Economic Growth and Carbon Dioxide Emissions in Italy, 1861-2003

Annicchiarico, Barbara and Bennato, Anna Rita and Costa, Andrea

Department of Economics, University of Rome 'Tor Vergata'

January 2009

Economic Growth and Carbon Dioxide Emissions in Italy, 1861-2003*

Barbara Annicchiarico† Anna Rita Bennato‡ Andrea Costa§

January 2009

Abstract

This paper examines the relationship between economic growth and carbon dioxide emissions in Italy for the period 1861-2003. Using cointegration, rolling regression and error correction modeling techniques, we find that growth and carbon dioxide emissions are strongly interrelated, and elasticity of pollutant emissions with respect to income has been decreasing over time. For the period 1960-2003 EKC estimates provide evidence for the existence of a *reasonable* "turning point". However, given the heavy dependence of Italian economy upon fossil fuels, meeting the emissions targets in the accomplishing of the Kyoto Protocol is a very challenging task.

Keywords: Environmental Kuznets Curve, Carbon Dioxide Emissions, Time Series Analysis, Italian Economy.

JEL classification: Q50, C22.

*We are very grateful to Vincenzo De Lipsis, Adrian McCourt, Alessandro Piergallini and Simone Valente for helpful comments and suggestions. The usual disclaimer applies.

†*Corresponding Author*: Department of Economics, University of Rome "Tor Vergata", Via Columbia 2, 00133 Rome, Italy. Phone: +390672595731; Fax: +39062020500. E-mail: Barbara.Annicchiarico@uniroma2.it

‡Department of Economics, University of Rome "Tor Vergata".

§Department of Economics, University of Rome "Tor Vergata".

1 Introduction

During the last decade many experts have warned against the risk of global climate change deriving from the increasing accumulation of anthropogenic greenhouse gases (GHG) in the atmosphere. For this purpose the Kyoto Protocol represents a decisive step forward in the process of containing global climate change.[1]

Following the seminal contributions of Grossman and Krueger (1991, 1995) and Selden and Song (1994, 1995), the increasing attention on this phenomenon has given rise to a huge strand of literature, studying the relationship between air quality and economic growth. The existence of a systematic relationship between pollution and economic growth, commonly referred to as Environmental Kuznets Curve (EKC), is still an open issue. The results of the empirical literature are controversial.[2] According to the EKC hypothesis, environmental degradation tends to increase as the economy develops, but begins to decline at higher levels of income.[3]

As far as studies on carbon dioxide (CO_2) emissions are concerned, the existence of a bell-shaped relationship between pollutant and income, postulated by the EKC hypothesis, has only been confirmed in some panel studies for OECD countries.[4] However, many authors claim that the EKC hypothesis does not hold

[1]According to the Fourth Assessment Report "Climate Change 2007" of the Intergovernmental Panel on Climate Change (IPCC), the main causes of global warming are considered to be the GHG produced by industrial processes. Human activities are responsible for the increasing emissions of four principal GHG: carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and halocarbons.

[2]For reviews of the EKC literature see e.g. Stern (1998, 2004); de Bruyn and Heintz (1999); Dinda (2004).

[3]For theoretical models on the EKC hypothesis see e.g. John and Pecchenino (1994), Selden and Song (1995), Stokey (1998), Andreoni and Levinson (2001), Dinda (2005), Egli and Steger (2007).

[4]For an exhaustive review of the empirical literature on carbon dioxide emissions, see Galeotti *et al.* (2006) who also reconsider the robustness of the existing evidence using alternative data and functional forms. For a carbon Kuznets curve theoretical analysis, see e.g. Müller-Fürstenberger and Wagner (2007).

for global pollutants that have long-lasting effects, and for which abatement costs tend to be high, such as CO_2. According to de Bruyn *et al.* (1998), Stern (1998, 2004), Dijkgraaf and Vollebergh (2005), a correct analysis of the relationship between growth and environment should be developed with regards to individual countries, underlying the importance of the specific historical experience.[5]

The main aim of this paper is to analyse the relationship between income growth and carbon dioxide emissions using data from 1861 to 2003. We have concentrated our time-series investigation on Italy, which is an industrialized economy characterized by specific features. Italy is a country with limited domestic energy resources and high dependence on external energy supply, with an energy import dependency of 84.5% in 2004 (see European Commission, 2007). Since 1990, final energy consumption has been increasing steadily, with transport and industry being the most energy-consuming sectors. Although Italian per capita CO_2 emissions are well below the EU-27 average, energy intensity in Italy is low relative to the EU-27 average and carbon dioxide emissions intensity is above the EU-27 mean level.[6] In 2004, Italy contributed to roughly 1.7% of the world's total carbon dioxide emissions stemming from fossil-fuel burning (see IEA, 2006). Oil and gas shares, in primary energy supply of Italy, are both above the EU-27 average, while hydroelectricity and other renewables play a very minor role.[7] Since Italy is highly dependent on fossil fuels, the reduction of carbon dioxide emissions represents a serious environmental challenge for the

[5]Country-specific studies have been conducted by e.g. Ang (2007), de Bruyn *et al.* (1998), Lindmark (2002), Friedl and Getzner (2003), Bruvoll and Medin (2003), Lise (2006), Lantz and Feng (2006), Roca *et al.* (2001), Roca and Serrano (2007).

[6]In 2004 Italian carbon dioxide emissions per capita were equal to 3,177 kgoe/cap, while the EU-27 level was 3,689 kgoe/cap. In 2004 energy intensity in Italy was 150 toe/MEUR '00 (compared to 185 toe/MEUR '00 of the EU-27 average); the Italian CO_2 intensity was 2.4 tCO_2/toe, while the average in the EU was equal to 2.2 tCO_2/toe. See European Commission (2007).

[7]It should be noted that, by national referendum in 1987, Italy chose to abandon the use of nuclear energy.

Italian economy.

The Kyoto Protocol obliges Italy to reduce its greenhouse gas anthropogenic emissions by 6.5%, with respect to the 1990-year emission level, by the end of the first commitment period, 2008-2012. It should be noted that in the year 2000, CO_2 emissions were already 6.5% above the 1990 level,[8] while in 2005 Italy was 12.1% above the 1990 emissions (see APAT, 2007).

In order to meet its reduction targets, Italy will be obliged to carry out significant abatement policies and adopt the flexible mechanisms of the Protocol by which industrialized countries can get emission credits. In the 1990s, the Italian manufacturing industry was already characterized by high energy efficiency levels due to the national policies undertaken after the oil crises of the 1970s. Thus the flexible mechanisms of the Kyoto Protocol will probably play an important role in the reduction of the CO_2 emissions in Italy.

