the field (gossip, direct criticism, etc.) and evaluate its effects on the next periods' extractive decisions. We consider that punishing others socially may also have a social cost to the punisher but we were not particularly interested in studying it; we just intended to show that NMP was not for free for the punisher.

Punishment points for actual choices were added up and yellow, orange and red flags were assigned in accordance with the ranges shown in Table A4.4 (see Appendix). It was

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[5] Subjects could also choose to punish a choice of a number of nets identical to their own. In that case, the punishment would be directed solely to others and not to themselves. This was only explained in case someone asked. Potentially they could disapprove of the eight extraction alternatives at the same time.

[6] The reason why the punisher was charged by the total disapproval points and not just for the ones that corresponded to effective fishnet choices is that it was much simpler to explain and it enabled the subject to calculate the cost by himself. We consider that simplifying mechanisms is particularly important in a framed field environment like ours.

not possible for someone to receive a red flag with just one subject disapproving his fishnet choice.

We employed a hybrid strategy method to implement this treatment. Punishment points were assigned after the subjects had been informed of the total number of nets used by the subgroup and therefore subjects could determine the average number of nets used by the others. It is a "hybrid" strategy method because individuals made decisions in two stages (and not as in the classical strategy method, where both decisions [extraction and punishment] are made at the same time). Brandts and Charness (2011) argue that following a strategy method instead of a direct punishment treatment can lead to lower disapproval among individuals. Also, Blount and Bazerman (1996) argue that individuals are less concerned with fairness when simultaneously choosing between two outcomes than when considering each outcome separately. For this reason, we chose a hybrid strategy method, one that is more similar to assigning punishment based on knowing the effective fishnet choices of each of the other members of the subgroup, but that still preserves anonymity. We discarded the alternative of disclosing actual individual levels of extraction in a random order because we considered there was a risk that anonymity would be violated.[7]

4.2.3 The structure of the experiment

Subjects were recruited during a survey that took place in March 2011. The aim of the survey was to gather data on socioeconomic characteristics and environmental perception among the resource users of artisanal fisher communities in Rocha's coastal lagoons. At the end of the questionnaire, the interviewee was asked whether he would be interested in participating in an activity where he could earn on average 2 daily wages (30 US dollars), depending on the decisions he would make. A week before the experiment we visited the communities where we delivered flyers in person to people from the five communities,

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[7] Keeping anonymity both in individuals' extraction decisions and in NMP was a priority. Indeed, as Anderies et al. (2011) point out, working with communities in field experiments requires developing this task with responsibility, because the game may not end when experimenters leave, and this may have spillover consequences in their daily life.

and we made phone calls to those who had already been surveyed but could not be located while we visited the communities.

The experiment was conducted in two sessions in November 2011. Both sessions took place at La Paloma, a town in the province of Rocha, Uruguay. The communities that participated in each session were determined randomly (Table 4.1). Contrary to most framed field experiments, in this study subjects were transported from the place where they lived to the town where the experiment took place.[8] The aim of this design was to make subjects from different communities meet. This required that fishermen leave their community to attend the activity. It was particularly cumbersome to convince subjects to travel, and we believe it was the main reason why the number of participants was not as high as desired.

When subjects arrived at the venue, they drew a number from a bag (one bag per community). This number represented their identifier, and assigned each subject into a group of either eight or twelve members for each stage. Within these groups, subjects would play a CPR game in subgroups of four. The out-group treatment implied subgroups in which two subjects belonged to one community and two to the other.[9] In order to avoid repeated game type of behavior as much as possible, after each period subjects were reshuffled among all subjects in a group of eight or twelve. The subgroups they would play in the 20 periods were predetermined by the identifier number. It was common knowledge that the matching procedure between periods was random and had been determined by the initial draw of participants' identifier numbers. After each period, the experimenters indicated to the participants which subgroup of four they would play in the next period; at the end of the first 10 periods, participants were told in which group they would then play in (this implied a change in treatment from in-group to out-group or vice versa). During session 1, subjects played in an in-group treatment during the first

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[8] Buses for each community were hired to pick up participants and transport them to the venue.

[9] In session 2, as there was one community in which there were twelve subjects (El Puente) and in the other two there were eight, during the out-group treatment, subgroups were composed of two subjects from el Puente and two from one of the other two communities or three from El Puente and one from the other community. In all cases the out-group treatment implied mixing just two communities.

stage, while in session 2 we reversed this order (see Table 4.1). This design enabled us to control for order effects.

Table 4.1: Characteristics of the experimental sessions

	Subjects		Treatments by period[a]			
	Included in analysis	Discarded[b]	1-5	6-10	11-15	16-20
Session 1						
Laguna de Rocha	8	3	ingroup	ingroup punishment	outgroup	outgroup punishment
Valizas	8	3	ingroup	ingroup punishment	outgroup	outgroup punishment
Session 2						
El Puente	12		outgroup	outgroup punishment	ingroup	ingroup punishment
Puerto los Botes	8		outgroup	outgroup-punishment	ingroup	ingroup punishment
Barrio Parque	8		outgoup	outgroup punishment	ingroup	ingroup punishment
Total	44	6				

[a] **In-group:** "Groups and subgroups with individuals belonging to the same community".
Out-group: "Groups and subgroups with subjects belonging to two communities".
NMP: "Expressing disapproval of others' extraction levels. Those punished receive flags".

[b] During session 1 the subjects who turned up from Laguna de Rocha and Valizas were not multiples of four so three subjects from each community were selected randomly to play in subgroups of three and were reshuffled solely among the six all the periods. They were not considered in the analysis.

Once in subgroups of four members, subjects were asked to sit with their backs facing each other so that they could not see the others' choices. Each group was conducted by a moderator who gave the instructions throughout the game, plus a monitor for every subgroup of four. This ensured that subjects did not interact during the game, and that an experimenter was always available to explain them how to use the material.

Subjects received a payoff table and an earnings sheet where they kept a record of their decisions and points gained. The payoff table summarized the pay-off consequences of all combinations of own nets used and the total number of nets used by the other three members of a subgroup (see Table A4.2 in the Appendix). The exchange rate was set at

100 points for 0.62 US dollars. When looking at the payoff table, subjects had to make a decision as to how many nets to use (minimum one, maximum eight), which they wrote on a slip of paper and handed it in to the experimenter. Once the four subjects had written out their decisions, the total number of nets used by the subgroup was announced so that each subject could calculate the number of points they had earned and write that figure on their earnings sheet. The explanation of the game followed Cardenas (2003). The actual experiment began once the moderator had conducted three rehearsal periods and once all questions from participants had been clarified. All decisions were made privately and individually and only the total extraction by the four players was publicly announced.

Before the punishing treatment started an example was provided. The example showed three subjects' disapproval cards: one punishing without any criteria, one punishing those who used many nets and one not punishing at all. The choice of nets and the disapproval points assigned were private information; the only public information was the flag received in case the subject was punished by the rest by more than one point. Subjects had to hold the flag so that others could see it during the next period of the game.

