Discussion Papers No. 447, February 2006
Statistics Norway, Research Department

Gang Liu

A causality analysis on GDP and air emissions in Norway

Abstract:
This paper conducts Granger-causality tests on real per capita GDP and four types of air emissions (CO_2, CO, SO_2 and NO_x) by using Norwegian data covering the period 1973-2003. The test results indicate that only unidirectional causal relationships exist between GDP and air emissions. For CO_2 and CO, we find long run causal relationships running from GDP to emissions, whereas for SO_2 and NO_x, only the short run causal relationships are found from emissions to GDP. Therefore, as far as the four types of air emissions in Norway are concerned, the presumption, employed in the conventional EKC analyses that the causal relationship between emissions and GDP is unidirectional from the latter to the former, may be retained for CO_2 and CO only. For SO_2 and NO_x, however, it is rejected.

Keywords: causality analysis, stationarity, cointegration, air emissions, economic growth

JEL classification: C32, Q53, Q56

Acknowledgement: I am very grateful to Terje Skjerpen, Pål Boug, Knut Einar Rosendahl, Kjetil Telle, Håvard Hungnes and Mads Greaker for valuable comments.

Address: Gang Liu, Statistics Norway, Research Department. E-mail: gang.liu@ssb.no

For printed Discussion Papers contact:

Statistics Norway
Sales- and subscription service
NO-2225 Kongsvinger

Telephone: +47 62 88 55 00
Telefax: +47 62 88 55 95
E-mail: Salg-abonnement@ssb.no

1. Introduction

In the past decade, numerous studies have been carried out to examine the relationship between environmental quality and GDP level for one or a group of countries. Such studies are labeled as environmental Kuznets curve (EKC, an inverted U-curve) analyses after the path-breaking work by Grossman and Krueger (1991, 1994, 1995).[1]

In most of the EKC analyses the reduced form regression technique is frequently applied, where an implicit assumption usually made is that the causal relationship between environmental quality and GDP level is unidirectional from the latter to the former, but not *vice versa*.

In reality, however, the causal relationship may very well be the other way around. For instance, in a country experiencing economic structure changes from lower value-added emission-intensive manufacturing to higher value-added less emission-intensive services, economic growth following a decline in emissions may be observed.

It has also been argued that environmental quality is likely to have a feedback effect on income growth, namely, rising levels of emissions due to economic growth may have harmful effects on production possibilities (Pearson, 1994; Stern et al., 1994). Thus, the causal relationship between them may be bi-directional.

Moreover, Agras and Chapman (1999) once found that energy price rather than income was the significant determinant of environmental quality when both were included as explanatory variables, which raises the inquiry on whether income level is at all an important determinant of environmental quality.

Hence, the evidences necessitate that investigation on the causal relationship between environmental quality and GDP should be carefully carried out before taking any EKC analysis.

Causality analyses are not only prerequisites for further investigation on the environmental quality - GDP relationship; results from the analyses may have implications on policy decisions as well. For example, if there exists no causality, it may indicate that policies for reducing emissions do not affect economic growth at all. However, if any causality is found, policy measures should be designed with clear awareness of the direction of the causal relationship between emissions and GDP.

Causality analyses have been applied in many empirical studies investigating the causal relationship between energy consumption and income level (e.g. Yang, 2000; Shiu and Lam, 2004;

---

[1] The EKC is a hypothesized relationship between various emissions (indicators of environmental quality) and GDP per capita, which proposes that in the early stages of economic growth emissions increase, but beyond some level of GDP per capita, economic growth will lead to environmental improvement.

Yoo, 2005). To the best of our knowledge, applications in exploring the causal relationship between, *inter alia*, emissions and income level are rather rare. In a study carried out by Coondoo and Dinda (2002), a unidirectional causal relationship was found to run from CO_2 emissions to income for the developed country groups of North America, Eastern and Western Europe to which Norway belongs. However, the data applied are cross-country panel data rather than a country specific time series data.

The purpose of this paper is, by using Norwegian time series data, to question the validity of the presumption employed in the conventional EKC analyses that the causal relationship between emissions and GDP is unidirectional from the latter to the former. To this end, different causal relationships are tested on real per capita GDP and four types of air emissions: CO_2 (carbon dioxide), SO_2 (sulphur dioxide), NO_x (oxides of nitrogen) and CO (carbon monoxide). Results from this study can be used for further analysis on the environment-GDP relationship and for policy decisions as well.

The causality analysis in this paper will be implemented by applying the statistical techniques of Granger-causality tests. First, stationarity and cointegration are tested for on annual per capita Norwegian time series data of four types of air emissionss and real GDP; second, depending on the results from the stationarity and cointegration tests, either a vector autoregression (VAR) model or an error-correction model (ECM) is estimated to test for the Granger-causality for different types of air emissions. This is performed by the (F-) t-tests to check the (joint) significance levels of causality between different air emissions and GDP. Through the analysis, instead of arbitrarily choosing a lag length, Akaike's information criterion (AIC) is employed to select the optimum lag.

The rest of the paper is structured as follows. Section 2 provides an overview of the proposed methodology. Section 3 explains the sources and the nature of the data employed. Empirical results are presented in Section 4. Some discussions and policy suggestions are made in Section 5.

2. Methodology

As mentioned earlier, the causal relationship analysis in this paper is implemented by applying the Granger-causality test proposed by Granger (1969). This is a rigorous statistical technique purporting to detect the nature of causality between two variables, say, X and Y. The idea is that if X (Granger) causes Y, then changes in X should precede changes in Y since the future cannot predict the past. Therefore, in a regression of Y on other variables (including its own past values) if one includes past or lagged values of X and it significantly improves the prediction of Y, then one can say that X (Granger) causes Y. If X causes Y, but Y does not cause X, or the other way around, then the causal relationship between X and Y is unidirectional. In case X causes Y and Y also causes X, we say the causal relationship is bi-directional.

2.1. Stationarity

It is worth noting that application of the Granger causality test requires the time series of the concerned variables, X and Y, to be stationary, which means that, loosely speaking, the mean and variance of each variable do not vary systematically over time. It has been shown that using non-stationary data in causality tests can yield spurious causality results (Granger and Newbold, 1974; Stock and Watson, 1989). Thus, it is necessary to examine whether the time series of the variables, X_t and Y_t, are stationary or not before taking the causality test.

