THE INSTITUTIONAL DETERMINANTS OF CO_2 EMISSIONS: A COMPUTATIONAL MODELLING APPROACH USING ARTIFICIAL NEURAL NETWORKS AND GENETIC PROGRAMMING

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The institutional determinants of CO_2 emissions: A computational modelling approach using Artificial Neural Networks and Genetic Programming

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Abstract

Understanding the complex process of climate change implies the knowledge of all possible determinants of CO_2 emissions. Most of the studies focused on the key role of economic growth on the emissions. Nevertheless, recent trends in economics have highlighted the relevance of the institutional structure of production on economic performance. This paper studies the influence of several institutional determinants on CO_2 emissions, clarifying which variables are relevant to explain this influence. For this aim, Genetic Programming and Artificial Neural Networks are used to find an optimal functional relationship between the CO_2 emissions and a set of historical, economic, geographical, religious and social variables, which are considered as a good approximation to the institutional quality of a country. Besides this, the paper compares the results using the computational methods with those employing a more traditional parametric perspective. Following the empirical results of the cross-country application, this paper generates new evidence on the binomial institutions and CO_2 emissions.

Keywords: Computational methods; CO_2 emissions; Institutional determinants

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1. Introduction

Climate change has emerged as one of the main issues in the political and scientific agenda. Nowadays it is widely accepted that this environmental problem represents a serious threat for the life conditions of hundred of million people; and it is considered one of the greatest challenges facing the world today. The principal consequence of climate change is associated generally with the increase of the temperature in the Earth. The global warming observed in recent decades has already led to negative and clearly perceptible effects for ecosystems, human settlements and economic activities such as tourism and agriculture, for example. It is directly responsible of more frequent and economically costly natural disasters (storms, hurricanes, floods and droughts), the melt of the ice caps, the rise of the sea level, and the irregular and unpredictable behaviour of the weather (IPCC, 2007).

The high concentration of greenhouse gases in the atmosphere is the main reason that explains the global warming and, therefore, the climate change. Among these gases, the anthropogenic carbon dioxide emissions (CO_2) are the main factor of the greenhouse effect. This fact justifies why CO_2 emissions are considered by the specialists as the best available indicator of climate change (Carlsson and Lundström, 2003; OECD, 2007; Quadrelli and Peterson, 2007). In spite of the international efforts to reduce the atmospheric level of CO_2, the emissions of this gas are still growing in many countries. Several papers in the specialized literature on energy economics and environmental economics have studied what possible factors contribute to the explanation of the increasing level of CO_2 emissions. Most of these efforts have focused on the key role of production and economic growth. For example, many studies provide empirical evidence of a monotonically increasing relation between CO_2 emissions and Gross National Product (GNP) (Shafik, 1994; Holtz-Eakin and Selden, 1995; Bertinelli and Strobl, 2005). However, as Bengoechea et al. (2001) point out, there may be other significant variables apart from the economic growth that explain the rising concentration of CO_2. Researchers are encouraged to make an effort to fill up this gap by discovering other possible determinants. In this sense, nowadays there is widespread agreement among economists that institutions matter and that they affect economic performance. Accordingly, it seems apparently reasonable to think that they must be included in the economic analysis on energy and environment. Thus, an effort to open the "black box" of the determinants of CO_2 emissions should focus on the role of organizational and institutional factors.

The new institutional economics (NIE) has constituted a program of research that has propelled the return of institutions into the agenda of mainstream economics. The NIE has already allowed significant advances in different areas such as economic history, economics of organization, law and economics, policy analysis, economic growth, development economics, ecological and environmental economics (Willliamson, 2000; Ménard and Shirley, 2005; Vatn, 2005; Paavola and Adger, 2005; Culas, 2007). The coasean notion of transaction costs (Coase, 1937, 1960) and the northian notion of institutions (North, 1990) established the foundations for the theoretical framework of the NIE. Political rules, informal norms and enforcement mechanisms constitute the "rules of the game" of a society, and these rules establish a structure of incentives that affects the level of transaction costs and the efficiency in the economy. In a broad sense, institutions include social, historical, economic, legal and religious rules.