At the end of each experimental session we conducted a post-experiment survey which contained questions about reasons for disapproval, and feelings when being disapproved of. Each session of the experiment lasted about three hours and participants earned on average 30 US dollars (including a 5 US dollar show-up fee), a figure which amounts to 10% of a monthly minimum wage. [10]

4.3 Results

Figure 4.2 shows average extraction levels by period and treatment for session 1 and 2, respectively. At first glance, it suggests that the in-group/out-group treatment does not seem to induce significant changes in behavior when NMP is not available. Subjects'

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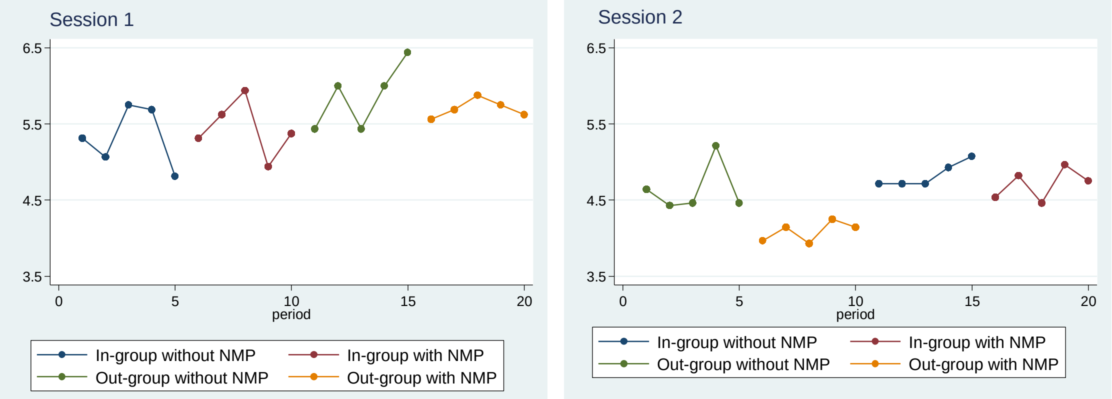
[10] The experimental design excluding the in-group out-group treatment was tested with 36 undergraduate students.

extraction levels in session 1 were higher during the out-group treatment without NMP but did not change substantially for subjects in session 2. The NMP treatment seems to have had a slight positive effect in terms of cooperation especially during the out-group treatment. It lowered average extraction levels in the second stage of session 1 and in both stages in session 2. It should also be noted that the three communities that participated in session 2 exhibited extraction levels significantly below those of the two communities that participated in session 1.

Figure 4.2: Average nets by treatment



4.3.1 Testing treatment effects

To test the in-group out-group and NMP treatments, we study players' extractive decisions in a dynamic analysis. Treatments were tested in two ways. First, two dummy variables were included in the model: *in-group* that equals 1 if the players are playing in an in-group (and 0 if they are playing the out-group treatment) and *NMP*, that equals 1 when the extraction decision is taken during a round that allows for NMP [rounds 6 to 10 and 16 to 20] and 0 otherwise). Second, we tested the interaction between treatments. For this purpose, three dummy variables were included: *out-group with NMP*, *in-group with NMP*, and *in-group without NMP* (*out-group without NMP* is the base scenario). Each of them equal 1 during the periods that they describe, and 0 otherwise.

A fixed effects model was performed to control for individuals' time invariant characteristics. The final model estimated (model 8 in Table 4.2) is:

(1) $$a_{it} = \alpha_i + \beta_1 out - group\ w/NMP\ _i + \beta_2 in - group\ \ w/\ NMP\ _i + \beta_3 in -$$
$$group\ w/out\ NMP\ i+\beta 4\pi i;t-\ 1+\beta 2\pi-\ i;t-\ 1+\beta 5 stagei+eit$$

Where $\boldsymbol{a_{it}}$ is *i*'s extraction level in period *t.* The following three dummy variables reflect the interaction between the two treatments: out-group/in-group and with/without non monetary punishment (the omitted category is out-group without NMP). We include two well established variables used in the literature as additional controls: $\boldsymbol{\pi_{i;t-1}}$ is individual *i's* payoff in a previous round and $\boldsymbol{\pi_{-i;t-1}}$ is the payoff of the rest of individual *i*'s subgroup (excluding individual *i*) in the previous round. High payoffs in the previous round can be achieved either because there is cooperation (high group payoff and high individual payoff) or because of self-interested behavior (low group payoff and high individual payoff). Controlling for the group's payoff allows us to distinguish which of the two strategies is reinforced over time. Even if the game is a series of one-shot rounds and members of a subgroup change in every period, subjects may use information on the behavior of other subjects as a guide for future behavior. A negative relation between the group's payoffs in the previous period and the individual's extraction levels may suggest the existence of social preferences. We also include a dummy variable (*second stage*), which equals 1 for rounds 11 to 20. Time fixed effects were not included because they show high correlation with treatment variables (treatment dummy variables are time fixed effects).

Columns (1) to (6) in Table 4.2 show that while the in-group treatment has no effect on individuals' decisions, players chose lower extraction levels when playing during the NMP. Column (2) shows that the NMP treatment effect is significant independently of the additional variables included.

Table 4.2: Dynamic net decisions

	Dependent variable: fishnets$_{it}$							
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
earnings $_{i;t-1}$				0.004*	0.004*	0.004*		0.004*
				(0.002)	(0.002)	(0.002)		(0.002)
earnings $_{-i;t-1}$				-0.002*	-0.002*	-0.002*		-0.002*
				(0.001)	(0.001)	(0.001)		(0.001)
in-group	0.002		0.002	0.023		0.023		
	(0.139)		(0.139)	(0.128)		(0.128)		
NMP		-0.225*	-0.225*		-0.227**	-0.227**		
		(0.113)	(0.113)		(0.107)	(0.107)		
out-group with NMP							-0.414**	-0.401**
							(0.160)	(0.153)
in-group without NMP							-0.187	-0.159
							(0.199)	(0.187)
in-group with NMP							-0.223	-0.215
							(0.172)	(0.158)
second stage	0.402***	0.402**	0.402***	0.392***	0.383**	0.376***	0.402***	0.379***
	(0.139)	(0.161)	(0.139)	(0.130)	(0.149)	(0.132)	(0.139)	(0.131)
_cons	4.733***	4.847***	4.846***	5.165***	5.358***	5.352***	4.940***	5.387***
	(0.120)	(0.106)	(0.137)	(0.526)	(0.539)	(0.540)	(0.164)	(0.534)
Obs.	880	880	880	836	836	836	880	836
Subjects	44	44	44	44	44	44	44	44
r2 within	0.019	0.025	0.025	0.031	0.037	0.037	0.029	0.041
r2 overall	0.009	0.012	0.012	0.180	0.180	0.180	0.014	0.171
r2 between	.	.	0.108	0.927	0.940	0.939	0.069	0.935
*** p<0.01;** p<0.05; * p<0.1 Robust standard errors in parenthesis								

Heterogeneous treatment effects of NMP between in-group and out-group settings are shown in columns (7) and (8) of Table 4.2. On the one hand, it can be seen that the level of nets chosen under the out-group without NMP are not significantly different from the ones under the in-group, both with and without NMP. On the other hand, subjects under the out-group with NMP treatments extract lower levels than when the NMP is not allowed (the -0.4 coefficient amounts to 20% of a standard deviation in nets). Finally, the behavior of individuals under the in-group treatment is not significantly affected by the NMP treatment. The *second stage* dummy variable is positive and significant in all models. That is, subjects increase the average extraction level during the second stage, independently of the treatment they played first. The fact that cooperation decays throughout the game follows previous literature.

Regarding earnings in previous rounds, Models (4), (5), (6) and (8) shows that $\beta_1 > 0$, and $\beta_2 < 0$. This result is consistent with Hayo and Vollan (2012), and suggests that social preferences mechanisms are influencing players' decisions. As stated before, $\beta_1 > 0$, jointly with $\beta_2 < 0$ implies that individuals behave more cooperatively if their group in the past round performed well. This implies that their recent past experience influences their decisions, despite changing partners after each round.

4.3.2 Determinants of extraction decisions

In this section we analyze whether there are socio-demographic determinants of individual choices regarding extraction decisions. We do this for three variables of interest: number of nets chosen in the first period (columns 1 and 2), total number of nets chosen throughout the 20 periods (columns 3 to 5) and average nets (columns 6 to 8). Table 4.3 reports for each of these variables the general and reduced estimations.