To the best of our knowledge, most research has elaborated Italy's data only in panel analysis (see Galeotti *et al.*, 2006; Richmond and Kaufmann, 2006; Martínez - Zarzoso and Bengochea - Morancho, 2004). Using a dataset for OECD countries from 1960 to 1997, Dijkgraaf and Vollebergh (2005) investigate parameter homogeneity in panel studies and reject the existence of a turning point for Italy in their time-series analysis.

This paper examines the relationship between carbon dioxide emissions and gross domestic product using different, but complementary approaches. First, we study time series properties testing for the existence of unit roots and cointegration. Then, we estimate an error correction model in order to study the short and the long-term relation between the two relevant variables. Finally, we test the EKC hypothesis and we utilize rolling regression techniques in order to verify the evolution of the critical parameters over time.

[8]For details see OECD/IEA (2003).

Our results suggest that real GDP and carbon dioxide emissions are strongly interrelated and pollutant emissions elasticity on income has been decreasing sharply in the last three decades. For the period 1960-2003, we find evidence for the existence of a reasonable "turning point" from which emissions should start to decline.

The paper is organized as follows. In Section 2 we describe the dataset and discuss the historical evolution of carbon dioxide emissions and GDP in Italy. In Section 3 we study the properties of the time series by testing for unit roots and stationarity. The results of the cointegration analysis and of the error correction model approach are presented in Section 4, while in Section 5 we estimate a standard EKC model for carbon dioxide emissions. The main conclusions of the analysis are summarized in Section 6.

2 Data and Time Series Properties

In order to study the relationship between CO_2 and GDP for Italy, we utilize annual data on total fossil fuel CO_2 emissions, real GDP and total population for the period 1861-2003. Data on carbon dioxide emissions, stemming from fossil-fuel burning and the manufacture of cement, are from the CDIAC database (Carbon Dioxide Information and Analysis Centre), provided by the Oak Ridge National Laboratory. Emissions are expressed in thousand metric tons of carbon.[9] The 1861-2003 data on GDP and population are drawn from the database World Population, GDP and Per Capita GDP compiled by Angus Maddison. Gross domestic product is expressed in million of 1990 International Geary-Khamis dollars.[10]

[9] See http://cdiac.ornl.gov/ftp/trends/emissions/ita.dat, and Marland *et al.* (2007) for details on database construction.

[10] For details on data construction see Historical Statistics: World Population, GDP and Per Capita GDP, 1-2003 AD, Last Update: March 2007.

Figures 1-4 illustrate the historical patterns of GDP, and carbon dioxide emissions in Italy, for the period 1861-2003. Figure 1 depicts the time series of per capita GDP for the whole period. In the middle of the nineteenth century the Italian economy was largely agricultural, precisely it was not until the 1890s that Italy began to industrialize. Following World War II and the economic reconstruction, Italy experienced an unprecedented economic growth (*miracolo economico*). In the years from 1950 to 1973, per capita GDP rose by an average of 5.06% per annum, reaching a peak of 7.72% in 1961. After the 1973 increase in oil prices, there was a significant downturn of the economy. In the second half of the 1980s, Italian economy was again prospering until the recession of the earlier 1990s.

At earlier stages of Italian economic development, we observe a slight increase in CO_2 emissions, and then two dramatic falls during the First and the Second World Wars (see Figure 2). From 1950 until the late 1970s, we notice a continuous, or even accelerating, growth of per capita CO_2 emissions. Immediately after the second oil shock in 1979, the growth of per capita CO_2 emissions with per capita gross domestic product levels out, as it emerges clearly from inspection of Figure 3. This could be the result of the Italian economy's adjustment to the oil price shocks. Actually, the early 1980s saw some radical changes in the organization of Italian big industry with the introduction of automation and the dramatic reduction in the industrial work-force.[11] The recession in the early 1990s reduced the emissions slightly. From the second half of the 90's onwards there has been a constant, but slower, growth of carbon dioxide emissions amounting to around 125 million tons in 2003.

http://www.ggdc.net/maddison/content.shtml.

[11] In the period 1981-1983 Italy experienced economic stagnation. The large industry was facing the repercussions of a second oil shock and the consequences of low profit margins due to the wage-indexing mechanisms, which had been revised in the workers' favour after the first oil shock. See Zamagni (1993) for details.

Figure 4 reports the ratio between CO_2 emissions and GDP, expressed as CO_2 metric tons per unit of GDP. The CO_2/GDP ratio increases sharply from 1861, and then it falls during the World Wars. From 1950 until the earlier 1970s, we observe a prolonged increase in the ratio, up to a level of 0.16 in 1973. Since then, the CO_2/GDP ratio has been declining persistently up to a level of 0.11 in 2003. The decline was mainly due to the increased energy efficiency of the Italian economy. Thanks to the energy efficiency policies implemented in the aftermath of the oil crises of the 1970s, the energy intensity of the manufacturing sector started to decrease sharply.

The observed historical pattern could reflect the existence of an inverted-U relationship between carbon dioxide emissions and GDP for Italy, along the lines suggested by the EKC literature. Moreover, inspection of the time series suggests the existence of four significant structural breaks in the data, that can be attributed to the World Wars and to the two oil shocks. In what follows we will adopt several distinct but complementary approaches to study the relationship between CO_2 emissions and real GDP in Italy.

3 Stationarity and unit root analysis of CO_2 emissions and real GDP in Italy

In the current section we test whether the time series of CO_2 emissions and GDP are being driven by some trend, or whether the evolutions over time of these processes exhibit a unit behavior. We first test for stationarity and then apply a battery of unit root tests. We will focus on the time series properties of emissions per capita and GDP per capita, expressed in natural logarithms. Table 1 presents all the details concerning the results of the applied stationarity and unit root tests, carried out for various lag lengths.

To test the stationarity assumption we apply the Kwiatkowski, Phillips, Schmidt and Shin (KPSS) test, which differs from the most popular unit root tests by having a null hypothesis of stationarity. The KPSS test is often used in conjunction with standard unit root tests to investigate the possibility that a time series is fractionally integrated. From the results obtained we can reject the null hypothesis of trend and level stationarity for both time series at a 1% level of significance.

We verify the hypothesis that our time series follow a unit-root process by using three different tests. In particular, we analyze our time series data by applying as first the widely used augmented Dickey-Fuller test (ADF). Since the lag length affects the power properties of the ADF test, we establish the right number of the lags that should be included in our model using both the Akaike Information Criterion (AIC) and the Schwarz's Bayesian Information Criterion (BIC). We fail to reject the null hypothesis of unit root for both variables. To achieve an increase in power of the standard ADF test, we also apply its variant test proposed by Elliott *et al.* (1996), the DF-GLS test, choosing lags according to the Ng-Perron modified AIC (MAIC), the Schwarz's criterion (SIC) and the Ng-Perron sequential t method. With reference to this test we fail to reject the null hypothesis of unit root for per capita CO_2 emissions, while for per capita GDP we reject the null when lags are set minimizing MAIC, SIC and when a trend term is not included. Finally, according to Phillips-Perron test results we fail to reject the null hypothesis of unit root for per capita GDP, while for CO_2 emissions we reject the null when a trend term is included in the regression. Reapplication of these tests to the first differences of each time series indicates that both variables are stationary. We deduce that both time series are integrated of order 1.[12]

[12] Results are available from the authors upon request.