If the variables involved are found stationary, then conventional Granger-causality test can be applied. In case they are found non-stationary, they ought to be transformed into stationary series by successive differencing until the differenced series become stationary and then apply the causality test with the differenced stationary data. In this paper, the augmented Dickey-Fuller (ADF) stationarity test is used to test for the presence of unit root in the original and differenced time series of the variables to ascertain the required stationarity.

2.2. Cointegration

Despite that X and Y are individually non-stationary, the possibility exists that a linear combination of these two variables, $X + aY$, could be stationary for some value of a. In other words, even if the mean and variance of each variable vary systematically over time, the linear combination of them, $X + aY$, may have constant mean and variance. Thus, if such a property holds true, then X and Y tend to move together and we say that X and Y are cointegrated (Engle and Granger, 1987).

As will be seen later, whether or not X and Y are cointegrated has substantially different implications for how one should carry through the test procedure to test for Granger-causality. In view of this, cointegration test is, therefore, a prerequisite procedure toward causality testing.

Since cointegration is a restriction on a dynamic model system, it can be tested for (Hendry and Juselius, 2001). In this paper, two Johansen's cointegration tests, namely, trace test and maximum eigenvalue test are applied to the following vector autoregression (VAR) model (Johansen, 1988):

$$(1) \qquad Y_t = \beta_{10} + \sum_{i=1}^{L_{11}} \beta_{11i} Y_{t-i} + \sum_{j=1}^{L_{12}} \beta_{12j} X_{t-j} + u_{1t}$$

$$(2) \qquad X_t = \beta_{20} + \sum_{i=1}^{L_{21}} \beta_{21i} Y_{t-i} + \sum_{j=1}^{L_{22}} \beta_{22j} X_{t-j} + u_{2t}$$

Here β_{10}, β_{11i}, β_{12j}, β_{20}, β_{21i}, β_{22j} are parameters to be estimated; L_{11}, L_{12}, L_{21}, L_{22} are the numbers of lags which are restricted in Johansen's test as $L_{11} = L_{12} = L_{21} = L_{22} = L$; u_{1t} , u_{2t} are usual error terms. The tests are performed sequentially, beginning with the null hypothesis that there is no cointegrating vector, and if this null hypothesis is rejected, continuing with the null hypothesis that there is (at most) one cointegrating vector in (trace) maximum eigenvalue test. In a VAR model of only two variables such as the case in our study, there can be at most one cointegrating vector.

2.3. Granger-causality test

Based on the results from stationarity and cointegration tests, Granger-causality test can be carried out as follows. If the results from stationarity test show that the two variables X and Y are stationary, then the standard Granger-causality test should be applied, which is to estimate the VAR model outlined in (1) and (2).

In this VAR model, X is caused by past values in both X and Y. Similarly, Y is also caused by past values in X and Y. Given such a specification, X can be said to (Granger) cause Y if one can reject the null hypothesis that the β_{12}s are jointly zero. Similarly, one can say that Y does not (Granger) cause X if the β_{21}s are jointly insignificant from zero. Both cases can be tested by a joint *F*-test.

If the two variables X and Y are both non-stationary and integrated of order 1[2], and, if they are not cointegrated, then the Granger-causality test is performed by estimating the following VAR model with variables in first difference form (Toda and Phillips, 1993; Yoo and Kwak, 2004):

$$(3) \qquad \Delta Y_t = \beta_{10} + \sum_{i=1}^{L_{11}} \beta_{11i} \Delta Y_{t-i} + \sum_{j=1}^{L_{12}} \beta_{12j} \Delta X_{t-j} + u_{1t}$$

$$(4) \qquad \Delta X_t = \beta_{20} + \sum_{i=1}^{L_{21}} \beta_{21i} \Delta Y_{t-i} + \sum_{j=1}^{L_{22}} \beta_{22j} \Delta X_{t-j} + u_{2t}$$

The interpretation of this VAR model is as follows. Changes in X are caused by past changes in both X and Y. The same holds for changes in Y. Given such a specification, X can be said to (Granger) cause Y if one can reject the null hypothesis that the β_{12}s are jointly zero. Similarly, one can say that Y

---

[2] All variables concerned in this paper, as shown later, are integrated of order 1, which means that although non-stationary, they become stationary after first differencing.

does not (Granger) cause X if the β_{21}s are jointly insignificant from zero. Again, both cases can be tested by a joint *F*-test.

As mentioned above, (3) and (4) can be applied only if X and Y are **not** cointegrated. In case cointegration is found between X and Y, the Granger-causality test performed by estimating the VAR model of (3) and (4) will be incorrect and inferences invalid. According to Engle and Granger (1987), a more comprehensive test of causality based on an error-correction model (ECM), should be adopted.

The ECM model for the Granger-causality test in this case is performed based on the following two equations:

$$\Delta Y_t = \beta_{10} + \sum_{i=1}^{L_{11}} \beta_{11i} \Delta Y_{t-i} + \sum_{j=1}^{L_{12}} \beta_{12j} \Delta X_{t-j} + \beta_{13} \hat{\varepsilon}_{t-1} + u_{1t} \tag{5}$$

$$\Delta X_t = \beta_{20} + \sum_{i=1}^{L_{21}} \beta_{21i} \Delta Y_{t-i} + \sum_{j=1}^{L_{22}} \beta_{22j} \Delta X_{t-j} + \beta_{23} \hat{\varepsilon}_{t-1} + u_{2t} \tag{6}$$

where all the variables and parameters have the same interpretations as in (3) and (4) except for $\hat{\varepsilon}_{t-1}$, which is the error correction term, derived from running OLS on the long-run cointegration relationship, $Y_t = \theta_0 + \theta_1 X_t + \varepsilon_t$, and calculated as $\hat{\varepsilon}_t = Y_t - \hat{\theta}_0 - \hat{\theta}_1 X_t$.

In (5) and (6), changes in X are assumed to be a function of not only past changes in both X and Y, but also the estimated previous period's disequilibrium in level, $\hat{\varepsilon}_{t-1}$. This holds for changes in Y as well. Within the context of this model, the presence of both short- and long-run causality can be tested.