Almost no individual-level economic and demographic variable seems to explain extraction choices, as Heinrich et al. (2001) and Hayo and Vollan (2012) found. Wealth and age are the only observable individual determinants of choices which are significant. The magnitude of the wealth coefficient is worth noting: a one standard deviation increase in the wealth index increases the average choice of nets in 44% of a standard deviation. The wealth index was elaborated by means of factor analysis. The index considers different durable goods a household may own.[11] Cardenas (2003) also finds a positive relation between wealth and choices of extraction, and hypothesizes that low wealth status may reflect greater experience in managing a common pool resource. However, in our study this does not seem to be the case. Being a subject whose main

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[11] The variables the index includes are the following: water heater, fridge, TV, radio, cable TV, DVD, washing machine, microwave, computer, Internet, phone, motorbike, car and horse.

activity is fishing is not related to extraction levels (see Table 4.3). Cardenas also provides an alternative explanation, which in our case can be understood if wealthier participants showed smaller marginal utilities from the cash earned in the experiment, thereby having less incentive to cooperate because the marginal value of potential gains is smaller than for the poorer participants. Hayo and Vollan (2012) report a positive coefficient on the upper middle and highest quartiles of income and also argue that high income might reveal a person's stronger preference for consumption, risk and competition.

The other significant determinant of fishnet choices is community membership. El Puente (the baseline in the regression) extracted significantly less than the other four communities. Also, the Wilcoxon-Mann-Whitney ranksum (WMW ranksum) tests reject median and mean extraction levels equality between places of residence, two-by-two, at 10% level of confidence.[12] . These results, together with the non-significance of individual characteristics, strongly support the hypothesis that group level institutions or social norms influence individuals' behavior.

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[12] This hypothesis is not rejected only in the case between Barra de Valizas and Barrio Parque, with reference to average nets thrown, and between Laguna de Rocha and Barra de Valizas and Barrio Parque, with reference to average earnings during the experiment. However, median average earnings equality between the last two is rejected by the WMW ranksum test.

Table 4.3: Determinants of subjects’ extraction decisions

	Dependent variable							
	Nets first period		Total nets			Average nets		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Laguna de Rocha	0.84	1.79**	31.01**	40.33***	39.94***	1.55**	2.02***	2.00***
	(1.13)	(0.87)	(13.48)	(11.44)	(12.15)	(0.67)	(0.57)	(0.61)
Valizas	2.53**	1.17	52.92***	51.88***	50.16***	2.65***	2.59***	2.51***
	(1.08)	(0.87)	(12.93)	(11.60)	(12.08)	(0.65)	(0.58)	(0.60)
Botes	2.97**	1.42	25.05	24.22**	25.25**	1.25	1.21**	1.26**
	(1.26)	(0.87)	(15.06)	(11.15)	(11.73)	(0.75)	(0.56)	(0.59)
Barrio Parque	3.23**	1.42	38.35**	29.81**	31.23**	1.92**	1.49**	1.56**
	(1.29)	(0.87)	(15.35)	(11.49)	(12.13)	(0.77)	(0.57)	(0.61)
female	0.64		-5.46			-0.27		
	(0.86)		(10.28)			(0.51)		
age	-0.02		-1.07***	-0.53*	-0.58*	-0.05***	-0.03*	-0.03*
	(0.03)		(0.36)	(0.27)	(0.29)	(0.02)	(0.01)	(0.01)
years of schooling	-0.02		-3.50*			-0.17*		
	(0.17)		(1.98)			(0.1)		
drinkable water	-1.8		-6.39			-0.32		
	(1.08)		(12.83)			(0.64)		
electricity	-1.04		-17.02			-0.85		
	(1.06)		(12.61)			(0.63)		
wealth	0.49*		11.94***	8.04***		0.60***	0.40***	
	(0.29)		(3.4)	(2.90)		(0.17)	(0.14)	
per capita income (logs)	-0.99**		1.5			0.07		
	(0.48)		(5.7)			(0.29)		
fishing main activity	1.11		-2.29			-0.11		
	(0.77)		(9.17)			(0.46)		
perception[a]	-0.28		-3.85			-0.19		
	(0.77)		(9.17)			(0.46)		
trust[b]	-0.16		-13.11			-0.66		
	(1.21)		(14.4)			(0.72)		
second quartile (wealth)					7.00			0.35
					(11.13)			(0.56)
third quartile (wealth)					25.35**			1.27**
					(11.82)			(0.59)
fourth quartile (wealth)					27.02**			1.35**
					(12.72)			(0.64)
Constant	11.85**	3.83***	114.58**	72.59***	81.56***	5.73**	3.63***	4.08***
	(4.46)	(0.55)	(53.1)	(15.38)	(16.34)	(2.65)	(0.77)	(0.82)
Obs.	43	44	43	44	44	43	44	44
R -squared	0.35	0.12	0.61	0.46	0.45	0.61	0.46	0.45

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

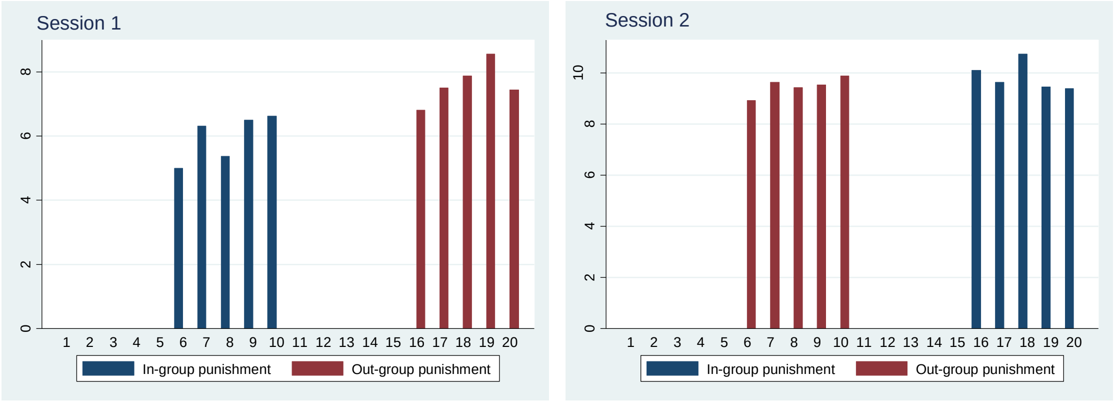
[a] Believes that preserving the environment in coastal lagoons is mainly a responsibility of the people rather than the government.

[b] Believes one can trust most people.

4.3.3 Punishing behavior

In this section we analyze punishers' behavior. On average, 71% of subjects chose to punish in each period in which punishment was allowed. Disapproval was substantial throughout the game and was surprisingly quite high in the last period, even if subjects knew the experiment would be over after that period. Figure 4.3 presents average punishing points by period for the two sessions separately. It should be noted that in the out-group treatment, subjects were mixed among in-group and out-group members and did not know the extraction levels of each of them. Therefore, punishment could not be directly specifically to out-group members with certainty. Session1 exhibited higher levels of punishment during the out-group treatment, though this did not occur in session 2 in which the average disapproval levels are not significantly different in the out-group and in-group treatments. Considering the two sessions together, the amount of punishment is not significantly different in the out-group and in-group treatments.[13]

Figure 4.3: Average punishing points by period



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[13] A Wilcoxon-Mann-Whitney ranksum does not reject the equality between punishment directed during the out-group and in-group treatments for the two sessions together (*p-value*: 0.54).

Following Herrmann et al. (2008), we consider punishment for extraction levels greater than one's own as punishment of free riding, and antisocial punishment to punishment directed to extraction levels equal to or smaller than one's own. Figures 4.1 and 4.2 disapproval points directed to punish free riders in positive values and points aimed at antisocial punishment in negative values. Figure 4.4.1 reports total disapproval points by the number of nets the subject chose to use in that period (horizontal axis) and to which choice of number of nets he decided to punish (bars). Those who use less than 6 nets disapprove of those who use more nets. This punishment of free riding could also be considered altruistic punishment as individuals incur material costs when punishing and reap no material benefits from punishing, because after punishing players are reshuffled before playing the next period. Also, we can observe antisocial punishment (punishment to cooperators): those who use 6 or more nets choose to disapprove of those who used fewer nets. Per subject disapproval points -instead of total points- show that the result above is not the consequence of only few subjects performing large amounts of punishment (Figure 4.4.2). There are only three subjects that used 6 or more nets and they spent a large number of disapproval points in lower extraction levels.[14] This misdirected punishment is also observed by Falk et al. (2000), Masclet et al. (2003) and Gätcher and Herrmann (2011). The effectiveness of the NMP treatment is greater than that observed in Figure 4.2 when excluding sub-groups in which these three subjects participated. Figure 4.4 also indicates that there is some punishment from senders toward receivers using the same number of nets as themselves, especially when using a large number of nets. This could be interpreted as trying to discourage others from free riding while not sticking to the social norm in their actions (i.e., "do as I say and not as I do").