In the econometric literature it is well-known that unit-root tests may produce wrong results when time series display structural breaks. In particular, when a time series exhibits structural shifts we may fail to reject the null of unit root even in the absence of nonstationarity. In order to test the unit root hypothesis taking into account the possibility of structural breaks in the data, we perform the Zivot and Andrews test (Zandrews test) and the tests proposed by Clemente-Montañés-Reyes. All results are reported in Table 2. Through the Zandrews test we have examined for a single structural break in the intercept and in the trend of the time series. The optimal lag length was selected via a t-test. When taking into account the existence of different kinds of structural breaks, we fail to reject the null hypothesis of unit root for both time series. We notice that the shift in the intercept corresponds to the season of the Italian economic reconstruction in the 1950's, while a structural change in trend is found during World War II for both time series.

According to Clemente-Montañés-Reyes unit root tests we proceed considering two alternative events within our time series: the "additive outlier" (CLEMAO) model that captures a sudden change in the series, and the "innovation outlier" (CLEMIO) model that allows a gradual shift in the mean of the series. For convenience, we test for unit root allowing for the existence of one or two structural breaks, in turn. According to the CLEMAO test results we fail to reject the null hypothesis of unit root in both cases. We can conclude that unit roots are present even when instantaneous structural breaks are accounted for. When instead we consider the possibility of innovation outliers, we reject the null for both variables.

4 Cointegration analysis and ECM

In order to examine the dynamic relationship between per capita GDP and CO_2 emissions and verify if the two nonstationary processes have the same stochastic trend, we check if the two variables are cointegrated. In particular, we perform a number of tests for cointegration of the logs of per capita GDP and CO_2 emissions. We carry out the cointegration test developed by Engle and Granger (1987) for single equation models and the Johansen (1995) procedures for multiple equation systems. All resuts are reported in Table 3.

Following the Engle-Granger approach, we first estimate the cointegrating equation by regressing the natural logarithms of per capita carbon dioxide emissions (CO_2) on the natural logarithms of GDP per capita (Y), and then check if the residuals from the regression are I(1) by applying the ADF test for unit root.[13]

The cointegrating equation is estimated as follows:

$$(CO_2)_t = -\underset{(0.0843)}{3.60} + \underset{(0.0528)}{1.62}\, Y_t + \widehat{u}_t, \tag{1}$$

where the standard errors are given in parentheses, the coefficient of Y is the long-run elasticity of CO_2 per capita with respect to real GDP per capita, and $\widehat{u}$ denotes the regression residuals. All coefficients are statistically significant at 1% level.

The first column of Table 3 reports the ADF test results for different lag lengths chosen according to the AIC and the BIC, respectively. The Table, moreover, reports the appropriate adjusted 1% critical value for this test, computed according to MacKinnon (1991). We can clearly reject the null of no

[13]The test has been carried out without the constant term, since a constant is already included in the regression and the OLS residuals have mean zero.

cointegration.

The second and the third columns of Table 3 report the results obtained by applying the Johansen approach, used to identify the number of cointegration relationships among the time series. Since the Johansen's trace statistic at $r = 0$ of 20.3687 exceeds its critical value of 20.04, we reject the null hypothesis of no cointegration. In contrast, since the trace statistic at $r = 1$ of 0.2897 is less than its critical value of 6.65, we cannot reject the null hypothesis that there is one cointegrating equation. Similarly, with reference to the maximum eigenvalue test, through which we test the null of cointegration of order $r = 1$ against the alternative hypothesis of no cointegrating vector, we fail to reject the null hypothesis of cointegration of order one. According to the results in Table 3, it may be deduced the existence of one cointegrating relationship between real GDP and CO_2 emissions.

Finally, it is worth noticing that the cointegrating relation in equation (1) implicitly assumes that the parameters are constant over time. In order to check for parameter stability, we perform a rolling regression analysis. In particular, we examine the parameter stability of the constant and of the coefficient of GDP, for a window of length 40 years, applying recursive rolling regression of the cointegrating equation. Figures 5 and 6 plot the recursive estimates of the parameters and the two-standard error bands. The recursive estimates of the long-run elasticity of CO_2 per capita with respect to real GDP per capita are visibly high in the first decades and then decline sharply. These results clearly show that the long-run relation between carbon dioxide emissions and gross domestic product in Italy has been changing over time, as result of continuous technology innovation and higher energy efficiency.

The cointegration analysis describes the long-run relationship between carbon dioxide emissions and gross domestic product, ignoring the short-run characteristics of the dynamics implicit in the data. Since both short-run and long-run forces could be important for explaining changes in the carbon dioxide emissions, we estimate an error correction model (ECM). The ECM approach allows us to explain changes in the CO_2 emissions in terms of changes in GDP, as well as deviations from the long-run relationship between the two variables. Following Engle and Granger (1987) two or more integrated time series, that are cointegrated, have an error correction representation as follows:

$$\Delta \left(CO_2\right)_t = \beta_0 + \beta_1 \Delta \left(Y\right)_t + \eta u_{t-1} + \epsilon_t, \tag{2}$$

where u denotes the equilibrium error term defined as, $u_{t-1} = \left(CO_2\right)_{t-1} - \alpha_0 - \alpha_1 \left(Y\right)_{t-1}$, ϵ_t indicates the error term, β_1 is the parameter capturing any immediate effect that GDP may have on CO_2 emissions, and $\eta < 0$ is the error correction parameter, representing the principle of negative feedback. If during the last period the carbon dioxide emissions per capita are above (below) their equilibrium level, in the current period the error correction term will reestablish the equilibrium by reducing (increasing) CO_2. Instead of including explicitly an error correction term, an alternative error-correction equation can be estimated as follows:

$$\Delta \left(CO_2\right)_t = \gamma_0 + \gamma_1 \Delta \left(Y\right)_t + \gamma_2 Y_{t-1} + \eta \left(CO_2\right)_{t-1} + \epsilon_t, \tag{3}$$

where $\gamma_0 = \beta_0 - \eta\alpha_0$, $\beta_1 = \gamma_1$, $\gamma_2 = -\alpha_1\eta$. Notice that this representation can be estimated directly, with no need to follow a two-step estimation procedure. Moreover, the term η is still interpreted as the speed at which the dependent variable responds to any discrepancy from the long-run equilibrium condition. Similarly, the coefficient γ_1 captures the immediate response of carbon dioxide emissions to GDP changes. The long-run effect produced by any change in GDP on CO_2 emissions, can be simply obtained from the above specification of the ECM model as $k = -\frac{\gamma_2}{\eta}$.