This paper studies the institutional determinants of CO_2 emissions. For this purpose, we analyze the relationship between the CO_2 emissions and a set of historical, geographical, religious, social and economic variables. This set of variables characterizes some of the main institutional features of the countries in our sample (La Porta et al. 1999; Álvarez-Diaz and Caballero, 2008). Jointly to the conventional parametric approach, we make also use of computational modelling methods to specify the functional relationship between variables. Basically, one reason justifies the use of these novel techniques. The traditional modelling procedure has usually adopted a parametric perspective when the effects of institutions on diverse variables have been studied. Therefore, the functional form of these models is discretionally imposed by the researcher rather than observed in the data, and the unknown parameters are later estimated using some optimization procedure such as Ordinary Least Squares (OLS). Assuming this parametric point of view might cause a serious bias in the results due to a misspecification problem. It seems to be more suitable to consider a modelling perspective which does not assume any a priori and discretional hypothesis on the functional form of the model and allows obtaining models in which "*data speak for themselves*" without assuming any parametric restriction.

The great advances carried out in the field of Computer Science have allowed developing and applying new non-parametric techniques for the estimation and prediction of different scientific phenomena, and for modelling and solving engineering problems. One of these computational techniques, called Artificial Neural Networks (ANN), has been broadly applied to several economic and energy issues in recent years, such as the world green energy use (Ermis et al., 2007), the transport energy demand (Murat and Ceylan, 2006) and the energy consumption (Nizami and Al-Garni, 1995; Hamzaçebi, 2007; Sözen and Arcaklioglu, 2007). All these applications recognize the validity of this non-parametric approach in the study of energy issues. Another technique, Genetic Programming (GP), is inspired by Genetics and by the Darwinian theories of natural selection and survival (Holland, 1975; Koza, 1992; Mitchell 2001). The method has already been used satisfactorily in different areas, including economics (Beenstock and Szpiro, 2002), finance (Álvarez-Díaz and Álvarez, 2003, 2005), natural resource economics (Álvarez-Díaz and Domínguez-Torreiro, 2006), energy (Azadeh and Tarverdian, 2007) and institutional economics (Álvarez-Díaz and Caballero, 2008). The increasing and intense spread of GP in the last years is mainly due to its advantages. Unlike other methods based on Computer Science, the GP offers explicitly a mathematical equation which allows a simple ad hoc interpretation of the results.

The main goal of this study is to apply these two computational methods to analyse how institutions influence the CO_2 emissions, and which variables are the most relevant to explain this influence across countries. We compare the results using these computational methods with those employing a more traditional parametric perspective (OLS). Besides this, a secondary objective is to detect possible misspecifications problems associated to the traditional parametric models. This verification is crucial in an empirical application and it should be always done in order to verify and corroborate the adequacy of the parametric results.

The paper is presented as follows. After this introduction, Section 2 presents a brief explanation of the methods used in our study. In Section 3, the data are described. In Section 4, the results obtained for each method are presented. Finally, in Section 5, we draw our conclusions.

2. Computational Methods: Artificial Neural Network and Genetic Programming

Remarkable developments of computer hardware and software have allowed an improvement and generalized use of sophisticated non-parametric modelling methods. Among them, artificial neural networks and genetic programming are two of the most relevant methods. Next, we technically describe these computational methods.

2.1. Artificial Neural Networks

Artificial neural network is a modelling technique inspired by the findings of studies on how the brain and the nervous system work. It has been widely employed in numerous fields such as medicine, national defense and security, entertainment, robotics and physics, among many other. The use of ANN in economics and finance for forecasting and modelling purposes is noteworthy (Refenes, 1995). The literature on this topic distinguishes among different types of networks (Gately, 1996), although the feed-forward multi-layer network with a learning algorithm based on the back-propagation technique (Rumelhart et al., 1986) is certainly the most popular in economics and finance (Trippi and Turban, 1996). Other types of networks such as radial-basis function networks, recurrent neural networks or wavelets are also very useful, but much less used.

The main advantage offered by ANN is the great capability to detect and exploit any non-linearity that might exist in the data, even under conditions of incomplete data or where the presence of noise is important. Specifically, the technique is considered a universal functional approximator. Indeed, it has been demonstrated that a neural network correctly designed can approximate any continuous function to any desired level of accuracy (Cybenko, 1989). In this manner, the technique is more suitable than traditional methods to model and predict phenomena characterized by a complex behavior (Bishop, 1995; Smith, 1995).