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[14] As with what was observed for overall punishment, antisocial punishment does not significantly differ between in-group and out-group treatments.

Figure 4.4: Punishing behavior by receiver and sender extraction choices'

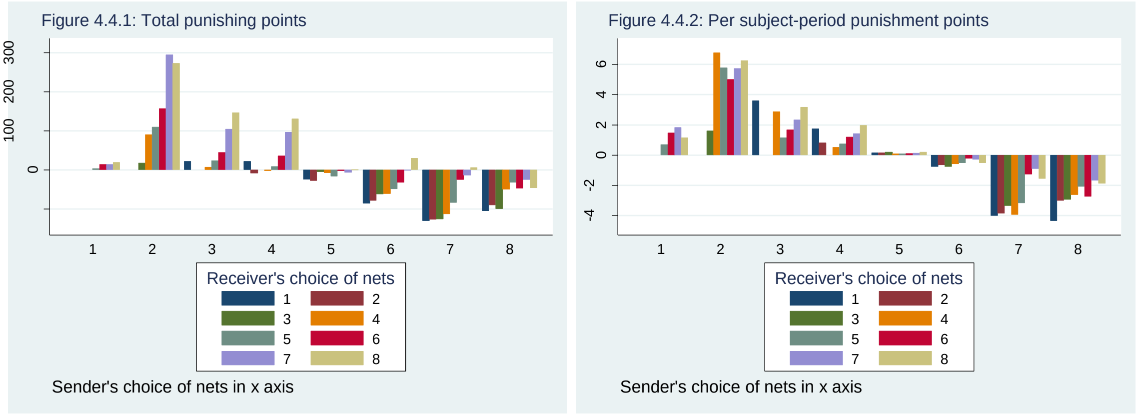
Figure 4.4.1: Total punishing points

Figure 4.4.2: Per subject-period punishment points

NMP was quite intense, when translating disapproval points into flags effectively received. We observe that on average there were 1.7 flags delivered per subgroup of 4 per period. Table 4.4 shows the distribution of flags received depending on whether the subject had chosen an extraction level below or above the subgroup's mean. Although the majority of the flags were awarded to subjects with extraction levels above the subgroups' mean, still 40% of flags were awarded to individuals with extraction levels below their subgroup's mean.

Among the post-experiment questions, we asked the player which are their reasons for disapproving. The majority of subjects chose to disapprove of others' behavior because they were using too many nets (55%).[15]

Table 4.4: Total flags shown by round

Period	Total flags	Negative deviation max{0;$\bar{a}_{t-1}$-$a_{i,t-1}$}				Positive deviation max{0;$a_{i,t-1}$-$\bar{a}_{t-1}$}			
		Total flags	**Yellow**	**Orange**	**Red**	**Total flags**	**Yellow**	**Orange**	**Red**
Total flags	190	76	42	32	2	114	75	28	11
%	100%	40.0%	22.1%	16.8%	1.1%	60.0%	39.5%	14.7%	5.8%

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[15] The other reasons expressed were "without any criteria" (14%), "did not disapprove" (11%), "those who threw few nets" (7%), "those who play differently" (5%), "because it was part of the game" (5%) , and "did not understand" (5%).

Next, we analyze the determinants of showing disapproval to each level of others´ extraction following the model bv Masclet et al. (2003):

$$(2)\ \ P_{ik}^{t} = \beta_0 + \beta_1(max\{0, a_i^t - a_k^t\}) + \beta_2(max\{0, a_k^t - a_i^t\}) \\ + \beta_3\left(max\left\{0, a_k^t - \bar{a}_{sgroup}^t\right\}\right) + \beta_4\left(max\left\{0, \bar{a}_{sgroup}^t - a_k^t\right\}\right)$$

Where P_{ik}^{t} is the number of disapproval points that *i* assigns to *k* in round *t*, the coefficient β_1 is associated with positive deviations from the punisher's fishnet choice, that is, cases in which the punished chose fewer nets than the punisher, while β_2 reflects the relevance of negative deviations from the punisher's fishnet choice, that being situations in which the punished subject chose more fishnets than the punisher. In turn, β_3 reflects the impact of positive deviations from the subgroup's average. Finally, β_4 is associated with the negative deviation from the subgroup's average. We included individual fixed effects to control for individuals' time invariant characteristics. We estimated the following model for each fishnet choice that could be punished. For instance, the first column in Table 4.5 reflects the determinants of punishing those subjects who chose 1 fishnet. As Table 4.5 shows, both positive (antisocial punishment) and negative (punishment of free riding) deviations from the punisher's fishnet choice are significant. But as Masclet et al. (2003) showed, there is an additional effect regarding deviations of the punished subject from the subgroup's average. [16]

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[16] Estimates from a Tobit model point to the same conclusions but in that model, coefficients are slightly smaller in magnitude.

Table 4.5 Determinants of disapproval points directed to each of the fishnet options

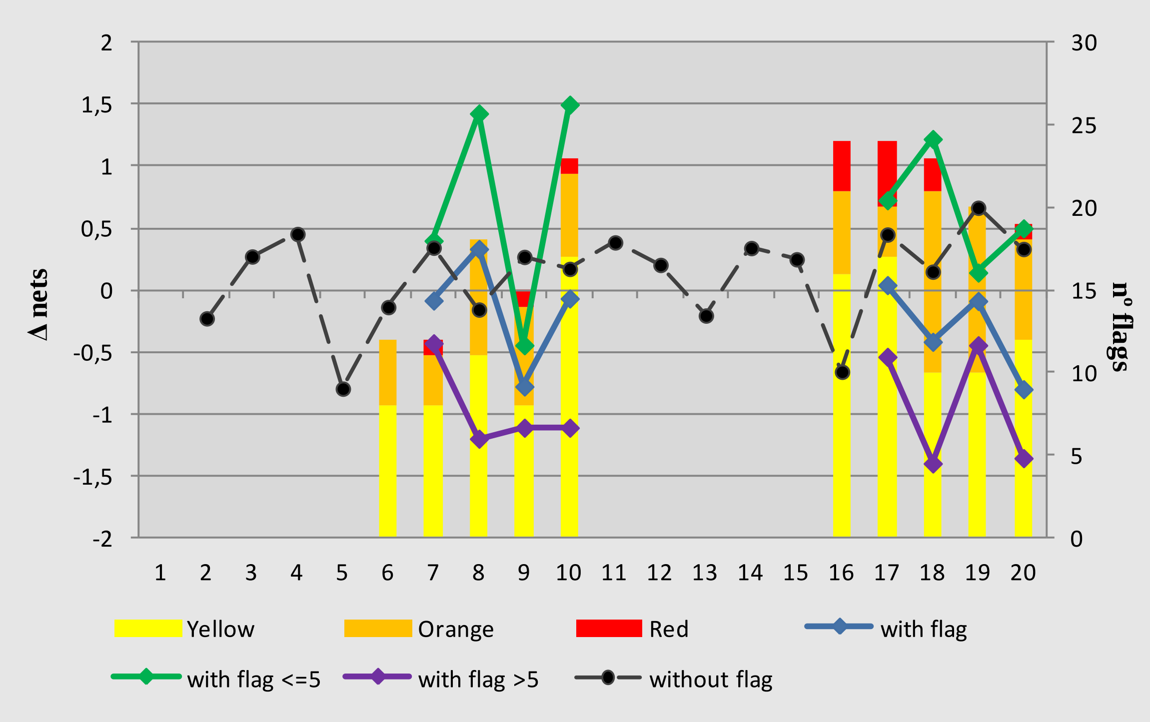
	Dependent variable: Disapproval points							
	Others´ fishnet options							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Positive deviation from i's own extraction ($\max\{0, nets_i - nets_k\}$)	0.79***	0.53***	0.89***	0.48***	0.67***	2.22***	1.46***	
	(0.07)	(0.07)	(0.10)	(0.10)	(0.12)	(0.15)	(0.42)	
Negative deviation from i's own extraction ($\max\{0, nets_k - nets_i\}$)				1.33***	0.35***	0.49***	0.33***	0.04
				(0.28)	(0.09)	(0.06)	(0.06)	(0.06)
Positive deviation from average ($\max\{0, nets_{av} - nets_k\}$)	0.13	0.31***	0.03	0.83***	0.70***	0.54	0.31	
	(0.09)	(0.10)	(0.15)	(0.16)	(0.20)	(0.52)	(1.91)	
Negative deviation from average ($\max\{0, nets_k - nets_{av}\}$)			-0.43	-0.16	0.32*	0.26***	0.29***	0.62***
			(0.62)	(0.32)	(0.16)	(0.09)	(0.08)	(0.08)
Constant	0.24***	0.28***	0.30***	0.42***	0.49***	0.38***	0.84***	0.98***
	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.08)	(0.10)
Obs.	440	440	440	440	440	440	440	440
R-squared	0.55	0.47	0.44	0.32	0.24	0.51	0.29	0.30
Number of id_	44	44	44	44	44	44	44	44