Table 4 reports the results of the ECM analysis. In particular, we apply the ECM analysis on the whole sample, and on two separate periods, 1861-1959 and 1960-2003, respectively. As discussed in the previous section, the two periods might be different in terms of short- and long-run relationship between CO_2 emissions and GDP, since in late Fifties, Italy started to experience a long period of sustained economic growth. The Chow test suggests the presence of a structural break.

The ECM estimates of the model (3) have the expected signs and are significant at 1% level, with the exception of the estimated parameter $\widehat{\gamma}_2$ for the sample period 1861-1959, which is significant only at 15% level.

The short-run relationship between per capita GDP and CO_2 emissions is always positive, as expected. However, the estimated coefficient is much lower for the sample 1960-2003. The error correction parameter has the expected sign, and the estimate is slightly lower in the second period. Turning to the estimated long-run relationship, we find that for the whole sample $\widehat{k}_{1861-2003} = 1.345$, while for the two subsets we have $\widehat{k}_{1861-1959} = 1.178$ and $\widehat{k}_{1960-2003} = 0.45$, respectively. These results suggest that the long-run multiplier between per capita CO_2 emission and per capita GDP has significantly decreased over time. Again, this result evidences the increased energy efficiency of the Italian manufacturing, which has taken place in the last decades in response to the higher energy costs.

The results of the Ramsey's RESET test for omitted variables reveals that there is no functional form misspecification in the linear ECM for the two subperiods. The residuals from the regressions do not indicate the presence of any serial correlation for the second sub-sample. In general, we notice that the ECM specification performs much better for the sub-period 1960-2003 in terms of adjusted R^2, standard error of the regression and AIC.

5 Testing the EKC for Italy

In this section we test the EKC hypothesis, by estimating a standard polynomial relationship between carbon dioxide emissions and GDP for Italy. In particular, we model the relationship between carbon dioxide emissions and gross domestic product, as follows:

$$(CO_2)_t = \gamma_0 + \gamma_1 Y_t + \gamma_2 Y_t^2 + \varepsilon_t, \tag{4}$$

where ε_t denotes the error term and, as before, all variables are expressed in per capita terms and converted in natural logarithms. The turning point income, where pollutant emissions reach the peak, is given by $\tau = e^{-\gamma_1/2\gamma_2}$. The parameters γ_1 and γ_2 are long-term elasticities of carbon dioxide per capita emissions with respect to per capita real GDP, and squared per capita real GDP, respectively. An inverted-U relationship between GDP and CO_2 requires that $\gamma_1 > 0$ and $\gamma_2 < 0$.

We estimate the EKC model (4) for the whole sample, 1861-2003, and for the two subsets, 1861-1959 and 1960-2003, using GLS in order to consider possible serial correlation. Actually, in the presence of autocorrelated disturbances the standard errors estimated by OLS are likely to be too small.

Estimating the EKC for the whole sample and the first sub-period, in order to account for the structural breaks related to the two World Wars, we also include the dummy variable D_{WW}, which takes a value of 1 for the period 1915-

1945. For the second sub-period we also estimate equation (4), by including the dummy variable D_{1979}, which is equal to 1 for the period 1980-2003. In this last case, the inclusion of the dummy variable enables us to take into account the structural break observed in the data, due to the efficiency gains in terms of energy consumption. The results are reported in Tables 5-7.

Table 5 shows the results from estimating equation (4) for the whole sample. The estimated coefficients of the linear term and of the quadratic term are highly significant, and exhibit the theoretically expected sign. When we account, for the structural break due to the World Wars, the coefficient of the dummy variable D_{WW} is significant, and has the expected sign. Test results show the presence of serially correlated residuals for the simple quadratic specification, but not for the second specification with the dummy variable. Similarly, the first model presents problems of heteroskedasticity, which are removed with the inclusion of the dummy in second model. In both specifications, the turning points for CO_2 emissions are estimated to occur at a per capita real GDP value of $\$39,625$ and $\$39,462$, respectively. It should be noticed that in 2003 the per capita GDP of Italy was about \$19.150.

Table 6 shows the regression results for the period 1861-1959. We clearly reject the existence of an inverted-U relationship for the first sub-period, since the estimated coefficients of the quadratic term are not significant in both specifications. For this reason, in Table 6 we also report estimation results for the simple linear model (i.e. $\gamma_2 = 0$). In both cases the coefficient of Y_t is highly significant, and has the correct sign. Hence, there is strong evidence for the existence of a simple linear relationship between carbon dioxide emissions and gross domestic product in the first sub-period.

Table 7 presents regression results of the EKC for the second period. In this case all coefficients are highly significant and have the correct sign. Moreover, the coefficient of the dummy variable D_{1979} is significant, and confirms that a structural change has occurred. According to the results of the Ramsey's RESET test, there is no functional form misspecification. The residuals from the regressions do not indicate the presence of any serial correlation, neither of heteroskedasticity. In general, we notice that the statistical quality of the estimation, in terms of measures of goodness of fit, is much better for the second sub-period 1960-2003 than for the whole sample. More interestingly, for the two model specifications we find that increases in GDP should be associated with lower emissions at a level of per capita income of about $\$20,212$ and $\$20,716$, respectively. These results suggest that carbon dioxide emissions should start to curb in less than a decade, even without considering Italy's obligations under the Kyoto Protocol.

Finally, in order to verify the time evolution of the estimated parameters, we utilize rolling regression techniques. Figures 7 and 8 plot the recursive estimates of the parameters γ_1, γ_2, and the corresponding 95% confidence intervals, for a window of 40 year length. The estimated model in the rolling regression is the EKC curve of equation (4) augmented to include the dummy variable D_{WW}. Given the high variability of the estimated coefficients using earlier data, we just plot recursive regression results with sample end date from 1960 onward. Figure 7 shows that the elasticity of CO_2 emissions on real GDP has initially increased, and then stabilized. Figure 8 reveals that the relationship between carbon dioxide emissions and real GDP per capita started to be concave in the 1970s. As already remarked, the observed tendency could be the result of a decrease of the energy intensity in the Italian industrial sector, which has taken place in the last 30 years following the oil shocks.

6 Conclusions

Since the ratification of the Kyoto Protocol, environmental awareness has become a central issue in the policy debate. Given the heavy reliance of Italy on fossil fuels, the reduction of carbon dioxide emissions, in the accomplishing of the Kyoto Protocol, remains a serious environmental and policy challenge.

In this paper we have analyzed the relationship between income growth and carbon dioxide emissions for Italy, in a historical perspective. Using cointegration, rolling regression and error correction modeling techniques, our results suggest that the CO_2 emission trajectory is closely related to the income time path. Nevertheless, we show that pollutant emissions elasticity on income has been declining over time.