The great majority of empirical applications have showed that ANN scored as good as, or significantly better than, the traditional parametric methods. Nevertheless, the method is not exempt of some important drawbacks. For example, it is difficult to analyze the impact of the explanatory variables on the dependent variable and, moreover, it is difficult to perform traditional statistical inference to construct confidence intervals or check the statistical significance of the predictions. Moreover, the design of a neural network is a tedious and time-consuming procedure in which the user must specify a correct architecture. Finally, and more important, the great power of the neural networks to replicate data can be also a disadvantage. There is a risk that the network merely mimic data and it cannot generalize new observations. In this case, the model would fit irrelevant characteristics existing in the data rather than fitting the underlying function which links inputs and outputs. If this fact occurred, the network would lose its capacity to predict accurately untouched observations (overfitting problem).

Technically speaking, an ANN is composed by an input layer, an output layer and one or more hidden layers. Each layer has a group of process units called neurons or nodes. These nodes are connected to nodes at adjacent layer. The connections, called synapses, are weighted by a series of coefficients. The goal will be to find the values of these weights that minimize the forecast errors. Formally, the statistical formulation of a feed-forward network can be expressed as

$$\hat{y}_t = \Phi\left(\beta_0 + \sum_{h=1}^{H} \beta_h \cdot \Psi_h\left(\alpha_0 + \sum_{j=1}^{J} \alpha_{hj} \cdot x_j\right)\right)$$

where $\hat{y}_t$ is the output of the model, and the functions $\Psi(\cdot)$ and $\Phi(\cdot)$ are denoted as transfer functions of the hidden and output levels, respectively. The network has J inputs (explanatory variables or delays of the dependent variable), H process units (neurons) in the hidden level and one output. Initially, the weights α_{jh} and β_h are randomly determined within a given range. By means of an iterative learning process, based on the back-propagation technique, the values of these weights are modified such that the difference between the real value and the estimated value (i.e., the output of the neural network) is minimal. Several theoretical studies done on this sort of network, with just one hidden level and a high enough number of units, have demonstrated that it can approximate any non-linear function with a certain degree of accuracy (Cybenko, 1989; White, 1990).

In addition to the complexity of the data, the success of the prediction of a neural network depends, to a great extent, on the correct determination of its architecture. It is therefore necessary to accurately specify the number of inputs (J) and the number of process units in the hidden level (H), as well as to select the right structure of the transfer functions, ($\Psi(\cdot)$ and $\Phi(\cdot)$). An excessive number of H, for example, might create overfitting problems, thus eliminating any generalization. On the other hand, with an insufficient number of process units, the network could lose its forecasting capability because it would not fully exploit the non-linearity in the data. In the literature, one can find different rules for defining how many inputs and process units there must be in the hidden unit, but none of them is perfect nor have any of them ever been adopted as a general rule (Yao et al., 1999). A frequent recommendation is to determine J and H through a process of *trial-and-error*. Therefore, following this recommendation, it is necessary to consider different architectures and choose that which produces the least errors in a sub-set reserved exclusively to this purpose, (i.e., the *selection set*).

With regard to the transfer functions $\Psi(\cdot)$ and $\Phi(\cdot)$, only a small number of "well-behaved" (bounded, monotonically increasing and differentiable) functions are used in practice (Zhang et al., 1998). Among them, we have chosen for our exercise the hyperbolic tangent function which is one of the most frequently employed.

Besides determining the number of inputs, hidden neurons and the form of the transform functions, an additional problem to be solved is that of the excessive variability in the results when considering different initial weights for the values of α_{jh} and β_h (Racine, 2000). The solution proposed in the specialized literature and followed in our application will be to run the networks considering different weights and choose that architecture which optimises the fit criterion in the selection sub-sample (Hu et al., 1999).

2.2. Genetic Programming

Genetic Algorithms, originally developed by Holland (1975), enclose a whole series of computing procedures inspired in biologic concepts based on the Theory of Evolution of Species*:* survival of the fittest individuals, reproduction and birth of offspring with a good genetic heritage. The basic characteristic of these procedures is to use some evolutionary rules observed in the Nature as inspiration for solving certain mathematical optimization process. Specifically, from the evolution of a random set of possible solutions and by means of applying operators based on natural selection concepts, these methods allow finding an optimal approximation to the solution of different types of problems, including modelling issues.