Testing the presence of short-run causality has been explained within the context of the VAR model of (3) and (4). Long-run causality, on the other hand, can be claimed if a *t*-test on the coefficient of the error correction term $\hat{\varepsilon}_{t-1}$ (β_{13} in (5) or β_{23} in (6)) is statistically significant. Furthermore, the strong Granger-causality can be claimed if one finds a joint statistical significance of β_{12}s and β_{13} in (5), or β_{22}s and β_{23} in (6) by means of a joint *F*-test.

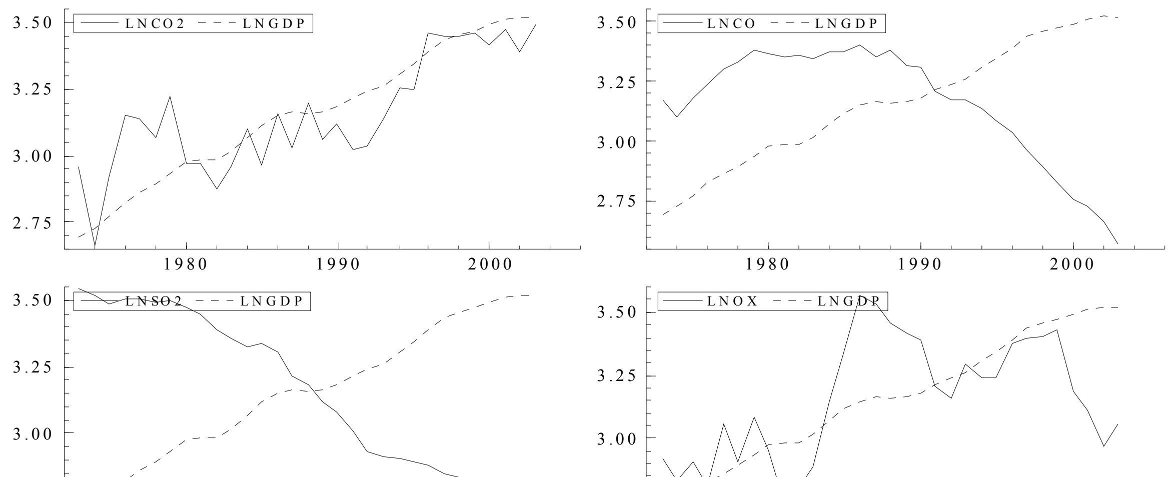
To sum up, the procedure of causality analysis employed in this paper is as follows. First of all, we test whether or not the variables, X and Y, are stationary. If both are stationary, then the standard Granger-causality test is applied to X and Y, which is implemented by estimating (1) and (2). If both are non-stationary and integrated of order 1, then we further test whether or not they are cointegrated. If not, (3) and (4) will be applied; whereas if they are cointegrated, then we should estimate the ECM model of (5) and (6).

3. Data

In this study we use annual data spanning from 1973 to 2003 on four types of air emissions (CO_2, CO, SO_2 and NO_x) obtained from the Norwegian pollution inventory; see Flugsrud et al. (2003). Annual data on population and real GDP (in 2000 prices) during the same period have been collected from Statistics Norway (2003).

All variables of air emissions and real GDP are divided by the population variable. Therefore, CO_2, CO, SO_2, NO_x and GDP in this paper represent their corresponding per capita terms[3]. Finally air emissions per capita and real GDP per capita are log-transformed. To be precise, we have taken X = ln(GDP); Y = $\ln(CO_2)$, ln(CO), $\ln(SO_2)$ and $\ln(NO_x)$, respectively, when applying the methodology outlined in Section 2.

Fig. 1. Time series of air emissions and GDP in Norway (1973-2003)



Note: $\ln(CO_2)$, ln(CO), $\ln(SO_2)$, $\ln(NO_x)$ are rescaled and adjusted such that the means of them are changed to that of ln(GDP).

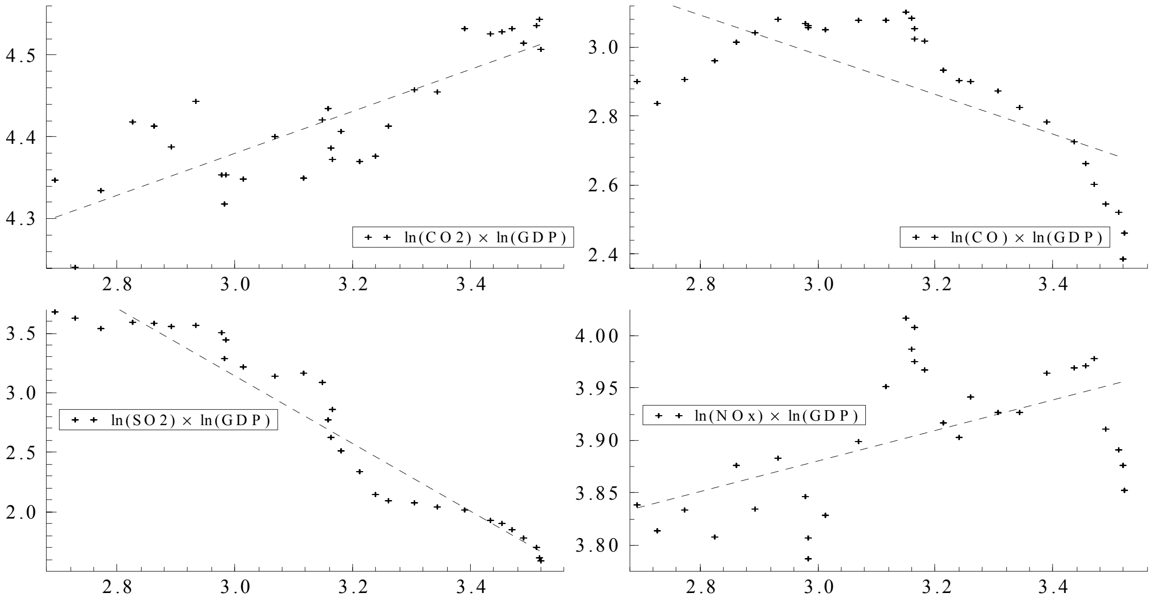
---

[3] The units for CO_2, CO, SO_2, NO_x and GDP are 100 kg per capita, 10 kg per capita, kg per capita, kg per capita and 10, 000 NOK per capita, respectively.

