Statistical Analysis of Greenhouse Gas Emission Trends under the Kyoto Protocol

Valutazione e analisi statistica dell'attuazione del Protocollo di Kyoto

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Riassunto: Il rischio di un riscaldamento globale dovuto all'aumento delle emissioni di origine antropica dei gas serra è ormai accertato e la necessità di idonee contromisure è il tema ambientale più dibattuto a livello internazionale dell'ultimo decennio. Secondo gli obiettivi previsti dal Protocollo di Kyoto, le emissioni di gas serra dovranno ridursi complessivamente del 5%, entro il periodo 2008-2012, rispetto l'anno base. Nel presente lavoro si analizzano gli andamenti delle emissioni di gas serra, disaggregate nei principali settori, e di alcuni indicatori economici ed energetici relativi a diversi paesi dal 1990 al 2002. La dinamica degli andamenti e l'attuazione di politiche di riduzione, data la complessità dell'informazione nell'arco del periodo temporale considerato, sono studiate mediante un'analisi fattoriale dinamica.

Keywords: Greenhouse gas emissions, Kyoto Protocol, Dynamic Factor Analysis, Fuzzy C-Medoids clustering

1. Introduction

Over a decade ago, most countries joined an international treaty, the United Nations Framework Convention on Climate Change (UNFCCC), to begin to consider what could be done to reduce global warming and to cope with temperature increases. In 1997 governments agreed to an addition to the treaty, called the Kyoto Protocol, linked to the existing treaty, but standing on its own; the Protocol has more powerful and legally binding measures especially with its entry into force in February 2005. The emission reduction objectives for the world's leading economies were established; nevertheless targets are mandatory only for the Parties which have ratified the Protocol. Commitments comprise an overall reduction by at least 5 per cent below existing 1990 levels in the period 2008 to 2012 which vary from nation to nation. The

overall 5 per cent target for developed countries is to be met through cuts (from 1990 levels) of 8 per cent in the European Union (EU[15]), Switzerland, and most Central and East European states; 6 per cent in Canada; 7 per cent in the United States (although the US has since withdrawn its support for the Protocol); and 6 per cent in Hungary, Japan, and Poland. New Zealand, Russia, and Ukraine are to stabilize their emissions, while Norway may increase emissions by up to 1 per cent, Australia by up to 8 per cent (subsequently withdrew its support for the Protocol), and Iceland by 10 per cent. The EU has made its own internal agreement to meet its 8 per cent target by distributing different rates to its member states. These targets range from a 28 per cent reduction by Luxembourg and 21 per cent cuts by Denmark and Germany to a 25 per cent increase by Greece and a 27 per cent increase by Portugal (UNFCCC, 1998).
In spite of the binding targets, the agreement offers flexibility as to how the various countries may meet their targets. They may partially compensate for their emissions by increasing "sinks", forests, which remove carbon dioxide from the atmosphere either in their own territories or in other countries; or they may pay for foreign projects that result in greenhouse gas cuts. Other mechanisms are emissions trading, clean development mechanism and joint implementation.
In this paper, emission trends of greenhouse gases are examined for several countries as well as other relevant energy and socio-economic indicators. The countries chosen for the analysis are those with a complete time series of GHG emissions available, specifically from 1990 to 2002. In fact, although each Party joining the UNFCCC Convention is committed to submit to the UNFCCC Secretariat emission trends from 1990 onwards, not all the Parties fulfil this commitment, because of lack of resources or related problems, and missing data may appear in the time series (UNFCCC, 2004).
A dynamic factor analysis has been applied to the data set in order to study the feature and the effectiveness of measure reduction policies of the greenhouse gas emission trends and the other relevant energy and socio-economic variables.
A cluster analysis has therefore been applied to highlight the similarity among groups of countries; specifically a fuzzy C-medoids clustering model which classifies time trajectories and selects, within the set of the observed trajectories, typical trajectories representing synthetically the structural characteristics of the identified clusters (*medoid* time trajectories).