In the specialized literature there is no a commonly accepted definition of genetic algorithms which allows us to distinguish them from other computational evolutionary methods. However, there exist many programs considered as genetic algorithms which present the following common elements: initial population of possible solutions to the problem, selection process using some fit criterion, and use of crossover and random mutation to generate new solutions (Mitchell, 2001). Different variations of genetic algorithms have been applied to model a large number of scientific and engineering problems. In this paper we have used a kind of genetic algorithm, called genetic programming (Koza, 1992; Álvarez et al., 2001), as a modelling tool. The evolutionary process was programmed in FORTRAN, and it can be explained by means of a series of stages. At a first stage, the genetic programming creates a random initial population of N mathematical equations susceptible of representing accurately the relationship between the dependent variable Y_i and a set of possible explanatory variables $X = \{X_{1i}, X_{2i}, ..., X_{ki}\}$. These mathematical equations are created by means of a random combination of operators and arguments in the following way:

$$S_j : \ \left((A \otimes B) \otimes (C \otimes D)\right) \quad \forall\ 1 \leq j \leq N$$

where A, B, C, and D are the arguments, the symbol $\otimes$ represents the mathematical operators and the subscript j refers to each one of the N equations belonging to the initial population. The arguments can be real numbers included in a certain interval (the coefficients of the model) or explanatory variables. Besides, the mathematical operators ($\otimes$) used will be the sum (+), subtraction (-), multiplication ($\cdot$) and division (/), being the latter 'protected' to prevent zero divisors. It is also possible to include other mathematical operators (such as logarithm or the trigonometric ones) but at the expense of increasing the complexity in the functional optimisation process.

At a second stage, after determining the initial population of candidates, the evolution process starts selecting those equations that fit best to the problem. For this purpose, the adjusted R-Square has been adopted as fitness criterion. This performance measure is defined as:

$$\overline{R}^2{}_j = 1 - \frac{M-1}{M-k} \cdot \frac{\sum_{i=1}^{M} (Y_i - \hat{Y}_i)^2}{\sum_{i=1}^{M} (Y_i - mean(Y_i))^2} \qquad \forall\, 1 \leq j \leq N$$

where $\overline{R}^2{}_j$ is the adjusted R-Square obtained by equation j, Y_i is the observed value, $\hat{Y}_i$ is the estimated value, k is the number of explanatory variables and M is the total number of observations in the sub-sample employed to train the genetic program. Later on, all equations of the initial population are classified in decreasing order according to the value of $\overline{R}^2{}_j$. Those equations whose value of $\overline{R}^2{}_j$ is very low are rejected, while those with a high value are more likely to survive, being the base for the next generation of equations.

The equations that survived after the selection process are used to create the equations of a new solutions generation (i.e., reproduction process). In order to do that the so-called genetic operators will be applied: cloning, crossover and mutation. With the cloning operator, the fittest equations are replicated in the next generation. With the crossover operator pairs of equations with high values of $\overline{R}^2{}_j$ are selected and they exchange part of their arguments and mathematical operators. Finally, mutation means that any operator or argument is randomly replaced in a small number of equations. The first top ranked individuals are exempted from mutation, so that their information is not lost. Let us consider, for example, that the following equations belong to the initial population:

$S_1 : (A + B)/C$

$S_2 : (D \cdot E) - G$

where A, B, C, D, E and G are the equation arguments (coefficients and independent variables). Let us suppose that both expressions will survive the selection process and so they become the base equations for the next generation. The crossover operator means the random selection of a block of operators and arguments in each equation and their later exchange. For instance, let us suppose that the block (A+B) in expression S_1 and the argument G in expression S_2 have been selected. By means of an exchange of blocks two news equations appear as follows:

$S_3 : G/C$

$S_4 : (D \cdot E) - (A + B)$

As one can observe, the new equations inherit certain features from their parents. Now let us suppose that the expression S_1 is selected again and the mutation operator is applied. So, the following equation can be obtained from S_1:

$S_5 : (A \cdot B)/C$

where the mutation was the random alteration of a mathematical operator.