Although a visual inspection of the time series of ln(CO_2), ln(CO), ln(SO_2), ln(NO_x) and ln(GDP) (Fig. 1) indicates that all variables are nonstationary, rigorously statistical test need to be implemented.

It appears that there are positive associations between ln(CO2) and ln(GDP) as well as between ln(NO_x) and ln(GDP), while negative association between ln(SO_2) and ln(GDP) as well as between ln(CO) and ln(GDP). This observation is confirmed by the scatter plots with air emission series against GDP series in Fig. 2.

Fig. 2. Scatter plots between air emissions and GDP (1973-2003)



4. Empirical results

4.1. Results from stationarity tests

Applying the augmented Dickey-Fuller (ADF) test to ln(CO_2), ln(CO), ln(SO_2), ln(NO_x) and ln(GDP) yields the estimated results in Table 1. The τ-statistics are generated by the econometrics software *PcGive* (Hendry and Doornik, 1999) with the critical values derived from the response surfaces in MacKinnon (1991).

The results in Table 1 indicate that according to ADF tests, the null hypothesis of presence of unit root in the level variables, ln(CO_2), ln(CO), ln(SO_2), ln(NO_x) and ln(GDP), can not be rejected at the 10% significance level, no matter whether a constant only or a constant plus a linear time trend are included in the estimation. This may lead to the conclusion that ln(CO_2), ln(CO), ln(SO_2), ln(NO_x) and ln(GDP) are non-stationary variables.

Table 1. Results of augmented Dickey-Fuller (ADF) tests of unit root hypotheses

Variable	τ-statistic				Variable	τ-statistic			
	c	n	ct	n		c	n	ct	n
ln(CO_2)	-1.57	1	-3.42	0	Δln(CO_2)	-8.89***	0	-8.73***	0
ln(CO)	0.50	2	-2.00	1	Δln(CO)	-1.24	1	-3.78**	2
ln(SO_2)	-0.13	1	-2.10	1	Δln(SO_2)	-3.76***	0	-3.66**	0
ln(NO_x)	-2.45	2	-2.60	2	Δln(NO_x)	-5.02***	0	-5.13***	0
ln(GDP)	-1.59	2	-2.47	3	Δln(GDP)	-3.71***	1	-4.02**	1

Notes:

1. The letters c and ct indicate whether Eq. (1) contains a constant only or a constant plus a linear time trend.
2. The heading n is the optimal lag length that is chosen according to the Akaike's information criterion (AIC). The AIC is defined as $\mathrm{AIC} = \ln\left(\left(\sum_{t=1}^{T}\hat{v}_t^2\right)/T\right) + 2k/T$, where $\hat{v}_t$ is the residual in period t from estimating Eq. (1), k is the number of parameters to be estimated, and T is the number of total observations.
3. **, *** indicate significance at the 5% and 1% level, respectively.

For the corresponding first difference variables, Δln(CO_2), Δln(CO), Δln(SO_2), Δln(NO_x) and Δln(GDP), at the 5% significance level, the null hypothesis of presence of unit root can be rejected, except for Δln(CO) when only a constant is included in the estimation. However, the τ-statistic becomes significant after including a constant plus a linear trend in the estimation for Δln(CO). Thus, we may conclude that ln(CO_2), ln(CO), ln(SO_2), ln(NO_x) and ln(GDP) are all non-stationary variables and integrated of order 1.

4.2. Results from cointegration tests

Under the assumption that all variables concerned in the present study are non-stationary and integrated of order 1, cointegration test should be conducted as a preceding step toward a causality test as stated in Section 2. Johansen's tests for cointegration are performed for this purpose. Table 2 presents the test results generated by the econometrics software *PcGive* (Hendry and Doornik, 2001). The *p*-vaules reported here are based on the approximations to the asymptotic distributions derived by Doornik (1998).

Table 2. Results of Johansen's tests for cointegration between air emissions and GDP

Trace statistics

Variable	H_0: The number of co-integrating equation is zero (r = 0)	H_0: The number of co-integrating equation is at most one ($r \leq 1$)
$\ln(CO_2)$	19.27** (0.011)	2.39 (0.122)
$\ln(CO)$	13.84* (0.087)	0.17 (0.678)
$\ln(SO_2)$	9.59 (0.319)	1.02 (0.312)
$\ln(NO_x)$	7.00 (0.584)	1.32 (0.250)

Maximum eigenvalue statistics

Variable	H_0: The number of co-integrating equation is zero (r = 0)	H_0: The number of co-integrating equation is one (r = 1)
$\ln(CO_2)$	16.88** (0.017)	2.39 (0.122)
$\ln(CO)$	13.67* (0.060)	0.17 (0.678)
$\ln(SO_2)$	8.57 (0.331)	1.02 (0.312)
$\ln(NO_x)$	5.67 (0.660)	1.32 (0.250)

Notes:

1. r denotes the number of cointegration vector.
2. *, ** indicate significance at the 10% and 5% level, respectively.
3. *p*-values are in parentheses.
4. The optimal lag lengths are chosen as 5 for $\ln(CO_2)$, 3 for $\ln(CO)$, $\ln(SO_2)$, and $\ln(NO_x)$ by using Akaike's information criterion. The AIC is defined as $\mathrm{AIC} = \ln\left|\hat{\Omega}\right| + 2kT^{-1}$, where $\hat{\Omega}$ is the maximum likelihood estimate of the system variance-covariance matrix, k is the total number of parameters to be estimated in the VAR model, and T is the number of observations.

One of the problems with Johansen's cointegration tests is that the asymptotic critical values used for the test may not be applicable in small samples. Although the sample size of our study is not shorter than what typically is used in many studies in the EKC literature, a small sample adjustment for Johansen's cointegration tests is needed. The test statistics reported in Table 2 have been adjusted by using a simple small sample correction method proposed by Reimers (1992) and recommended by Maddala and Kim (1998).

The estimated results in Table 2 show that for $\ln(CO_2)$, $\ln(CO)$, at the 10% significance level, the null hypothesis of absence of cointegration relation (r = 0) can be rejected whereas the null hypothesis of existence of at most one ($r \leq 1$ for trace test) or exactly one ($r = 1$ for maximum eigenvalue test) cointegration relation can not be rejected. The situation is different for $\ln(SO_2)$ and $\ln(NO_x)$ where the null hypotheses of $r = 0$ can not be rejected at the 10% significance level.