Estimating the EKC for the period 1960-2003, we find evidence for the existence of a reasonable turning point. Our results suggest that Italy could start to curb its carbon dioxide emissions in less than a decade, even without considering its commitments under the Kyoto Protocol. However, a significant abatement of the GHG emissions calls for relevant policy shifts.

References

[1] Ang, J.B., 2007. CO_2 Emissions, Energy Consumption, and Output in France, Energy Policy 35, 4772-4778.

[2] Andreoni, J., Levinson, A., 2001. The Simple Analytics of the Environmental Kuznets Curve, Journal of Public Economics 80, 269-286.

[3] APAT, 2007. Annuario dei dati ambientali 2007.

[4] Bruvoll, A., Medin, H., 2003. Factors Behind the Environmental Kuznets Curve. A Decomposition of the Changes in Air Pollution, Environmental and Resource Economics 24, 27-48.

[5] de Bruyn, S.M., van den Bergh, J.C.J.M., Opschoor, J.B., 1998. Economic Growth and Emissions: Reconsidering the Empirical Basis of Environmental Kuznets Curves, Ecological Economics 25, 161-175.

[6] de Bruyn, S.M., Heintz, R.J., 1999. The Environmental Kuznets Curve Hypothesis, in van den Bergh, J.C.J.M., (Ed.), Handbook of Environmental and Resource Economics, Edward Edgar, Cheltenham, UK, 656-677.

[7] Dinda, S., 2004. Environmental Kuznets Curve Hypothesis: A Survey, Ecological Economics 49, 431-455.

[8] Dinda, S., 2005. A Theoretical Basis for the Environmental Kuznets Curve, Ecological Economics 53, 403-413.

[9] Dijkgraaf, E., Vollebergh, H.R.J., 2005. A Test for Parameter Homogeneity in CO2 Panel EKC Estimations, Environmental and Resource Economics 32, 229–239.

[10] Egli, H., Steger, T.M., 2007. A Dynamic Model of the Environmental Kuznets Curve: Turning Point and Public Policy, Environmental and Resource Economics 36, 15-34.

[11] Elliot, G., Rothenberg, T.J., Stock, J.H., 1996. Efficient Tests for an Autoregressive Unit Root, Econometrica 64, 813-836.

[12] Engle, R.F., Granger, C.W.J., 1987. Cointegration and Error Correction: Representation, Estimation and Testing, Econometrica 55, 251-276.

[13] European Commission, 2007. Italy - Energy Mix Fact Sheet.

[14] Friedl, B., Getzner, M., 2003. Determinants of CO_2 Emissions in a Small Open Economy, Ecological Economics 45, 133-148.

[15] Galeotti, M., Lanza, A., Pauli, F., 2006. Reassessing the Environmental Kuznets Curve for CO_2 Emissions: A Robustness Exercise, Ecological Economics 57, 152-163.

[16] Galeotti, M. Manera, M., Lanza, A., 2006. On the robustness of robustness checks of the Environmental Kuznets Curve, Paper 13, Università degli Studi di Milano.

[17] Grossman, G.M., Krueger, A.B., 1991. Environmental Impacts of a North American Free Trade Agreement, NBER Working Paper no. 3914.

[18] Grossman, G.M., Krueger, A.B., 1995. Economic Growth and the Environment, The Quarterly Journal of Economics 110, 353-377.

[19] IEA, 2006. CO_2 Emissions from Fuel Combustion, 1971-2004.

[20] IPCC, 2007. Climate Change 2007 - The Physical Science Basis, Cambridge University Press, Cambridge.

[21] John, A.A., Pecchenino, R.A., 1994. An Overlapping Generations Model of Growth and the Environment, The Economic Journal 104, 1393-1410.

[22] Johansen, S. 1995, Likelihood-Based Inference in Cointegrated Vector Autoregressive Models, Oxford University Press, Oxford.

[23] Lantz, V., Feng, Q., 2006. Assessing Income, Population, and Technology Impacts on CO_2 Emissions in Canada: Where's the EKC?, Ecological Economics 57, 229-238.

[24] Lindmark, M., 2002. An EKC - Pattern in Historical Perspective: Carbon Dioxide Emissions, Technology, Fuel Prices and Growth in Sweden 1870-1997, Ecological Economics 42, 333-347.

[25] Lise, W., 2006. Decomposition of CO2 Emissions over 1980-2003 in Turkey, Energy Policy 34, 1841-1852.

[26] Marland, G., Boden, T.A., Andres, R.J., 2007. Global, Regional, and National Fossil Fuel CO_2 Emissions, In Trends: A Compendium of Data on Global Change. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A.

[27] Martínez–Zarzoso, I., Bengochea-Morancho, A., 2004. Pooled Mean Group estimation for an Environmental Kuznets Curve for CO2, Economic Letters 82, 121-126.

[28] MacKinnon, J.G., 1991. Critical values for cointegration tests, in Engle R.F., Granger C.W.J., (Eds), Long Run Economic Relationships: Readings in Cointegration, Oxford University Press, Oxford, 267-276.

[29] Müller-Fürstenberger, G., Wagner, M., 2007. Exploring the Environmental Kuznets Hypothesis: Theoretical and Econometric Problems, Ecological Economics 62, 648-660.

[30] OECD/IEA, 2003. Energy Policies of IEA Countries. Italy 2003 Review.

[31] Richmond, A.K., Kaufmann, R.K., 2006. Is there a Turning Point in the Relationship between Income and Energy Use and/or Carbon Emissions?, Ecological Economics 56, 176-189.

[32] Roca, J., Padilla, E., Farre, M., Galletto, V., 2001. Economic Growth and Atmospheric Pollution in Spain: Discussing the Environmental Kuznets Curve Hypothesis, Ecological Economics 39, 85-99.

[33] Roca, J., Serrano, M., 2007. Income Growth and Atmospheric Pollution in Spain: An Input-Output Approach, Ecological Economics 63, 230-242.

[34] Selden, T.M., Song, D., 1994. Environmental Quality and Development: Is there a Kuznets Curve for Air Pollution Emissions?, Journal of Environmental Economics and Management 27, 147-162.

[35] Selden, T.M., Song, D., 1995. Neoclassical Growth, the J Curve for Abatement and the Inverted U Curve for Pollution, Journal of Environmental Economics and Management 29, 162-168.

[36] Stern, D.I., 1998. Progress on the Environmental Kuznets Curve?, Environment and Development Economics 3, 173-196.

[37] Stern, D.I., 2004. The Rise and Fall of the Environmental Kuznets Curve, World Development 32, 1419-1439.

[38] Stokey, N.L., 1998. Are There Limits to Growth?, International Economic Review 39, 1-31.

[39] Zamagni, V., 1993. The Economic History of Italy 1860-1990, Clarendon Press, Oxford.