In short, the new population created from the initial population of equations is composed of cloned equations (such as S_2), mutated expressions (such as S_5), or crossed (such as S_3 and S_4). From this moment, the process will repeat the selection and reproduction stages in an iterative way. After a given number of generations, determined by the user, the iteration procedure ceases and an optimal mapping $\hat{Y} = F(X_1, X_2, ..., X_k)$ is given by the strongest mathematical equation in the population.

3. Data

This paper analyses the functional relation between the CO_2 emissions and a set of historical, geographical, economical, religious and social variables. Table 1 provides a brief description of the database used in this study. The CO_2 emissions per capita (CO2) are the endogenous variable, while the other nine variables are considered as explanatory variables. In this way, the database constructed for our study contains complete information about 113 countries, whose emission levels are shown in Fig. 1.

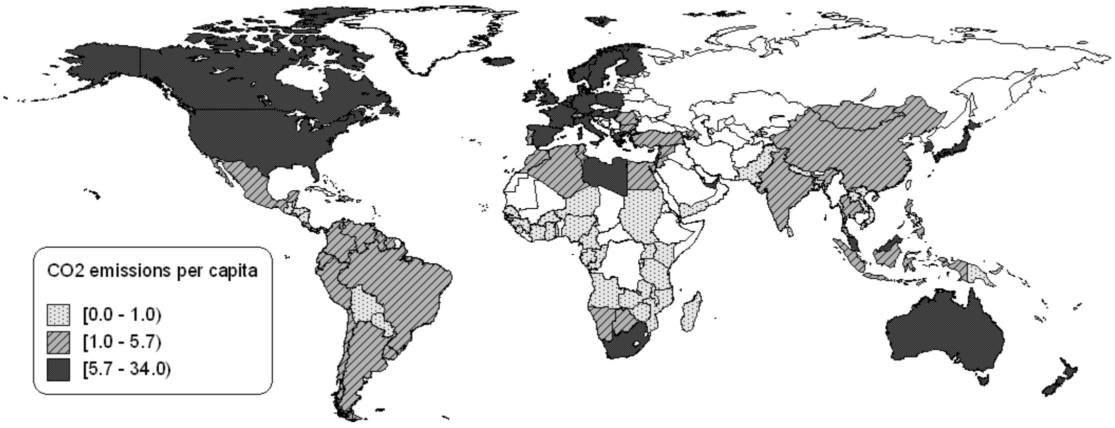

Fig. 1. Countries database and CO_2 *emissions per capita (metric tons, 2003)*

Table 1. Variables included in the analysis

CO2	Logarithm of CO_2 emissions per capita (measured in metric tons for the year 2003). From UNDP (2007).
ETHF	Ethnolinguistic Fractionalization: Average value of five different indices of ethnolinguistic fractionalization. Its value ranges from 0 to 1 (Easterly and Levine (1997), as used in La Porta et al. (1999) and Acemoglu et al. (2001)).
ENG	English Common Law: Identifies the English Common Law Origin of a country. From La Porta et al. (1999).
SOCI	Socialist/Comunist Law: Identifies the Legal Origin of the Socialist/Communist Law of a country. From La Porta et al. (1999).
FRENCH	French Commercial Code: Identifies the Legal Origin of the French Commercial Law of a country. From La Porta et al. (1999).
PROT	Protestant Religion: Identifies the percentage of the population of each country that is protestant. The numbers are in percent (scale from 0 to 100). From La Porta et al. (1999).
CAT	Catholic Religion: Identifies the percentage of the population of each country that is catholic. The numbers are in percent (scale from 0 to 100). From La Porta et al. (1999).
OTHERS	Other Religion: Identifies the percentage of the population of each country that belongs to other religions (non-catholic and non protestant). The numbers are in percent (scale from 0 to 100). This data series was elaborated for this paper based on La Porta et al. (1999).
LATIT	Latitude: Absolute value of the latitude of the country (i.e., a measure of distance from the equator), scaled to take values between 0 and 1, where 0 is the equator. From the CIA, as used in La Porta et al. (1999).
GNP	Logarithm of GNP per capita (expressed in current US dollars for the period 1970–1995). From La Porta et al. (1999).

Regarding to the dependent variable, the data come from the 2006 Human Development Report (UNDP, 2007)[1]. CO_2 emissions, measured in metric tons, include contributions to the carbon dioxide flux from the consumption of solid, liquid and gaseous fuels, gas flaring and the production of cement.