Based on these results it may be concluded that both $\ln(CO_2)$ and ln(CO), while neither $\ln(SO_2)$ nor $\ln(NO_x)$, are cointegrated with ln(GDP). When cointegration is present, there exists only one cointegration relationship between $\ln(CO_2)$ and ln(GDP) as well as between ln(CO) and ln(GDP).

4.3. Results from Granger-causality tests

In this subsection, Granger-causality tests are carried out for the relationships between $\ln(CO_2)$ and ln(GDP) as well as between ln(CO) and ln(GDP) by applying the ECM model of (5) and (6). In an ECM model, both short- and long-run causal relationships can be tested.

Granger-causality tests are also implemented for the relationships between $\ln(SO_2)$ and ln(GDP) as well as between $\ln(NO_x)$ and ln(GDP) by applying the VAR model of (3) and (4). Since neither $\ln(SO_2)$ nor $\ln(NO_x)$ is cointegrated with ln(GDP), any causality between either $\ln(SO_2)$ and ln(GDP) or $\ln(NO_x)$ and ln(GDP), if it exists, must be short run in nature.

We report the test results in Table 3. The results show that for $\ln(SO_2)$ and $\ln(NO_x)$, at the 10% significance level, the null hypothesis that air emissions do not cause GDP can be rejected while the null hypothesis that GDP does not cause air emissions can not be rejected. This evidence indicates that there is unidirectional causal relationship running from $\ln(SO_2)$ and $\ln(NO_x)$ to ln(GDP), respectively.

For $\ln(CO_2)$ and ln(CO), at the 10% significance level, the null hypothesis that air emissions do not cause GDP can not be rejected for either the short run, long run or joint short/long run. The null hypothesis that GDP does not cause air emissions cannot be rejected for the short run. However, for the long run, it can be rejected. Moreover, for $\ln(CO_2)$, the null hypothesis can be rejected even for the joint short/long run. Hence, one may conclude that in the long run there is unidirectional causal relationship running from ln(GDP) to $\ln(CO_2)$ and ln(CO), respectively. Furthermore, one may claim that ln(GDP) strongly (Granger) causes $\ln(CO_2)$.

Table 3. Results of Granger-causality tests

Variable	H_0: Air emissions do not (Granger) cause GDP			H_0: GDP does not (Granger) cause air emissions		
	Short-run	Long-run	Joint (short run/long-run)	Short-run	Long-run	Joint (short-run/long-run)
F-statistics or *t*-statistics (based on error correction model)						
$\ln(CO_2)$	-	-	-	1.42 (0.168)	-2.38** (0.025)	6.56** (0.038)
	4.45 (0.108)	-0.30 (0.767)	4.83 (0.185)	-	-	-
$\ln(CO)$	-	-	-	0.80 (0.433)	-1.85* (0.077)	4.53 (0.104)
	0.06 (0.812)	0.17 (0.864)	0.08 (0.961)	-	-	-
F-statistics or *t*-statistics (based on VAR model in first differences)						
$\ln(SO_2)$	-			1.53 (0.138)		
	5.11* (0.078)			-		
$\ln(NO_x)$	-			1.21 (0.239)		
	7.86** (0.020)			-		

Notes:

1. *p*-values are in parentheses.
2. *, ** indicate significance at the 10% and 5% level, respectively.
3. The optimal lag lengths are chosen by using Akaike's information criterion (see notes in Table 1) and are as follows: $L_{11}=L_{12} = 1, 1, 1, 1$ and $L_{21}=L_{22} = 2, 2, 2, 2$ for $\ln(CO_2)$, $\ln(CO)$, $\ln(SO_2)$, and $\ln(NO_x)$, respectively.
4. The estimation for $\ln(CO)$ includes a linear time trend.

5. Concluding remarks

As prerequisite steps toward Granger-causality testing for the causal relationships between four types of air emissions (CO_2, SO_2, NO_x and CO) and GDP in Norway, stationarity and cointegration tests are carried out for time series of these variables.

The results from ADF tests suggest that $\ln(CO_2)$, $\ln(CO)$, $\ln(SO_2)$, $\ln(NO_x)$ and $\ln(GDP)$ all are non-stationary and integrated of order 1. The results from Johansen's cointegration tests provide some evidence for existence of cointegration (long-run) relationships between $\ln(CO_2)$ and ln(GDP) as well as between ln(CO) and ln(GDP). However, no such long-run relationships could be found neither between ln(SO_2) and ln(GDP) nor between ln(NO_x) and ln(GDP).

The results of Granger-causality analysis in this paper indicate that the causal relationships between ln(CO_2), ln(CO), ln(SO_2), ln(NO_x) and ln(GDP) are all unidirectional and run from air emissions to GDP for SO_2 and NO_x, while from GDP to air emissions for CO_2 and CO.

The causal relationships found between ln(SO_2) and ln(GDP) as well as between ln(NO_x) and ln(GDP) are short-run in nature. Nonetheless, for CO_2 and CO emissions, the long run effects are significant, which indicates that in the long run GDP (Granger) causes CO_2 and CO emissions in Norway during the sample period.

Our results reveal a preference to reduced form model as a common approach to analyzing the environment-GDP relationship because only unidirectional causal relationships are found in this study. However, the presumption suggested by the conventional EKC analyses that the causal relationship between environmental quality and GDP runs from the latter to the former is rejected for SO_2 and NO_x emissions. For CO_2 and CO emissions, the presumption may be retained.

Among the four types of air emissions in Norway, only CO_2 emissions appear to be increasing along the time (see Fig.1 in Section 3). Given that CO_2 is one of the major green house gases, implications from our study will be relevant to the current concern about global climate changes.

The results indicate that GDP strongly (Granger) causes CO_2, which implies that CO_2 is so pervasive in the economy that the economic growth actually increases the CO_2 emissions over time. Given that Norwegian GDP per capita is already among the highest in the world, if there were an environmental Kuznets curve for CO_2 emissions, a turning point after which the level of GDP sets out to lead to a reduction of CO_2 will be extremely high. Our findings are in line with Holz-Eakin and Selden (1995) who estimated turning points up to \$8 million per capita.