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

4.3.4 Reaction to punishment

In this section we analyze whether punishment generated a change in behavior among those who were punished. At a first glance, the descriptive analysis suggests that flags produce variations in individuals' behavior. Figure 4.5 shows that individuals who received a flag in the previous period, on average, reduced their extraction in the next period by 0.26 nets. However, at the individual level this is not always the case. One of the reasons for observing heterogeneity in terms of reaction to punishment is due to the fact that those who are punished are not only the ones who choose a high number of nets, but also those with a low number of nets. Figure 4.5 shows that while those who received a flag when throwing more than 5 nets diminish their choice in the next period (their extraction level variation is -0.99 nets on average), those who received a flag when throwing 5 or less nets increase the number of nets chosen in next period (they increase their extraction on average by 0.61). Also, it is worth noting that net variations of those that do not receive a flag during periods that NMP is allowed, range around zero.

Figure 4.5: Total fishnets variations and total number of flags



A significant percentage of the individuals who received a flag did not change their behavior in the next round (33%). Decisions to throw two or eight nets were the modes of nets' distribution. A large number of subjects who chose these values decided not to change their choice, independently of what others think (55% and 48% respectively). The norm of cooperation may not be viewed as the norm that punishment should enforce. Other norms such as "try to fish as much as possible" may be the prevailing ones (Noussair et al., 2011). Therefore, some punished subjects may interpret punishment for using many nets as inappropriate and respond by raising the number of nets or maintaining their choice at the maximum number of nets.

Also, not all the flag colors produced the same reaction (see flag range in Table A4.5 in Appendix). Subjects are more indifferent to yellow flags than to the others: 42% of the cases in which a subject received a yellow flag, he did not change his decision in the next period.

The next step is to formally test for the behavior depicted above. We first test whether player´s *i* decision changes from period *t-1* to period *t* as a function of own and others' punishment received in the previous period. Then, we adapt the reaction function included in Masclet et al. (2003) and Noussair and Tucker (2005) and test whether player´s *i* decision changes from period *t-1* to period *t* is still a function of the punishment received in the previous period, once his extraction deviations from group average decisions are included:

$$(3)\quad a_i^t - a_i^{t-1} = \beta_0 + \beta_1 * Flag_i^{t-1} + \beta_2 * OthersFlag_i^{t-1} + \beta_3 * (max\{0, a_i^{t-1} - \bar{a}^{t-1}\}) + \beta_4 * (max\{0, \bar{a}^{t-1} - a_i^{t-1}\})$$

Where $Flag_i^{t-1}$ is a dummy variable that indicate if the individual received a flag in a previous period, $OthersFlag_i^{t-1}$ is a variable that indicates how many of individual *i* partners in period *t* received a flag in previous period (ranges from 0 to 3). Variable $max\{0, a_i^{t-1} - \bar{a}^{t-1}\}$ indicates if the individual extracted more than his subgroup average in a previous period, and the deviation magnitude, while $max\{0, \bar{a}^{t-1} - a_i^{t-1}\}$ is the same but for negative deviations from the subgroup average in a previous period.[17] We test this model for periods where flag reaction could take place (periods 7 to 10 and 17 to 20) and separately for those that chose 5 or less nets and more than 5 nets, respectively. A control model during periods where reaction is not possible is also included in column (11) of Table 4.6 to compare conformity effects. In all specifications we included individual fixed effects to control for non-observable factors that may affect individual decisions.

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[17] Also alternative specifications distinguishing the different flag colors are estimated..

Table 4.6: Reaction to punishment

	Dependent variable: Fishnets$_{i,t}$ -fishnets$_{i,t-1}$											
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Periods	**NMP**	**NMP**	**NMP**	**nets <=5 NMP**	**nets >5 NMP**	**NMP**	**NMP**	**NMP**	**nets <=5 NMP**	**nets >5 NMP**	**No-NMP**	**NMP**
Positive deviation from average; $max\{0;a_{i,t-1}-\bar{a}_{t-1}\}$			-0.912***	0.186	-0.691***			-0.953***	0.172	-0.663***	-0.554***	-0.967***
			(0.173)	(0.527)	(0.175)			(0.163)	(0.530)	(0.161)	(0.119)	(0.179)
Negative deviation from average; $max\{0;\bar{a}_{t-1}-a_{i,t-1}\}$			0.855***	0.700***	0.103			0.836***	0.664***	0.170	0.917***	0.832***
			(0.147)	(0.157)	(0.501)			(0.144)	(0.161)	(0.476)	(0.152)	(0.144)
Flag in t-1	-0.61*	-0.637*	-0.289	-0.117	-0.127							
	(0.32)	(0.333)	(0.223)	(0.266)	(0.308)							
Yellow flag in t-1						-0.471	-0.521	-0.302	-0.083	-0.005		
						(0.328)	(0.340)	(0.253)	(0.366)	(0.326)		
Orange flag in t-1						-0.793*	-0.778	-0.324	-0.270	-0.622		
						(0.467)	(0.467)	(0.325)	(0.375)	(0.502)		
Red flag in t-1						-1.105	-1.074	0.340	2.055*	0.510		
						(1.205)	(1.203)	(0.661)	(1.052)	(0.669)		
Flag rest of the group members in t-1		0.229*	0.196	0.388**	-0.126		0.218*	0.197	0.411**	-0.166		
		(0.115)	(0.120)	(0.157)	(0.099)		(0.115)	(0.125)	(0.160)	(0.121)		
_constant	0.29**	0.016	-0.048	-0.677*	0.517	0.300**	0.035	-0.018	-0.677*	0.515	-0.178	0.132
	(0.14)	(0.166)	(0.253)	(0.348)	(0.363)	(0.138)	(0.172)	(0.243)	(0.352)	(0.358)	(0.163)	(0.172)
Nº observations	352	352	352	213	139	352	352	352	213	139	396	352
Nº individuals	44	44	44	39	32	44	44	44	39	32	44	44
r2 within	0.020	0.029	0.360	0.182	0.164	0.023	0.032	0.363	0.204	0.186	0.291	0.350
r2 overall	0.018	0.030	0.202	0.111	0.096	0.018	0.029	0.205	0.119	0.105	0.185	0.196
r2 between	0.013	0.073	0.047	0.001	0.024	0.001	0.035	0.049	0.000	0.008	0.021	0.038

*** $p<0.01$;** $p<0.05$; * $p<0.1$

robust standard errors in parenthesis

All the regresions correspond to periods where individuals could show a reaction to NMP in previous period, except col. (11), that refers to the ones where punishment in previous period was not available.