On the other hand, the explanatory variables include the ethnolinguistic fractionalization, the legal tradition (English Common Law, Socialist/Communist Law, French Commercial Code), the religion (Roman Catholic, Protestant, Others), the geographical (latitude) and economic (GNP) condition. We dedided to consider these variables because they are considered relevant to explain the institutional quality across countries and, therefore, they are a good approximation to the "traditions and institutions by which authority in a country is exercised" (Kaufmann et al., 1999). The relevance of these variables as a good proxy of the quality of institutions has been tested by La Porta et al. (1999) and Álvarez-Díaz and Caballero (2008). Of course, several sets of institutional variables could be considered to study the institutional determinants of CO_2 emissions. Nevertheless, we had to select one of these posible sets, and we have decided to use that set that has been used in the previous relevant literature on the quality of institutions.

The nine explanatory variables may be characterized as follows. Ethnolinguistic fractionalization (ETHF) is the average value of five indices that measure the existence of different ethnolinguistic groups in a country and the percent of population not speaking the official language, among other elements. Legal tradition is a dummy explanatory variable that shows the legal origin of the company law or commercial code of each country, distinguishing the English tradition (ENG), the socialist tradition (SOCI) and the French

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[1] The data are originally from the Carbon Dioxide Information Analysis Center, Environmental Sciences Division, Oak Ridge National Laboratory, US Department of Energy.

tradition (FRENCH). In regard to religion, we consider the percentage of the population of each country that professes the protestant religion (PROT), the catholic religion (CAT) and other religions (OTHERS). Regarding economic development, the model incorporates the distance of the country from the equator (LATIT) and the logarithm of Gross National Product per capita (GNP). Table 2 shows descriptive statistics of the endogenous and explanatory variables.

Table 2. Descriptive statistics

	Mean	Std. Dev.	Minimum	Maximum
Endogenous variable				
CO2	4.5667	5.6345	0.10	33.60
Continuous explanatory variables				
ETHF	0.3341	0.2993	0.0	0.89
PROT	13.6423	22.3854	0.0	97.80
CAT	33.6685	36.6493	0.0	97.30
OTHERS	52.5196	39.5973	0.9	100.00
LATIT	0.2782	0.1881	0.01	0.72
GNP	7.3354	1.4555	4.72	10.15
Dummy explanatory variables				Frequency
ENG				34.23
SOCI				8.11
FRENCH				48.65

Once that the data have been described and before carrying out the modelling exercise, an important issue should be commented. Usually, in the majority of the empirical studies using computational methods, the total available data are divided into a training set (in-sample data) and a test set (out-of-sample or hold-out sample). In theory, the training set is used for the construction of the model while the test set is employed for measuring the adequacy and predictive ability of the method. Nevertheless, researchers using non-linear forecasting methods can be tempted to try different modeling structures in the training set and select that with the highest accuracy in the test set. The result would be a model that fits the data too closely and with a strong predictive ability in the test set. However, it would be not capable of generalizing and performing well with new data. The modelling procedure would suffer from an overfitting problem and the utility of the model would be practically null.

In order to detect overfitting problems and develop a useful and fair modelling exercise, researchers should follow the technical and practical recommendations and guidelines proposed in the literature on computer science (Bishop, 1995). These recommendations advise to divide the sample into three sub-sets. For this reason, in this paper we assume this advice and consider three sub-sets when applying computational methods. The first one is composed by 67 observations randomly chosen, and it is reserved to train the ANN and develop the evolutionary process of the genetic programming. The second sub-set covers 23 observations randomly chosen. It constitutes the selection sub-sample and is used to adjust the technical parameters of the genetic programming and to find an optimal architecture of the neural network. Finally, the last 23 observations are not employed in the modelling process. These untouched data conform the out-of-sample set and the value of the accuracy measure obtained in this sub-sample is employed to check the adequacy of the model. Specifically, it will be necessary that the considered accuracy measure shows a similar and relatively high value in the selection and out-of-sample sets. If this condition was verified, it would be proved the ability of the non-parametric method set-up to get a model that generalizes new observations and, therefore, without showing overfitting problems.