The results from our study differ from those of some other studies. For instance, Coondoo and Dinda (2002) found a unidirectional causal relationship running from CO_2 emissions to income for the developed country groups of North America, Eastern and Western Europe to which Norway belongs. The difference could be due to that they use panel data in their study while we use pure time series data for a specific country instead. In addition, note that Norway is such a small country and thereby, one may have reasonable speculation that its exclusion from the panel data for the developed country groups used by Coondoo and Dinda (2002) may not lead to a significant change to their conclusions. However, Coondoo and Dinda (2002) did find that Japan, one of the developed countries in the world, displayed a unidirectional causal relationship from income to CO_2 emissions.

In analyzing economic growth and the environment in Canada, Day and Graften (2003) found that there does not exist a long run causal relationship between per capita income and the measures of environmental degradation. Their causality tests indicate that only short run bi-directional causality, not unidirectional causality, runs between income and the environment.[4]

Finally, several caveats on the application of Granger-causality test should be made clear. First, although unidirectional causal relationships are found between ln(CO_2), ln(CO), ln(SO_2), ln(NO_x) and ln(GDP) in this study, it has not been possible to fully examine these relationships because the specific functional forms which illustrate how much, and through what mechanisms, air emissions give impacts on GDP or GDP on air emissions, are still unknown. In addition, a comprehensive analysis of the environmental quality-GDP relationship necessitates an examination of the effects of other factors such as the industrial and energy structure of the economy, environmental policy, etc. (Liu, *et al.*, 2006). However, our goal in this study is essentially to see to what extent the Granger-causality test can be utilized to question the validity of the presumption employed in the conventional EKC analyses that the causal relationship between emissions and GDP is unidirectional from the latter to the former. Therefore, the test itself can be considered to be a prerequisite analysis to further investigation on the environmental quality-GDP relationship.

Second, Granger causality test is in its essential to test a causal effect by means of data in lead-lag structure (See subsection 2.3 and (1)-(6)). For emissions that immediately follow the change of GDP, the employment of annual data may not be appropriate. Thus, higher frequency data such as quarterly, monthly or even weekly data are wanted in Granger-causality analyses for such emissions, which naturally remains a possible avenue for future studies in this field.

---

[4] The measures of environmental degradation used in Day and Graften (2003) are: emissions of carbon dioxide (CO_2), concentrations of carbon monoxide (CO), sulphur dioxide (SO_2) and total suspended particulate matter (TSP). Only the first one is measured by emission rather than concentration, and therefore, comparable with the result of our study.

References

Agras, J., Chapman, D. (1999): A dynamic approach to the environmental Kuznets curve hypothesis, *Ecological Economics*, **28**, 267-277.

Coondoo, D. and Dinda, S. (2002): Causality between income and emission: A country group-specific econometric analysis, *Ecological Economics*, **40**, 351-367.

Day, K.M. and Graften, R.Q. (2003): Growth and the environment in Canada: An empirical analysis, *Canadian Journal of Agricultural Economics*, **51**, 197-216.

Doornik, J.A. (1998): Approximations to the asymptotic distribution of cointegration tests, *Journal of Economic Surveys*, **12**, 573-593.

Engle, R.F. and Granger, C.W.J. (1987): Cointegration and error correction: representation, estimation and testing, *Econometrica*, **55**, 251-276.

Flugsrud, K., Gjerald, E., Haakonsen, G., Holtskog, S., Høie, H., Rypdal, K., Tornsjø, B. and Weidemann, F. (2003): "The Norwegian Emission Inventory: Documentation of Methodology and Data for Estimating Emissions of Greenhouse Gases and Long-range Transboundary Air Pollutants", Reports 1/2000, Statistics Norway.

Granger, C.W.J. (1969): Investigating causal relation by econometric and cross-sectional method, *Econometrica*, **37**, 424-438.

Granger, C.W.J. and Newbold, P. (1974): Spurious regressions in econometrics, *Journal of Econometrics*, **2**, 111-120.

Grossman, G.M. and Krueger, A.B. (1991): Environmental impacts of a North American Free Trade Agreement, National Bureau of Economic Research Working Paper 3914, NBER, Cambridge MA.

Grossman, G.M. and Krueger, A.B. (1994): Environmental impacts of a North American Free Trade Agreement, In P. Garber (ed.), *The US-Mexico Free Trade Agreement*. Cambridge MA: MIT Press.

Grossman, G.M. and Krueger, A.B. (1995): Economic growth and the environment, *Quarterly Journal of Economics*, **110**, 353-377.

Hendry, D.F. and Doornik, J.A. (2001): *Empirical Econometric Modelling Using PcGive, Volume 1*, Timberlake Consultants Ltd.

Hendry, D.F. and Juselius, K. (2001): Explaining Cointegration Analysis: Part II, *Energy Journal*, **22**, 75-120.

Holz-Eakin, D. and Selden, T.M. (1995): Stoking the Fires? CO_2 Emissions and Economic Growth, *Journal of Public Economics*, **57**, 85-101.

Johansen, S. (1988): Statistical analysis of cointegration vectors, *Journal of Economic Dynamics and Control*, **12**, 231-254.

Liu, G., Skjerpen, T., Swensen, A.R. and Telle, K. (2006): Unit Roots, Polynomial Transformations and the Environmental Kuznets Curve, Discussion Paper No. 443, Statistics Norway, January 2006.

MacKinnon, J.G. (1991): "Critical Values for Cointegration Tests", in Engle, R.F. and Granger, C.W.J. (eds.), *Long-Run Economic Relationships*, 267-276. Oxford: Oxford University Press.

Maddala, G.S. and Kim, In-Moo (1998): *Unit Roots, Cointegration and Structural Change*, Cambridge, UK: Oxford University Press.

Pearson, P. (1994): Energy, externalities and environmental quality: will development cure the ills it creates? *Energy Studies Review*, **6**, 199-215.

Reimers, H.-E. (1992): Comparisons of tests for multivariate cointegration, *Statistical Papers*, **33**, 335-359.

Shiu, A. and Lam, P.-L. (2004): Electricity consumption and economic growth in China, *Energy Policy*, **32**, 47-57.

Statistics Norway (2003): *Annual Yearbook of Statistics*, Statistics Norway, Oslo.