Flag rest of the group members in *t-1* is variable that ranges from 0 to 3 depending on how many current group members received a flag in the previous period.

Col. (4) and (9) only consider individuals with extraction levels lower or equal to 5, while col. (5) and (10) refer only to individual with extraction levels higher than 5

Model (1) in Table 4.6 suggests that being punished generates a downward adjustment in the following periods. Models (2) to (5) and (7) to (10) include a variable that counts how many of the three group members in *t*, received a flag in *t-1*. Having partners who were punished in the previous period increases own extraction. This effect is more pronounced if the subject extracted 5 nets or less in the previous period (Models 4 and 9). In turn, sharing the group with subjects who were punished in the previous round has no effect on an individual who had extracted more than 5 nets in the previous period (Model 5 and 10). Observing that one or more of the group members was punished in the previous period appears to be a signal that the group is likely to exert high extractions.[18] We conclude that social preferences are context dependent: when individuals see themselves among non-cooperative subjects they react by raising their own extraction to avoid the risk of being disadvantaged. In this sense, individuals seem to assume punished subjects will not react to the punishment. Subjects may also interpret they are less likely to be punished for extracting a large number of nets in a group that is used to extracting high levels.

When conformity effects are allowed (how individuals deviate from the subgroup's average in the previous period), receiving a flag does not determine a decrease in extraction any longer (Models (3) to (5) and (8) to (10). Those who threw fewer nets than the subgroup's average in the previous period increase their decision in the next period, while those who threw more than average in previous period decrease their decision the next period. The presence of conformity effects is consistent with Masclet et al. (2003), and Hayo and Vollan (2012). As might be expected, the second mechanism does not take place if we look only at the reaction of those who received a flag when throwing five or less nets, while the first mechanism does not work when the reaction of those who threw more than five nets is studied. The magnitude of the conformity effect is larger during the NMP periods (especially positive deviations of the subjects' extraction relative to the subgroup's mean), which could indicate that there may be an additional impact of NMP increasing the convergence to the social norm. However, confidence intervals for these

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[18] Recall that the punishment implied holding the flag received in the next period of the game.

effects in periods with and without NMP overlap at the 95% confidence level (Models 11 and 12). Interactions between deviations from the subgroup in previous periods and having received a flag are not significant, which confirms that the high significance of conformity effects do not seem to be picking the effect of being punished. Also, the conformity effects are not different when individuals are playing solely with people of their own community, relative to the out-group treatment (Table A4.6 in Appendix).

When we distinguish by flags' colors (Model 6), we observe that receiving an orange flag appears to have a small influence on diminishing individuals' nets choice, but its effect is diluted when splitting the sample between those people who receive a flag when they threw five or less nets, and more than five (Models 9 to 10). It is worth noting the large increase in fishnets choices in *t* when receiving a red flag, having thrown five or less nets in *t-1* (Model 9). Subjects react strongly, in a non-cooperative way, when they feel they have been unfairly punished.

To sum up, as shown in section 4.1, the NMP treatment has an effect that reduces extraction levels, especially during the out-group treatment. However, when analyzing period-by-period variations in extraction decisions, individuals adjust their choice mainly taking into account the subgroup's average in the previous period rather than react to punishment. This conformity effect is present both when NMP is available and when it is not. Only those who are punished with a red flag and perceive that action as unfair appear to react by raising their extraction levels. This may be explained because they experience anger. The fact that receiving a flag does not have consequences on individuals' decisions can be explained because subjects who are sensitive to NMP lower their extraction levels in advance, to avoid being punished and experiencing shame. Indeed, they correctly anticipate that in order to reduce the probability of being punished the best they can do is lower their extraction levels. Subjects are aware that if they choose high extraction levels they are likely to be punished and if they choose to do so it is because the punishment does not generate a significant disutility. This explains why when individuals are punished they do not react to punishment (unless they did not expect it, as in the case of being punished by antisocial punishers). This is also suggested by the behavior of subjects that raise their own extraction their current partners were punished in the previous period. Subjects expect punished subjects not to react to punishment by interpreting the fact that they received a flag as a signal they will extract a large number of nets in the next period. Overall subjects try to adapt their behavior both to the behavior of the group in which they played in the previous round and to the signals provided by the members of their current group.

4.4. Discussion and conclusions

In this study we performed a framed field experiment to test the effectiveness of non-monetary punishment (NMP) in the context of a CPR game. We combined this treatment with an in-group/out-group treatment, letting fishermen from different communities play one stage of the experiment solely with members of their own community and the other stage mixed with another community.

First, our findings suggest that NMP has an effect diminishing extraction levels only in the out-group treatment. That is, subjects derive more disutility from being punished when interacting with subjects who do not belong to their own community. Subjects take the NMP institution more seriously during the out-group treatment. In a context in which individuals do not know each other (or hardly know each other) but are aware that there is a slight chance they might see each other again, being publicly punished would provide the only information others have about oneself and in this sense it may be important to avoid being flagged in such a way. However, the NMP may not be perceived as intimidating when coming from workmates or neighbors. NMP may not matter either if it takes place in a context of complete strangers in which subjects know for sure they will not meet again. In other words, the relationship between the sensitivity to peer punishment in in-group/out-group contexts may be non-monotonic.

Previous literature regarding contributions in public good games finds that non-monetary punishment increases cooperation in a public good game (López et al., 2012), but its effect is smaller than that of monetary sanctions (Masclet et al., 2003), and it is more effective in increasing cooperation when combined with this kind of sanction (Noussair and Tucker, 2005). Our findings are consistent with these studies in pointing that non-monetary punishment, solely by affecting pro-social emotions, can enhance cooperation in a context in which subjects belong to different groups.

Second, the NMP's effectiveness is diminished by the fact that was employed for punishing both, players with high and low extraction levels. The presence of antisocial punishment can decrease cooperation if subjects perceive the sanctions as unfair (Beckenkamp and Ostmann, 1999; Masclet et al., 2003). Antisocial punishment is also observed by Falk et al. (2000), and Gächter and Herrmann (2011). Herrmann et al. (2008) point out that one plausible explanation of antisocial punishment is that people might not accept punishment and therefore seek revenge. Alternatively, it could also be interpreted as features of their daily lives that subjects bring into the game (Cardenas and Ostrom, 2004). For instance, they may perceive that intensifying current fishing does not have any consequences on the availability of fish in the future (for instance, because they may believe that climate factors or other industries are more important determinants of fish availability). Indeed, subjects may not view the norm of cooperation as the norm that punishment should enforce, other norms such as "try to catch as many fish as possible" may be the prevailing ones (Casari and Luini, 2009; and Noussair et al., 2011). A fourth explanation could be that this behavior is a consequence of bounded rationality, related to cognitive limitations of the game on the part of some players. Janssen et al. (2010) argue that in a context in which participants can punish back but cannot discuss why they are sanctioned, receiving a sanction does not carry a clear message.

Subjects seem to correctly anticipate that the likelihood of being punished is increasing in extraction levels and those who would experience disutility by being punished reduce their extraction levels beforehand. Those who do not reduce extraction levels do not react to punishment because they are insensitive to it. Instead, those who were unexpectedly punished and who considered the punishment unfair, experienced anger and increased their extraction levels in the subsequent period. Also, we conclude that social preferences are context dependent. Cooperative individuals, raise their own extraction when they observe that their current partners were punished in the previous period.

Third, we find strong conformity effects, in line with Velez et al. (2009) and Hayo and Vollan (2012): individuals adjust their period-by-period decisions in order to converge with their peers' average in a previous period. When studying how subjects react to punishment we observe that punishment is no longer relevant when conformity effects are taken into account. These results highlight the potential relevance of social comparisons as a form of non-pecuniary policy seeking changes in behavior (Ferraro and Price, 2011).