4. Results

4.1. OLS Results

In order to analyze the institutional determinants of CO_2 emissions, we model firstly the relationship between variables assuming the parametric point of view. Specifically, we estimate a linear model using OLS regression in the in-sample. The explanatory variables of the OLS model were chosen following the backwards stepwise procedure with a significance level at 10%. As we can observe in Table 3, OLS results reveal that the relevant variables to explain the CO_2 emissions are GNP, ENG, ETHF, PROT and SOCI. The sign of the estimated coefficients is positive for GNP, ENG and SOCI, while it is negative for ETHF and PROT. The positive relationship between CO_2 emissions and GNP is in accordance with the a priori expectative and the economic logic: more economic growth implies more CO_2 emissions. Moreover, the results also reveal that those countries with a Socialist or English Law tradition tend to produce higher levels of CO_2 emissions, whereas those countries with a high level of ethnolinguistic fractionalization and a high percentage of protestant population have a more controlled level of emissions. Other variables such as CAT, OTHERS or LATIT do not have a significant effect on CO_2 emissions**.**

Table 3. OLS results

Variables	Coefficients (p-values)	
CONSTANT	-5.583 (0.00)	
GNP	8.851 (0.00)	
ENG	0.413 (0.01)	
ETHF	-1.174 (0.00)	
PROT	-0.007 (0.03)	
SOCI	0.666 (0.00)	
Adjusted R-Square	**In-Sample**	0.8348
	Out-of-Sample	0.7825

Table 3 also shows the Adjusted R-Square for the first 90 observations (the in-sample), and for the last 23 observations (the out-of-sample). This fit criterion exhibits a relatively high value for the in-sample (0.8473), while that for the out-of-sample the value decreases up to 0.7925. This reduction, even small, seems to reveal a possible lack of generalization using the OLS model. The model gets a high value in the sample where the coefficients are estimated (in-sample) but the performance is damaged when new data are considered (out-of-sample). Thus, the model could suffer from a problem of misspecification, biasing the results and, therefore, misunderstanding our conclusions. For example, are really the selected variables the most important to explain the CO_2 emissions? We could question as well if the effect of the selected variables are real of spurious because of assuming a specific and rigid functional form. In order to validate and investigate the possible existence of a bias in the OLS results, we compare them with those obtained employing computational non-parametric methods.

4.2. GP Results

Regarding the GP results, the optimal model survival to the evolutionary process is given by the expression shown in Table 4.

Table 4. GP results

Equation	**Survival Variables**	
$CO2_i = 3 \cdot GNP_i - ETHF_i - \frac{1.38}{3.0170 \cdot GNP_i \cdot (0.07 + GNP_i)}$	GNP (+) ETHF (-)	
Adjusted R-Square	**Training**	0.8143
	Selection	0.8141
	Out-of-sample	0.8256

As we can see analyzing the equation provided by the GP, there are only two variables that are relevant to explain the CO_2 emissions: GNP and ETHF. Jointly to the positive and foreseen effect of GNP, ETHF shows again a negative and linear effect on CO2. This implies that for a same level of economic growth, those countries with a higher ethnolinguistic fractionalization show lower levels of CO_2 emissions. On the other hand, the GP did not discover any clear effect of the religious, legal and geographical variables.

The adjusted R-Square is relatively high (over 0.80) and nearly constant when Training, Selection and Out-of-sample are considered (0.8143, 0.8141 and 0.8256, respectively). This stability reveals the absence of a possible lack of generalization. It seems that the model has discovered a good approximation to the general pattern existing in the data rather than memorizing some specific features of the individual observations (overfitting problem).

4.3. ANN Results

Before analyzing and discussing the results obtained by the ANN, it is necessary to explain how the inputs were finally selected. Given the complexity of the modelling process using ANN, the literature usually recommends to select as inputs those variables that were already chosen using a simpler method such as the linear model (Bishop, 1995). Therefore, we should insert as inputs of our ANN the explanatory variables of the OLS model: GNP, ENG, ETHF, PROT and SOCI. Table 5 depicts the optimum number of neurons and the Adjusted R-Square for an ANN with those variables used in the linear model. Observing the results, we can underline, first, the stability of the adjusted R-Square in the different sub-samples and, second, the fact that the network has considerably improved the out-of-sample performance of the linear model (0.8497 versus 0.7825). It seems, therefore, that there exists an important non-linear relationship between CO_2 emissions and the explanatory variables considered in this study. Unlike the OLS model, the network is capable of exploiting the nonlinearity existing in the data.