Stern, D.I., Common, M.S. and Barbier, E.B. (1994): Economic growth and environmental degradation: a critique of the environmental Kuznets curve, Discussion Paper in Environmental Economics and Environmental Management, No.9409, University of York.

Stock, J.H. and Watson, M.W. (1989): Interpreting the evidence in money-income causality, *Journal of Econometrics*, **40**, 161-182.

Toda, H.Y. and Phillips, P.C.B. (1993): Vector autoregressions and causality, *Econometrica*, **61**, 1367-1393.

Yang, H.-Y. (2000): A note on the causal relationship between energy and GDP in Taiwan, *Energy Economics*, **22**, 309-317.

Yoo, S.-H. and Kwak, S.-J. (2004): Information technology and economic development in Korea: a causality study, *International Journal of Technology Management*, **27**, 57-67.

Yoo, S.-H. (2005): Electricity consumption and economic growth: evidence from Korea, *Energy Policy*, **33**, 1627-1632.

Recent publications in the series Discussion Papers

354 E. Halvorsen (2003): A Cohort Analysis of Household Saving in Norway

355 I. Aslaksen and T. Synnestvedt (2003): Corporate environmental protection under uncertainty

356 S. Glomsrød and W. Taoyuan (2003): Coal cleaning: A viable strategy for reduced carbon emissions and improved environment in China?

357 A. Bruvoll T. Bye, J. Larsson og K. Telle (2003): Technological changes in the pulp and paper industry and the role of uniform versus selective environmental policy.

358 J.K. Dagsvik, S. Strøm and Z. Jia (2003): A Stochastic Model for the Utility of Income.

359 M. Rege and K. Telle (2003): Indirect Social Sanctions from Monetarily Unaffected Strangers in a Public Good Game.

360 R. Aaberge (2003): Mean-Spread-Preserving Transformation.

361 E. Halvorsen (2003): Financial Deregulation and Household Saving. The Norwegian Experience Revisited

362 E. Røed Larsen (2003): Are Rich Countries Immune to the Resource Curse? Evidence from Norway's Management of Its Oil Riches

363 E. Røed Larsen and Dag Einar Sommervoll (2003): Rising Inequality of Housing? Evidence from Segmented Housing Price Indices

364 R. Bjørnstad and T. Skjerpen (2003): Technology, Trade and Inequality

365 A. Raknerud, D. Rønningen and T. Skjerpen (2003): A method for improved capital measurement by combining accounts and firm investment data

366 B.J. Holtsmark and K.H. Alfsen (2004): PPP-correction of the IPCC emission scenarios - does it matter?

367 R. Aaberge, U. Colombino, E. Holmøy, B. Strøm and T. Wennemo (2004): Population ageing and fiscal sustainability: An integrated micro-macro analysis of required tax changes

368 E. Røed Larsen (2004): Does the CPI Mirror Costs.of.Living? Engel's Law Suggests Not in Norway

369 T. Skjerpen (2004): The dynamic factor model revisited: the identification problem remains

370 J.K. Dagsvik and A.L. Mathiassen (2004): Agricultural Production with Uncertain Water Supply

371 M. Greaker (2004): Industrial Competitiveness and Diffusion of New Pollution Abatement Technology – a new look at the Porter-hypothesis

372 G. Børnes Ringlund, K.E. Rosendahl and T. Skjerpen (2004): Does oilrig activity react to oil price changes? An empirical investigation

373 G. Liu (2004) Estimating Energy Demand Elasticities for OECD Countries. A Dynamic Panel Data Approach

374 K. Telle and J. Larsson (2004): Do environmental regulations hamper productivity growth? How accounting for improvements of firms' environmental performance can change the conclusion

375 K.R. Wangen (2004): Some Fundamental Problems in Becker, Grossman and Murphy's Implementation of Rational Addiction Theory

376 B.J. Holtsmark and K.H. Alfsen (2004): Implementation of the Kyoto Protocol without Russian participation

377 E. Røed Larsen (2004): Escaping the Resource Curse and the Dutch Disease? When and Why Norway Caught up with and Forged ahead of Its Neughbors

378 L. Andreassen (2004): Mortality, fertility and old age care in a two-sex growth model

379 E. Lund Sagen and F. R. Aune (2004): The Future European Natural Gas Market - are lower gas prices attainable?

380 A. Langørgen and D. Rønningen (2004): Local government preferences, individual needs, and the allocation of social assistance

381 K. Telle (2004): Effects of inspections on plants' regulatory and environmental performance - evidence from Norwegian manufacturing industries

382 T. A. Galloway (2004): To What Extent Is a Transition into Employment Associated with an Exit from Poverty

383 J. F. Bjørnstad and E.Ytterstad (2004): Two-Stage Sampling from a Prediction Point of View

384 A. Bruvoll and T. Fæhn (2004): Transboundary environmental policy effects: Markets and emission leakages

385 P.V. Hansen and L. Lindholt (2004): The market power of OPEC 1973-2001

386 N. Keilman and D. Q. Pham (2004): Empirical errors and predicted errors in fertility, mortality and migration forecasts in the European Economic Area

387 G. H. Bjertnæs and T. Fæhn (2004): Energy Taxation in a Small, Open Economy: Efficiency Gains under Political Restraints

388 J.K. Dagsvik and S. Strøm (2004): Sectoral Labor Supply, Choice Restrictions and Functional Form

389 B. Halvorsen (2004): Effects of norms, warm-glow and time use on household recycling

390 I. Aslaksen and T. Synnestvedt (2004): Are the Dixit-Pindyck and the Arrow-Fisher-Henry-Hanemann Option Values Equivalent?