Fourth, it is particularly interesting to note that subjects are willing to face a monetary cost in order to punish others non-monetarily while may not necessarily expect that this punishment will determine an increase in cooperation. This result is in line with Fehr and Gachter (2000) findings regarding monetary punishment.[19] Following Casari and Luini (2009), Fudenberg and Pathak (2010) and Noussair et al. (2011), we can say that punishment is not necessarily applied instrumentally to increase cooperation and that subjects have preferences for punishing.

Fifth, contrary to what has been mostly documented in the literature, we do not find an in-group bias regarding cooperation. That is, individuals do not behave differently when interacting with subjects from their own community than when they are mixed with

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[19] Even if the monetary cost of social punishment was low, subjects were reminded at every period that by socially punishing others they were themselves bearing a cost, as they had to subtract the total cost of punishment from their earnings in their balance sheet. Despite this fact, subjects chose to punish others during the whole experiment, including the last period when no change in others' behavior was possible. In fact, on average per period each subgroup awarded 1.7 disapproval flags to the members of that group.

subjects from other communities, except for being more sensitive to NMP during the out-group treatment. Hewstone et al. (2002) argue that negative feelings toward out-group members tend to occur mostly in circumstances in which belonging to a group draws a strong sense of identity. This is not the case of our framework, where although fishers came from different communities that do not interact during their daily life, everybody acknowledges being an outsider at some point in time. As stated by Buchan et al. (2006), the power of the in-group bias is heterogeneous across societies. For this reason, as regards to social preferences, granting exclusive access to a common pool resource to a certain community appears not to be a requisite from a resource conservation point of view

We do not find significant differences in punishing behavior between in-group and out-group treatments. This finding is in contrast to McLeish and Oxoby (2007) and Miguel and Gugerty (2005), who argue that subjects punish free riders more harshly in in-groups than out-groups. On the contrary, Chen and Xin (2009) and Currarini and Mengel (2012) find that subjects are less likely to punish in-group members than out-group members.

Finally, community membership appears to have an influence over individuals' decisions, a finding not explained by observable socioeconomic factors. This may suggest that social norms regarding extraction levels differ among communities. The importance of community membership has been noted by Henrich et al. (2001) and Hayo and Vollan (2012). In our case it is quite striking to find differential behavior by community, as the communities we studied do not differ in terms of ethnicity or economic organization. Also, in line with other studies (Cardenas, 2003; Hayo and Vollan, 2012), we do find that cooperation is negatively correlated with wealth. This relationship should be studied more in depth, in order to disentangle the causal link between the two.

Overall, our results are consistent with the view that cooperation in a CPR dilemma is determined not only by repeated game behavior but also by social preferences.

Individuals limit their resource exploitation (cooperate) in response to the threat of punishment when they are mixed with individuals from other communities. However, we do not find strong evidence of reactions to being effectively punished. This result is due to two reasons. First, subjects anticipate that the probability of being punished increases with their extraction level decision. Therefore, they reduce their extraction decision in advance, avoiding the experience of shame. Second, antisocial punishment was substantial and generated in some cases an increase in extraction among those being unfairly punished. Our results suggest that for peer punishment to be effective it requires coordination, in order to prevent anti-social targeting and to enhance the social signal conveyed by the punishment. Finally, even if individuals played a series of one shot games, previous interactions with other subjects exerted substantial influence on behavior, reflecting strong preferences for conformism.

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Appendix

Table A4.1: Mean socioeconomic characteristics by community

Community	Years of schooling	Electricity at home	Wealth[a]	Per capita income (US)	Fishing main activity
Laguna de Rocha	6,0	13%	1,85	149	75%
Valizas Puente	6,7	75%	3,06	175	67%
Barra de Valizas	7,6	38%	1,68	373	63%
Puerto los Botes	6,0	100%	2,52	246	100%
Barrio Parque	8,0	100%	4,32	320	38%

[a] The wealth index considers different durable goods a household may own.

Table A4.2 Payoff table

	My fishnets								
Others' total	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Others' average**
3	354	360	366	372	378	384	390	396	1
4	342	348	354	360	366	372	378	384	1
5	330	336	342	348	354	360	366	372	2
6	318	324	330	336	342	348	354	360	2
7	306	312	318	324	330	336	342	348	2
8	294	300	306	312	318	324	330	336	3
9	282	288	294	300	306	312	318	324	3
10	270	276	282	288	294	300	306	312	3
11	258	264	270	276	282	288	294	300	4
12	246	252	258	264	270	276	282	288	4
13	234	240	246	252	258	264	270	276	4
14	222	228	234	240	246	252	258	264	5
15	210	216	222	228	234	240	246	252	5
16	198	204	210	216	222	228	234	240	5
17	186	192	198	204	210	216	222	228	6
18	174	180	186	192	198	204	210	216	6
19	162	168	174	180	186	192	198	204	6
20	150	156	162	168	174	180	186	192	7
21	138	144	150	156	162	168	174	180	7
22	126	132	138	144	150	156	162	168	7
23	114	120	126	132	138	144	150	156	8
24	102	108	114	120	126	132	138	144	8

Table A4.3: Punishment card

If the other throws:	I disapprove (0 to 10 points)
1 net	
2 nets	
3 nets	
4 nets	
5 nets	
6 nets	
7 nets	
8 nets	
Total	

Table A4.4: Flag range

Flag	Total punishment points received
Yellow	2 - 5
Orange	6 - 10
Red	11 - 30

Table A4.5: Net variations and flag color in previous round (%)

	Total			If nets in previous round <=5			If nets in previous round >5		
nets variation	**Yellow**	**Orange**	**Red**	**Yellow**	**Orange**	**Red**	**Yellow**	**Orange**	**Red**
-	28,4	44,9	45,5	25,0	32,1	0,0	30,8	61,9	62,5
=	42,1	20,4	18,2	25,0	14,3	0,0	53,9	28,6	25,0
+	29,6	34,7	36,4	50,0	53,6	100,0	15,4	9,5	12,5
Total	100	100	100	100	100	100	100	100	100

Table A4.6: Net variations, flags and deviations from group's average in previous round including interactions terms

	Dependent variable: fishnets$_t$ -fishnets$_{t-1}$	
Sample	**7-10 & 17-20**	**7-10 & 17-20**
Positive deviation from average ($a_{i,t-1}$-$\bar{a}_{t-1}$)	-0.952***	-0.940***
	(0.183)	(0.201)
Negative deviation from average ($\bar{a}_{t-1}$-ai,$_{t-1}$)	0.876***	0.934***
	(0.166)	(0.162)
Positive deviation from average ($a_{i,t-1}$-$\bar{a}_{t-1}$)*flag$_{t-1}$	-0.010	
	(0.204)	
Negative deviation from average ($\bar{a}_{t-1}$-$a_{i,t-1}$)*flagt-1	-0.095	
	(0.168)	
Positive deviation from average ($a_{i,t-1}$-$\bar{a}_{t-1}$)*outgroup		-0.076
		(0.166)
Negative deviation from average ($\bar{a}_{t-1}$-$a_{i,t-1}$)*outgroup		-0.235
		(0.156)
_cons	0.120	0.144
	(0.165)	(0.169)
N	352	352
N_g	44	44
r2_w	0.351	0.356
r2_o	0.197	0.201
r2_b	0.038	0.040
legend: *** p<0.01;** p<0.05; * p<0.1 standard errors in parenthesis		

Conclusions

Environmental problems caused by economic activity at different levels deserve different diagnostic methods and policy instruments. With this aim, the present thesis has analyzed the relationship between economic activity and the environment at three different dimensions: international, national, and local. A research problem at each dimension has been chosen, and the tools that better fit to analyze each problem have been applied. The present document is divided into three parts, each one corresponding to one dimension. Policy implications are directly derived from the analysis.