In spite of the good results following the recommendation suggested in the literature, it can be possible to improve our results considering those inputs that already were selected by another non-parametric method. This justification lies in the fact that a set of explanatory variables can be "linearly" appropriate, but from a non-linear point of view we could have found a better set of variables. For example, we can use the survival variables obtained by the GP (GNP and ETHF) as inputs of a network. Table 5 also shows the results for this case. The new specification of the network does not improve the previous result. However, it is still better than the OLS model in terms of fitness and stability.

Table 5. ANN results

Inputs	Neurons	Adjusted R-Square		
		In-Sample		Out-of-sample
		Training	Selection	
GNP ENG ETHF PROT SOCI	3	0.8528	0.8378	0.8497
GNP ETHF	5	0.8417	0.8355	0.8420
GNP CAT OTHERS PROT LATIT ETHF	4	0.8734	0.8745	0.8631

Finally, another way of selecting a set of variables as inputs of our ANN is to assume a trial-and-error approach. Different sets of inputs are considered, and that combination of variables with the highest fitness in the selection sub-sample will be finally chosen. The computational requirement is too high but, however, it can be a useful way of, first, improving even more the fitness and, second, knowing what variables are the most relevant to explain the CO_2 emissions. Analyzing all possible subsets of variables is not feasible from a practical point of view. For this reason, in our study we have restricted the number of combinations to one hundred sets of inputs. As we can see in Table 5, the inputs chosen using this approach are GNP, CAT, OTHERS, PROT, LATIT and ETHF. The Adjusted R-Square shows a high value and a great stability in the training, selection and out-of-sample sets (0.8734, 0.8745 and 0.8631, respectively). In this sense, this input set provides the best fitness in comparison with other possible combinations.

5. Conclusions

In the traditional economic literature, the CO_2 emissions have been explained by the level of production and economic growth. Nevertheless, there may be other variables that explain the rising concentration of CO_2. In this paper we consider a set of institutional factors in order to examine their functional relationship with CO_2 emissions around the world. This analysis helps to open the “black box” of the determinants of CO_2 emissions. For this aim, we employ two computational and non-parametric methods: Genetic Programming and Artificial Neural Networks. These sophisticated techniques imply a solid improvement when the relationship between variables is non-linear. The computational methods allow us to approach accurately to the underlying relationship which links CO_2

emissions with institutional and economic variables. Moreover, we have compared the results using the computational methods with those employing a more traditional parametric perspective.

According to the specialized literature and the economic insights, our results show that the level of GNP is the main determinant of CO_2 emissions. Nevertheless, the empirical results of this paper prove too that the institutional variables matter in determining the level of CO_2 emissions. In this sense, independently of the level of production, the institutional structure of society affects the economic organization of production, by which the institutional rules are useful for the understanding of the levels of CO_2 emissions across countries. Specifically, the application of different methods has allowed us to conclude the relevant influence of the ethnolinguistic fractionalization on CO_2 emissions: for a fixed level of GNP, the higher the ethnolinguistic fractionalization is, the lower the emissions of CO_2 are. The empirical results point out that those countries with a homogeneous ethnolinguistic society have an institutional structure of production that does not favor the control of the emission levels.

In summary, the institutional rules allow us a better understanding of the level of CO_2 emissions across countries. Thus, when we consider the institutional factors as explanatory variables of CO_2 emissions, the fitness of the models is around the 85%. The major results are associated with the computational methods. In this sense, the paper presents empirical evidence about the explanatory ability of the binomial GNP (positive effect) and ethnolinguistic fractionalization (negative effect) on CO_2 emissions. Moreover, an artificial neural network points out that other social, cultural and geographical variables are useful to explain CO_2 emissions across countries. This paper has opened a research avenue that will require new efforts in the future to advance in the knowledge of the institutional determinants of CO_2 emissions. In this sense, this paper has allowed us a first advance, but it is only a small piece of empirical work with a set of variables. We recognize that more effort should be taken into account for future endeavours and developments of this research, including the study of the role of other institutional and non-institutional variables.

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