391 G. H. Bjønnes, D. Rime and H. O.Aa. Solheim (2004): Liquidity provision in the overnight foreign exchange market

392 T. Åvitsland and J. Aasness (2004): Combining CGE and microsimulation models: Effects on equality of VAT reforms

393 M. Greaker and Eirik. Sagen (2004): Explaining experience curves for LNG liquefaction costs: Competition matter more than learning

394 K. Telle, I. Aslaksen and T. Synnestvedt (2004): "It pays to be green" - a premature conclusion?

395 T. Harding, H. O. Aa. Solheim and A. Benedictow (2004). House ownership and taxes

396 E. Holmøy and B. Strøm (2004): The Social Cost of Government Spending in an Economy with Large Tax Distortions: A CGE Decomposition for Norway

397 T. Hægeland, O. Raaum and K.G. Salvanes (2004): Pupil achievement, school resources and family background

398 I. Aslaksen, B. Natvig and I. Nordal (2004): Environmental risk and the precautionary principle: "Late lessons from early warnings" applied to genetically modified plants

399 J. Møen (2004): When subsidized R&D-firms fail, do they still stimulate growth? Tracing knowledge by following employees across firms

400 B. Halvorsen and Runa Nesbakken (2004): Accounting for differences in choice opportunities in analyses of energy expenditure data

401 T.J. Klette and A. Raknerud (2004): Heterogeneity, productivity and selection: An empirical study of Norwegian manufacturing firms

402 R. Aaberge (2005): Asymptotic Distribution Theory of Empirical Rank-dependent Measures of Inequality

403 F.R. Aune, S. Kverndokk, L. Lindholt and K.E. Rosendahl (2005): Profitability of different instruments in international climate policies

404 Z. Jia (2005): Labor Supply of Retiring Couples and Heterogeneity in Household Decision-Making Structure

405 Z. Jia (2005): Retirement Behavior of Working Couples in Norway. A Dynamic Programming Approch

406 Z. Jia (2005): Spousal Influence on Early Retirement Behavior

407 P. Frenger (2005): The elasticity of substitution of superlative price indices

408 M. Mogstad, A. Langørgen and R. Aaberge (2005): Region-specific versus Country-specific Poverty Lines in Analysis of Poverty

409 J.K. Dagsvik (2005) Choice under Uncertainty and Bounded Rationality

410 T. Fæhn, A.G. Gómez-Plana and S. Kverndokk (2005): Can a carbon permit system reduce Spanish unemployment?

411 J. Larsson and K. Telle (2005): Consequences of the IPPC-directive’s BAT requirements for abatement costs and emissions

412 R. Aaberge, S. Bjerve and K. Doksum (2005): Modeling Concentration and Dispersion in Multiple Regression

413 E. Holmøy and K.M. Heide (2005): Is Norway immune to Dutch Disease? CGE Estimates of Sustainable Wage Growth and De-industrialisation

414 K.R. Wangen (2005): An Expenditure Based Estimate of Britain's Black Economy Revisited

415 A. Mathiassen (2005): A Statistical Model for Simple, Fast and Reliable Measurement of Poverty

416 F.R. Aune, S. Glomsrød, L. Lindholt and K.E. Rosendahl: Are high oil prices profitable for OPEC in the long run?

417 D. Fredriksen, K.M. Heide, E. Holmøy and I.F. Solli (2005): Macroeconomic effects of proposed pension reforms in Norway

418 D. Fredriksen and N.M. Stølen (2005): Effects of demographic development, labour supply and pension reforms on the future pension burden

419 A. Alstadsæter, A-S. Kolm and B. Larsen (2005): Tax Effects on Unemployment and the Choice of Educational Type

420 E. Biørn (2005): Constructing Panel Data Estimators by Aggregation: A General Moment Estimator and a Suggested Synthesis

421 J. Bjørnstad (2005): Non-Bayesian Multiple Imputation

422 H. Hungnes (2005): Identifying Structural Breaks in Cointegrated VAR Models

423 H. C. Bjørnland and H. Hungnes (2005): The commodity currency puzzle

424 F. Carlsen, B. Langset and J. Rattsø (2005): The relationship between firm mobility and tax level: Empirical evidence of fiscal competition between local governments

425 T. Harding and J. Rattsø (2005): The barrier model of productivity growth: South Africa

426 E. Holmøy (2005): The Anatomy of Electricity Demand: A CGE Decomposition for Norway

427 T.K.M. Beatty, E. Røed Larsen and D.E. Sommervoll (2005): Measuring the Price of Housing Consumption for Owners in the CPI

428 E. Røed Larsen (2005): Distributional Effects of Environmental Taxes on Transportation: Evidence from Engel Curves in the United States

429 P. Boug, Å. Cappelen and T. Eika (2005): Exchange Rate Rass-through in a Small Open Economy: The Importance of the Distribution Sector

430 K. Gabrielsen, T. Bye and F.R. Aune (2005): Climate change- lower electricity prices and increasing demand. An application to the Nordic Countries

431 J.K. Dagsvik, S. Strøm and Z. Jia: Utility of Income as a Random Function: Behavioral Characterization and Empirical Evidence

432 G.H. Bjertnæs (2005): Avioding Adverse Employment Effects from Energy Taxation: What does it cost?

433. T. Bye and E. Hope (2005): Deregulation of electricity markets—The Norwegian experience

434 P.J. Lambert and T.O. Thoresen (2005): Base independence in the analysis of tax policy effects: with an application to Norway 1992-2004

435 M. Rege, K. Telle and M. Votruba (2005): The Effect of Plant Downsizing on Disability Pension Utilization

436 J. Hovi and B. Holtsmark (2005): Cap-and-Trade or Carbon Taxes? The Effects of Non-Compliance and the Feasibility of Enforcement

437 R. Aaberge, S. Bjerve and K. Doksum (2005): Decomposition of Rank-Dependent Measures of Inequality by Subgroups

438 B. Holtsmark (2005): Global per capita CO_2 emissions - stable in the long run?

439 E. Halvorsen and T.O. Thoresen (2005): The relationship between altruism and equal sharing. Evidence from inter vivos transfer behavior

440 L-C. Zhang and I. Thomsen (2005): A prediction approach to sampling design

441 Ø.A. Nilsen, A. Raknerud, M. Rybalka and T. Skjerpen (2005): Lumpy Investments, Factor Adjustments and Productivity

442 R. Golombek and A. Raknerud (2005): Exit Dynamics with Adjustment Costs

443 G. Liu, T. Skjerpen, A. Rygh Swensen and K. Telle (2006): Unit Roots, Polynomial Transformations and the Environmental Kuznets Curve

444 G. Liu (2006): A Behavioral Model of Work-trip Mode Choice in Shanghai

445 E. Lund Sagen and M. Tsygankova (2006): Russian Natural Gas Exports to Europe. Effects of Russian gas market reforms and the rising market power of Gazprom

446 T. Ericson (2006): Households' self-selection of a dynamic electricity tariff

447 G. Liu (2006): A causality analysis on GDP and air emissions in Norway