Part I is concerned in the analysis of the relationship between economic activity and the environment from a global perspective. Chapter 1 analyzes the hypothesis of homogeneity in the relationship between carbon dioxide emissions and economic activity level between 31 countries (28 OECD, Brazil, China, and India) during the period 1950 to 2006 using cointegration analysis, and a highly overlapped sample over time between countries. Homogeneity across countries is rejected, both in functional form and in the parameters of long run relationship. Nonetheless, it might be noted that there are cases in which countries with different paths achieve the turning point for a similar GDP per capita level.

Clearly, the results above do not support that economic growth will automatically drive to an EKC. Neither that despite there could be a turning point in some cases, it will be achieved for reasonable pollution levels. This would depend on the real determinants behind the relationship, where energy and environmental policies, institutions, and trade play an important role. This confirms the relevance of considering the heterogeneity in exploring the relationship between air pollution and economic activity to avoid spurious parameter estimates and infer a wrong behavior of the functional form, which could lead to induce that the relationship is reversed when in fact it is direct. Also, the functional form of the apparent long run relation for each country is explicitly defined. This would help to think over the policy instruments design involving countries with similar economic levels but different paths.

Part II, focused on the analysis between economic activity and the environment from a national perspective, is divided in two chapters (Chapters 2 and 3). Chapter 2 shows key sectors in GHG emissions of the Uruguayan economy in 2004. Key sectors analysis helps to identify productive sectors responsibility, considering their total emissions (direct plus indirect emissions). Also, policy design for mitigating emissions is different if a sector pollutes through its own production process or if it makes other sectors to pollute. Hence, sectoral linkages have been decomposed in terms of own and pure components. Also, total emissions have been split between those produced for external and domestic demand. This chapter also contributes constructing a sectoral GHG emissions vector, linking national accounts and environment, for the first time in Uruguay.

Technological improvements and better practices are only effective in directly polluting sectors. In the case of methane and nitrous oxide, Cattle farming (6) and Sewage and refuse disposal (55) are the main direct polluter, while Refined petroleum (33), Electricity, gas and water supply (42), Land transport and transport via pipelines (46), and Water and air transport (47) are the more direct polluters in the case of carbon dioxide emissions.

But the most interesting point of this chapter is that input-output analysis allows to identify those sectors that pollute through indirect channels. The most relevant sectors in reference to emissions related to electricity consumption are those that directly demand electricity. But while these sectors are indirect of first order, and more obvious to policy makers, the main contribution of this chapter is to shed light on those sectors that, whose emissions are of highly indirect order, despite their share in total emissions is lower. In this sense, Hotels and Restaurants (45) sector plays a very important role for all the pollutants. Demand policies on this sector, like labeling or product processes certifications, can help to mitigate the indirect emissions produced by it. However, given the extensive cattle farming production technique employed in Uruguay, the scope of this kind of measures as a tool for methane and nitrous oxide emissions is limited. Building (43) is a highly indirect polluter in reference to carbon dioxide emissions through its backward linkages. Also, Real estate activities (50) depicts a similar path, but its share in total emissions is much lower. This highlights the relevance of housing market as a tool for the design of mitigation policies. Also Acquaye and Duffy (2010) highlight the importance of providing emissions information by suppliers as a tool for incentivizing low-emissions materials substitution. Motor vehicles and oil retail trade (44), and Financial services (49) play a very important role for all the pollutants through their pure forward linkages (sector 44 is also relevant because of its pure backward linkages in reference to carbon dioxide emissions). This allows to design useful tools for pollution mitigation through both credit access and the oil retail trade market.

The scope of national final demand policies has to be weighted by its share in total demand. Methane and nitrous oxide emissions are produced mainly by primary sectors when providing inputs to industrial sectors to satisfy their external demand. Carbon dioxide emissions are more spread between industrial and services sectors, because they mainly come from fuel combustion. In this way, final demand policies are going to be more effective to mitigate carbon dioxide emissions than in the case of the other pollutants that are mostly pulled by exports.

Key sectors analysis provides an overview about the relationship between the productive structure and the environment. But in some occasions focusing on the most relevant sectors is most important than analyzing the environmental impact of the whole economic system. This complements previous chapter, allowing to study with greater complexity their relationship with the environment, while still considering their relationships with the entire production system (Alcántara, 1995). As exposed above, agro-industrial activities plays a fundamental role in reference to methane and nitrous oxide direct emissions, and are the main Uruguayan export sectors. Moreover, several services sectors where identified as highly indirect polluters, mainly in reference to carbon dioxide emissions. This supports the evidence against the non-materiality of services sectors, as shown by Suh (2006), Nansai et al. (2007), Alcántara and Padilla (2009), and Fourcroy et al. (2012).

Chapter 3 disentangles the relationship of these subsystems with the rest of the economy and within their self in greater detail. A multiplicative decomposition is employed to split the relationship of the subsystems with the rest of the economy. It is combined with an additive decomposition for the study of the linkages within them. Results show that almost all of total methane emissions from the agro-industrial subsystem are produced inside itself. Moreover, the internal spillover component explains almost all these internal emissions. This internal spillover transits a very short path through the productive system, given that it is explained by the food industry productive chains when requiring primary inputs from cattle farming activities for attending their final demand. Also, other industries that process leather have an important share in this component. When looking at services subsystem and carbon dioxide emissions, not only the internal component is significant, but also the spillover to the rest of the economy. This means that this subsystem also pulls other sectors of the rest of the economy to pollute. This decomposition confirms that the non-material perception of services sectors is refuted when considering their relationship with the rest of the economy.

Finally, Part III addresses the analysis from a local perspective. Because of market failures and information asymmetries, private or state property failed to avoid what Hardin (1968) named the *tragedy of the commons*. Many authors argue during last decades that in some cases incomplete contracts gaps can be filled by communal property regimes, because they are enforced by social norms that may enhance cooperation for common pool resources (CPR) conservation (Ostrom, 1990; Feeny et al. 1990; Baland and Platteau, 1996; Ostrom et al., 1999 and Ostrom, 2000; Bowles and Gintis, 2002).

Chapter 4 analyzes the effectiveness of peers' non-monetary punishment (NMP) in promoting cooperation among Uruguayan fishermen communities when exploiting a CPR. Informal sanctions typically take place in a setting where local communities exploit a resource in common. This makes NMP to be a plausible tool to enhance cooperation for CPR conservation. Also, because there is no presence of monetary incentives, this mechanism allows to better isolate the presence of pro-social emotions. NMP effectiveness can differ depending if fishermen are mixed with other from different communities, or if only individuals from the same community are allowed to exploit the resource. Previous evidence shows that when interacting with members of their own group rather than with outsiders, individuals may achieve greater levels of cooperation because of conditional social preferences on group membership (Bandiera et al., 2005; Miguel and Gugerty, 2005; Ruffle and Sosis, 2006; Goette et al. 2012; Bernhard, et al., 2006; Chen and Xin, 2009). In this way, the group composition can condition the channels through which NMP effectiveness is transferred.

Through a framed field experiment (Harrison and List, 2004), results are consistent with the view that cooperation in a CPR dilemma is determined not only by repeated game behavior but also by social preferences. Groups composed of fishers from different communities (out-groups), who are sometimes in conflict over fishing territories, reduced their exploitation of the resource in response to the threat of punishment, unlike groups from a single community (in-groups). However, previous interactions with other subjects have substantial influence on their behavior, reflecting strong preferences for conformism. Individuals with social preferences limit their resource exploitation (cooperate) in response to the threat of punishment, but we do not find evidence of reactions to being effectively punished. We argue that the latter result is due to two reasons. First, subjects anticipate that the probability of being punished increases with their extraction level decision. Therefore, they reduce their extraction decision in advance, avoiding the experience of shame. Second, individuals with lower extraction levels punished those with higher extraction decisions, while those tend to punish people that cooperate (antisocial punishment). This generated in some cases an increase in extraction among those being unfairly punished. Our results suggest that for peer punishment to be effective it requires coordination, in order to prevent anti-social targeting and to enhance the social signal conveyed by the punishment.

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