Table 1: Unit Root and Stationarity Tests for Per Capita GDP and CO_2 Emissions

	Per Capita GDP		*Per Capita CO_2*	
	no trend	with trend	no trend	with trend
KPSS	13.3***	2.62***	12.3***	0.662***
ADF	0.680(1)	−2.049(1)	−1.411(3)	−2.926(4)
	1.057(0)	−1.771(0)	−1.411(3)	−2.513(3)
DF-GLS	2.027*(1)	−1.172(1)	1.152(3)	−1.706(3)
	2.027*(1)	−1.172(1)	1.060(7)	−1.412(6)
	0.817(11)	−1.346(11)	1.060(7)	−1.670(7)
Phillips-Perron	0.862	−1.870	−1.912	−3.432**

Notes: Variables in natural logs. Lags reported in parentheses. A single asterisk, *, indicates significance at 10% level, a double asterisk, **, at 5% level and a triple asterisk, ***, at 1%. For the ADF the first row reports the statistic with the lag selected using the AIC, the second using the BIC. For the DF-GLS lags selected using the Schwarz's information criterion (SIC), the Ng-Perron modified Akaike information criterion (MAIC) and the Ng-Perron sequential t method, respectively.

Table 2: Unit Root Tests with Structural Breaks for Per Capita GDP and CO_2 Emissions

	Per Capita GDP		*Per Capita CO_2*	
	test statistics	Year	test statistics	Year
Zandrews (break in intercept)	−3.578(1)	1957	−3.085(3)	1959
Zandrews (break in trend)	−3.212(1)	1943	−2.692(3)	1944
CLEMAO1	−2.440	1964	−1.748	1941
CLEMAO2	−3.403	1910, 1964	−3.360	1889, 1957
CLEMIO1	−4.853**	1944	−5.289**	1943
CLEMIO2	−6.007**	1896, 1944	−9.909***	1941, 1944

Notes: Variables in natural logs. Lags reported in parentheses. For the Zandrews statistics lags selected via t test. A single asterisk, *, indicates significance at 10% level, a double asterisk, **, at 5% level and a triple asterisk, ***, at 1%.

Table 3: Cointegration Tests between Per Capita GDP and CO_2 Emissions

	Engle-Granger	Johansen's trace statistic	Johansen's max eigenvalue
test statistics	$-2.911^{***}(3)$	$20.3687^{***}(r=0)$	$20.0790^{***}(r=0)$
	$-2.911^{***}(3)$	$0.2897(r=1)$	$0.2897(r=1)$
1% critical value	-2.5805	20.04	18.63
		6.65	6.65
		VAR order: 2	VAR order: 2

Notes: Variables in natural logs. A single asterisk, *, indicates significance at 10% level, a double asterisk, **, at 5% level and a triple asterisk, ***, at 1%. Lags reported in parentheses. For the Engle-Granger test the ADF lags are chosen according to AIC and BIC, respectively. For the Johansen's statistics the order of the unrestricted VAR is chosen according to the AIC, the Schwarz's Bayesian information criterion and the Hannan–Quinn information criterion; r indicates the maximum rank.

Table 4: Error Correction Model

	1861-2003	1861-1959	1960-2003
constant	-0.4758^{***} (0.1245)	-0.4668^{***} (0.1908)	-0.0745 (0.0630)
ΔY_t	2.3711^{***} (0.3233)	2.3773^{***} (0.3994)	1.0026^{***} (0.2179)
Y_{t-1}	0.1974^{***} (0.0573)	0.1753 (0.1194)	0.0519^{***} (0.0291)
$(CO_2)_{t-1}$	-0.1468^{***} (0.0331)	-0.1488^{***} (0.0444)	-0.1244^{***} (0.0318)
$\widehat{k}$	1.345	1.178	0.417
obs.	142	98	43
F statistic	20.96^{***}	14.40^{***}	38.42^{***}
Adj. R^2	0.30	0.29	0.73
SER	0.2068	0.2486	0.0246
AIC	-46.59	4.11	-193.47
RESET	1.88	1.43	1.58
BG(1)	5.415^{**}	3.774^{**}	0.282
BG(2)	6.064^{*}	4.286	0.300
LB Q	43.53	31.48	24.549
ARCH(1)	0.088	0.006	2.331
Chow	0.3887		

Notes: The regressions are estimated by OLS. Standard errors are in parentheses. A single asterisk, *, indicates significance at 10% level, a double asterisk, **, at 5% level and a triple asterisk, ***, at 1%. Obs. denotes the number of observations; SER is the standard error of the regression; AIC is the Akaike information criterion value; RESET is the Ramsey specification test for omitted variables; BG is the Breusch-Godfrey LM test for the presence of first (1) and second order (2) autocorrelation; LB Q is the Ljung-Box Q statistic for white noise; ARCH(1) is the Engle's LM test for autoregressive conditional heteroskedasticity of order 1; Chow is the F test for structural change obtained using data for the entire sample, 1861-2003 and for the two subperiods, 1861-1959 and 1960-2003, respectively

Table 5: Environmental Kuznets Curve for Italian CO_2 Emissions, 1861-2003

	Quadratic	Quadratic with Dummy
constant	-4.4425^{***} (0.3257)	-4.2338^{***} (0.3379)
Y_t	2.9670^{***} (0.5088)	2.8600^{***} (0.5156)
Y_t^2	-0.4032^{**} (0.15097)	-0.3891^{**} (0.1636)
D_{WW}		-0.5814^{***} (0.1459)
ρ	0.8578	0.8808
turning point τ	$39,625$	$39,462$
obs.	143	143
F statistic	114.55^{***}	74.10^{***}
Adj. R^2	0.62	0.61
SER	0.2227	0.2105
AIC	-20.74	-35.92
BIC	-11.85	-24.07
log-likelihood	13.37	21.96
RESET	1.77	1.41
BP	25.31^{***}	0.29
BG(1)	3.917^{**}	0.259
ARCH(1)	1.149	0.543
DW	1.706	1.903

Notes: Variables in natural logs. The regressions are estimated by GLS based on the Prais-Winsten transformation. Standard errors are in parentheses. A single asterisk, *, indicates significance at 10% level, a double asterisk, **, at 5% level and a triple asterisk, ***, at 1%. The turning points are expressed in real 1990 International Geary-Khamis dollars; ρ is the estimated autocorrelation parameter; obs. denotes the number of observations; SER is the standard error of the regression; AIC is the Akaike information criterion value; BIC is Schwarz's Bayesian information criterion; the RESET is the Ramsey specification test for omitted variables; BP is the Breusch-Pagan test for heteroskedasticity; BG is the Breusch-Godfrey LM test for the presence of first order autocorrelation; ARCH(1) is the Engle's LM test for autoregressive conditional heteroskedasticity of order 1; D-W is the Durbin-Watson d statistic to test for first-order serial correlation.