2. Case Study

The case study refers to 23 countries including the western-Europe countries, eastern-Europe countries, such as Bulgaria, Poland, Romania, other important countries for economy and their effects on the atmospheric environment as Canada, Japan, Australia, New Zealand and United States. The choice of variables is related to their importance with respect to the economy of the country, the overall feature in the GHG emission trends as well as the policies and measures set up and applied in order to fulfil the Kyoto commitments. Emissions and socio-economic and energy related indicators were selected, for a total of 13 variables described in the following.
Total greenhouse gas emissions, expressed in terms of CO_2 equivalent excluding emissions and absorption of CO_2 from land use change, are derived for the whole time series from 1990 to 2002. Values are disaggregated into the principal sectors of emission sources: energy, industrial processes, agriculture, waste. Specifically, the

energy sector, which is the most important in terms of emissions therefore of reduction, is subdivided in energy industries, manufacturing industries and construction, transport, residential and commercial (Romano et al., 2005). In addition, other indicators have been selected: population density, agricultural area as percentage of total area, agricultural production per capita, gross domestic product (GDP), fertilizers use intensity, energy supply.
A dynamic factor analysis has been applied to the data set (Coppi and D'Urso, 2002). The data have been normalised and the direct approach of the dynamic factor analysis has been applied. The global quality indicators of the analysis are reported in Table1:

Table 1: *Global Quality Indicators for the direct approach*

Source	Indicator
Global Structure	0.81
Synthetic Structure	0.82
Differential Dynamics	0.53
Average Evolution	0.81
Total	**0.81**

The first four factorial dimensions account overall for 81% of the total variation due to the global structure. The correlation between countries and variables are well identified but the differential dynamics is accounted for to a lesser extent.
In fact, the first factorial dimension, accounting for 32% of the variation due to the global structure, highlights the relation among high density populated countries and their economical structure; the second dimension (24%) enhances countries where the economy is, in prevalence, based on agriculture production. The third dimension (14%) put into evidence countries with high levels of pro capita emissions from industrial and transport activities. Finally, the fourth dimension (10%) is characterized by high consumption and high emissions in the energy sectors.
There are only a few countries which show specific features on the different factorial axes, namely Australia, Canada, New Zealand, United Stated, while all the variables seem to play an important role in the model.
In contrast, the analysis shows a minor dynamic structure of the data. This can be explained by the fact that policies and measure set up by countries to reduce their greenhouse gas emission levels would need considerable time to become effective; in this sense the period between 1990-2002 could be considered short even though very close to the commitment period of the Kyoto Protocol.
In order to highlight the similarity among group of countries, i.e time trajectories, a fuzzy C-medoids model has been applied (Coppi et al., 2004). The choice of such analysis is justified by the fact that multivariate time trajectories, in this study, sum up several variables along various observational times so that the crisp definition of membership may not always be appropriate. The model detects the known medoids, real trajectories, which characterize each cluster.
The results of the analysis are shown in Table 2 for a fuzziness parameter equal to 1.30 and number of clusters C=3.

Table 2: *Membership degrees matrix*

	m=1.30		
	C1	*C2*	*C3*
Australia	1.0000	0	0
Austria	0.0002	0.7974	0.2024
Belgium	0.0001	0.0020	0.9979
Bulgaria	0.0095	0.9411	0.0494
Canada	0.8504	0.0767	0.0730
Denmark	0.0006	0.3674	0.6320
France	0.0002	0.6838	0.3160
Germany	0	0	1.0000
Japan	0.0001	0.0054	0.9946
Greece	0.0000	0.9981	0.0018
Ireland	0.1595	0.2416	0.5990
Italy	0.0000	0.5574	0.4426
Norway	0.0702	0.6617	0.2681
New Zealand	0.8751	0.0783	0.0466
Netherlands	0.0006	0.0068	0.9927
Poland	0.0005	0.9453	0.0542
Portugal	0.0001	0.9998	0.0001
United Kingdom	0.0001	0.0001	0.9998
Romania	0.0002	0.9953	0.0046
Spain	0	1.0000	0
United States	0.7989	0.0671	0.1340
Sweden	0.0003	0.9879	0.0118
Switzerland	0.0004	0.1394	0.8602

Australia, Spain and Germany are the medoids resulting from this analysis and only one country, Italy, is not assigned to exactly one cluster. Setting a higher fuzziness parameter, m=1.50, the same countries as the previous case belong to the first cluster, whereas Italy joins cluster 3. Differences among countries are not such relevant from a '*polluter*' point of view, but the variables which discriminate groups are, especially for the European countries, GDP values and economy, industrialised vs agriculture based economy.

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