Table 6: Environmental Kuznets Curve for Italian CO_2 Emissions, 1861-1959

	Linear	Linear with Dummy	Quadratic	Quadratic with Dummy
constant	-4.1710^{***} (0.3234)	-3.9716^{***} (0.3572)	-4.2632^{***} (0.5503)	-3.7084^{***} (0.5871)
Y_t	2.1991^{***} (0.3093)	2.1139^{***} (0.3158)	2.4579^{**} (1.2602)	1.3749 (1.2636)
Y_t^2			-0.1377 (0.6537)	0.3716 (0.6602)
D_{WW}		-0.6088^{***} (0.1756)		-0.6418^{***} (0.1773)
ρ	0.8665	0.8967	0.8632	0.9123
turning point τ	NA	NA	NA	NA
obs.	99	99	99	99
F statistic	91.11^{***}	48.97^{***}	44.88^{***}	30.31^{***}
Adj. R^2	0.48	0.50	0.48	0.47
SER	0.2659	0.2500	0.2675	0.2491
AIC	20.65	9.40	22.83	9.72
BIC	25.84	17.19	30.62	20.10
log-likelihood	-8.33	-1.70	-8.42	-0.86
RESET	1.14	0.89	1.12	0.91
BP	13.60^{***}	0.02	13.98^{***}	0.23
BG(1)	3.024^{*}	0.207	2.915^{**}	0.255
ARCH(1)	0.459	0.177	0.501	0.128
DW	1.69	1.91	1.696	1.913

Notes: Variables in natural logs. The regressions are estimated by GLS based on the Prais-Winsten transformation. Standard errors are in parentheses. A single asterisk, *, indicates significance at 10% level, a double asterisk, **, at 5% level and a triple asterisk, ***, at 1%; ρ is the estimated autocorrelation parameter; obs. denotes the number of observations; NA: not applicable because the coefficients are not significant in the quadratic specification and the relationship appears to be increasing. SER is the standard error of the regression; AIC is the Akaike information criterion value; BIC is Schwarz's Bayesian information criterion; the RESET is the Ramsey specification test for omitted variables; BP is the Breusch-Pagan test for heteroskedasticity; BG is the Breusch-Godfrey LM test for the presence of first order autocorrelation; ARCH(1) is the Engle's LM test for autoregressive conditional heteroskedasticity of order 1; D-W is the Durbin-Watson d statistic to test for first-order serial correlation.

Table 7: Environmental Kuznets Curve for Italian CO_2 Emissions, 1960-2003

	Quadratic	Quadratic with Dummy
constant	-6.7054^{***} (0.8477)	-6.6890^{***} (0.7717)
Y_t	4.9449^{***} (0.7442)	4.9216^{***} (0.6733)
Y_t^2	-0.8224^{***} (0.1592)	-0.8119^{***} (0.1438)
D_{1976}		-0.0482^{*} (0.0278)
ρ	0.9235	0.8868
turning point τ	$20,212$	$20,716$
obs.	44	44
F statistic	56.84^{***}	52.61^{***}
Adj. R^2	0.72	0.78
SER	0.0268	.02629
AIC	-190.59	-191.52
BIC	-185.24	-184.38
log-likelihood	98.30	99.76
RESET	1.26	1.07
BP	0.05	0.04
BG(1)	0.10	0.048
ARCH(1)	0.159	0.106
DW	1.880	1.896

Notes: Variables in natural logs. The regressions are estimated by GLS based on the Prais-Winsten transformation. Standard errors are in parentheses. A single asterisk, *, indicates significance at 10% level, a double asterisk, **, at 5% level and a triple asterisk, ***, at 1%. The turning points are expressed in real 1990 International Geary-Khamis dollars; ρ is the estimated autocorrelation parameter; obs. denotes the number of observations; SER is the standard error of the regression; AIC is the Akaike information criterion value; BIC is Schwarz's Bayesian information criterion; the RESET is the Ramsey specification test for omitted variables; BP is the Breusch-Pagan test for heteroskedasticity; BG is the Breusch-Godfrey LM test for the presence of first order autocorrelation; ARCH(1) is the Engle's LM test for autoregressive conditional heteroskedasticity of order 1; D-W is the Durbin-Watson d statistic to test for first-order serial correlation.

Figure 1: Per Capita GDP in Italy, 1861-2003

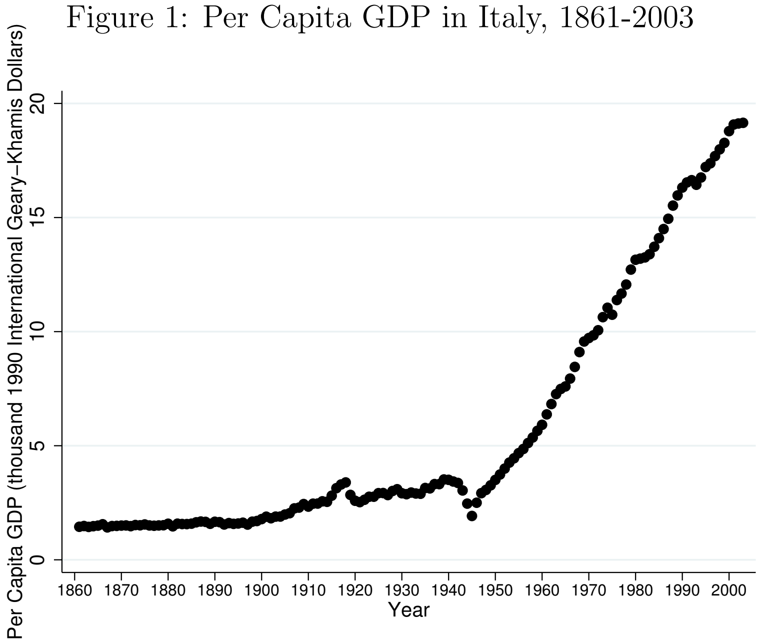

Figure 2: CO_2 Emissions in Italy, 1861-2003

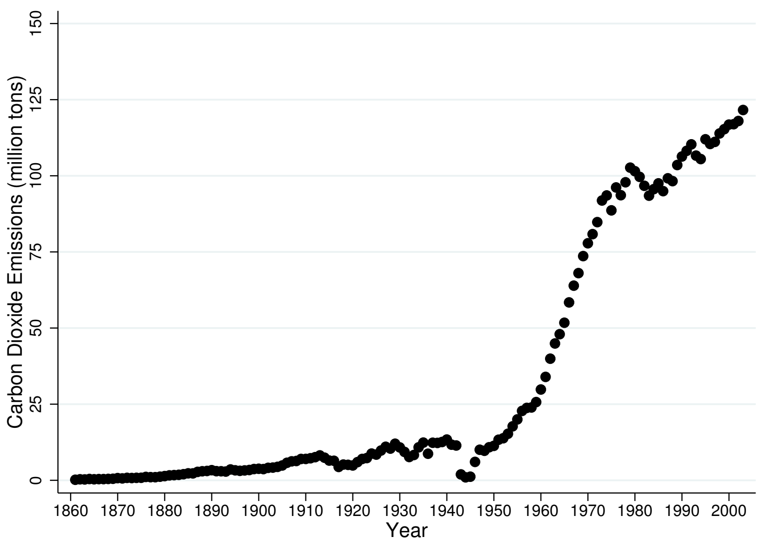

Figure 3: Per Capita CO_2 Emissions and Per Capita GDP in Italy, 1861-2003

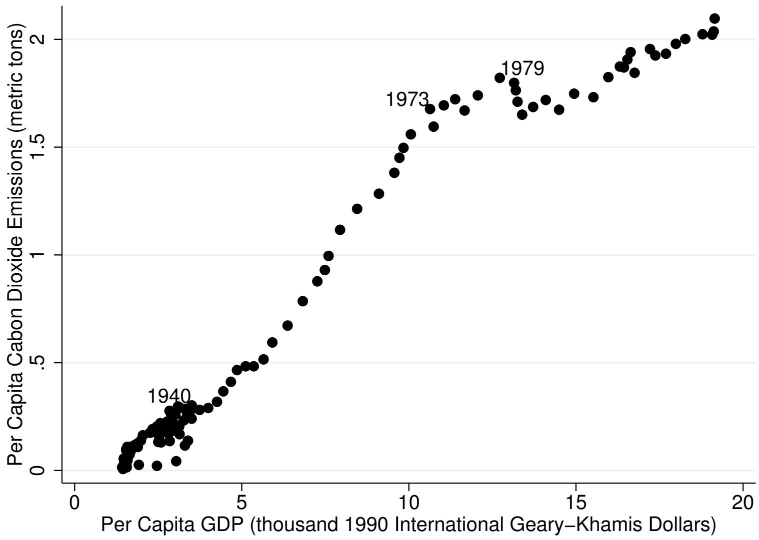

Figure 4: CO_2/GDP Ratio in Italy, 1861-2003

Figure 5: Recursive Estimates of the Cointegrating Equation, Intercept

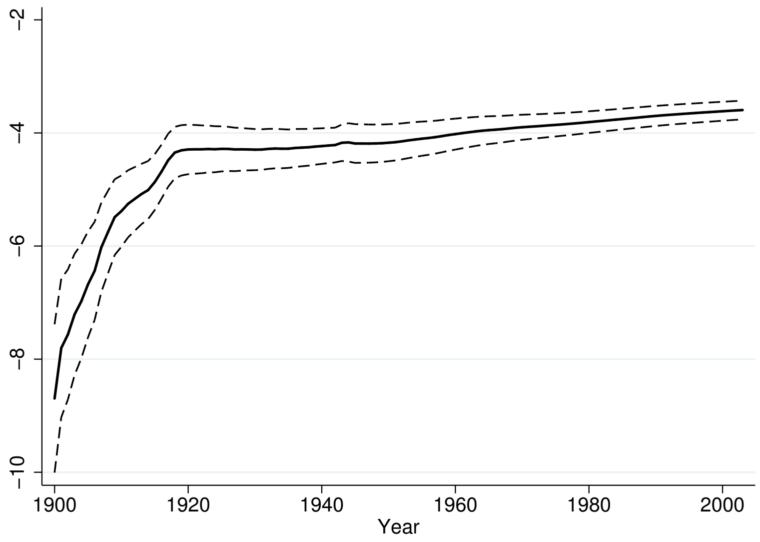

Figure 6: Recursive Estimates of the Cointegrating Equation, Coefficient on Per Capita GDP

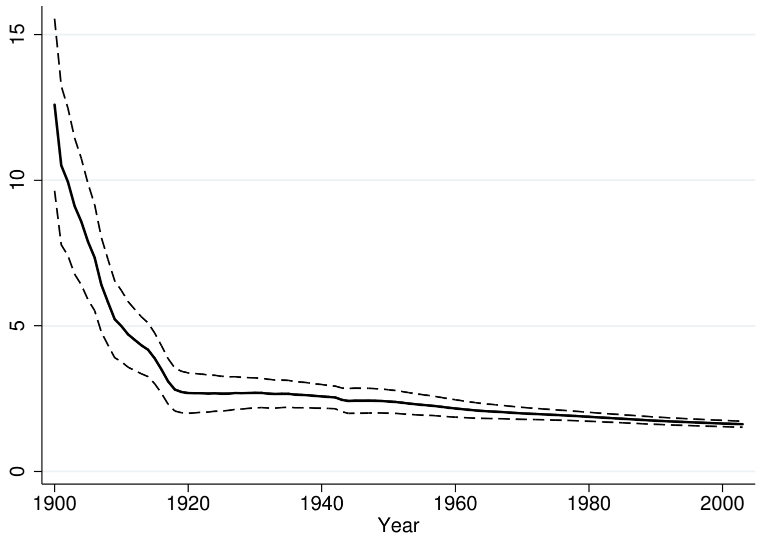

Figure 7: Recursive GLS Estimates of the EKC Equation, Coefficient on Per Capita GDP, γ_1

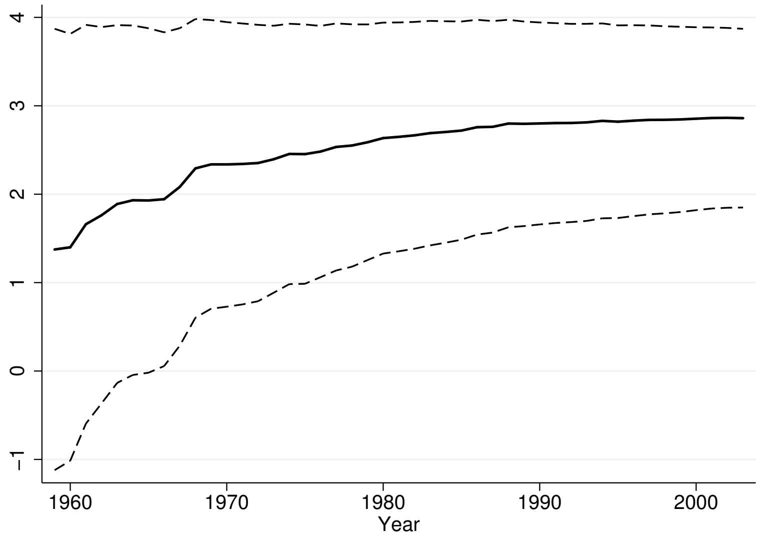

Figure 8: Recursive GLS Estimates of the EKC Equation, Coefficient on Per Capita GDP Squared, γ_2