CERE

CERE Working Paper, 2015:1

Periods of converging carbon dioxide emissions from oil combustion 1973-2004

Magnus Lindmark[a,c]
Sevil Acar[b]
[a] Department of Geography and Economic History
Umeå University, Sweden
e-mail: magnus.lindmark@ekhist.umu.se

[b] Istanbul Kemerburgaz University
Department of Economics
Istanbul, Turkey

[c] Centre for Environmental and Resource Economics
Umeå, Sweden

Department of Economics, Umeå University, S-901 87, Umeå, Sweden

www.cere.se

Periods of converging carbon dioxide emissions from oil combustion 1973-2004

Magnus Lindmark[a,c]
Sevil Acar[b]

[a] Department of Geography and Economic History
Umeå University, Sweden
e-mail: magnus.lindmark@ekhist.umu.se

[b] Istanbul Kemerburgaz University
Department of Economics
Istanbul, Turkey

January 2015

Abstract

This paper examines convergence of carbon dioxide (CO_2) emissions caused by oil combustion for a panel of 86 countries considering the importance of analyzing several sub-periods separately. Also, the investigation points at the necessity of choosing a restricted global sample, which takes into account that, for instance, eastern bloc countries reacted differently to increasing world market crude prices than the Western economies. The analysis builds on examining the β-convergence hypothesis in a neoclassical growth model setting with additional control variables such as combustion of solid fuels. The results reveal evidence in support of β-convergence of CO_2 emissions intensity due to oil combustion for the sub-periods 1973-1979 and 1979-1991, while no evidence for convergence was found for the post-1991 period. This is true both for the restricted global sample and the sub-samples comprised of western OECD economies. One possible interpretation of the results is that international carbon taxes or permit trading schemes may first be introduced for oil only.

Keywords: Carbon dioxide, Oil, Convergence, Carbon convergence, Energy history

1. Introduction

Convergence in terms of environmental quality has been studied in several articles and reports. As pointed out by Brännlund et al. (2014) an important aspect of this literature has been to analyze the conditions under which an economy can achieve economic growth combined with non-deteriorating environmental quality (see Brock and Taylor (2005) for a review). One general condition, which emanates from the optimality conditions in a dynamic neoclassical growth model, is pollution (β) convergence, implying that in the long-run pollution should be bounded as well as approach a steady-state level even in the presence of positive growth in per capita GDP. In a contemporary setting, carbon dioxide convergence is especially important in this respect, due to the ongoing discussions of international agreements on emissions cuts and the implementation of policy tools such as carbon taxes or carbon trading schemes.

We also notice that there is a rich empirical literature devoted to convergence of carbon dioxide (CO_2) emissions at the global or regional level (e.g., Aldy, 2006; Ezcurra, 2007; Strazicich and List, 2003; Nguyen Van, 2005; Panopoulou and Pantelidis, 2007; Westerlund and Basher, 2008; Camarero et al., 2008; Brock and Taylor, 2010; and Camarero et al., 2013). Still, there are important aspects to consider, which may further advance such analyses. A first important condition is that carbon convergence is a historical process. In other words, carbon convergence evolves over time. This implies, in turn, that the relevant historical context of the process is also likely to change. However it is difficult to determine what the relevant historical context exactly is. World energy prices are one such factor, but also global power politics and energy security issues are certainly prime candidates especially when emissions emanating from oil combustions are considered. This brings us to a second important condition when carbon dioxide convergence is studied; namely that the primary energy sources giving rise to carbon emissions (oil, coal or other sources) are related to partly different technologies.

While oil in the contemporary world is primarily used in the transport sector, the importance of coal in transports already decreased in the 1930s in some countries. Coal was defiantly phased out in the transport sector during the 1950s and 1960s. Today, coal is primarily used in the energy and steel manufacturing sectors. In most countries, oil was phased out from the energy sector during the 1970s and 1980s. However, the logic for oil producing countries may have been very different as compared to the general Western experience. In short, this means that analyses of carbon convergence should consider the following: First, it should be paired with a historical analysis of the general energy-political context aiming at a periodization of the full sample of analysis, recognizing that convergence may have been present during certain sub-periods, but may have been absent during other periods. Second, a careful selection of the countries that are to be included is necessary. For instance, countries belonging to the Soviet bloc, with a planned economy and bilateral trading schemes following the agreements of the COMECON, should not necessarily be included in the same sample of countries as open, liberal and oil dependent Western economies. This may also be relevant for the post-1991 period, since the transition to market economies has not generally been smooth, nor complete. Third, oil and coal should be analyzed separately, since oil is of larger strategic importance, and therefore pertains to power politics and since the use of coal in the energy system is influenced by various historical structures, known in the literature as technical and institutional path dependence.

This article therefore seeks to explore carbon beta-convergence along these lines over the period 1973 to 2004 with a specific focus on oil-related emissions. The basic design is to conduct an econometric test of oil convergence over three sub-periods, corresponding to major energy policy phases from a mainly Western perspective. It is important to notice that such periodization should be based on the knowledge of the historically relevant context and should not be elaborated with statistical methods. This is simply to say that a historical method is used for the periodization, rather than a statistical one. The analysis therefore examples from individual countries. These examples are, of course, not generalizations, but show how a certain country's experience would fit the big picture. We distinguish between the global sample and the Western economies. Besides, the main results are given a historical interpretation from the perspective of the country which experienced the highest transformation pressure over the period, such as Canada, Ireland and Sweden. The main conclusion is that oil intensity convergence in non-oil producing countries was significantly present in the periods 1973-1979 and 1979-1991, while it was absent in the period 1991-2004.

2. Theory

It is widely known that convergence in per capita income is rooted in the Solow model (Solow, 1956), where countries (or regions) at lower income levels are envisaged to enjoy higher income growth rates than those that are at higher income levels due to the assumption of diminishing marginal returns to capital. Convergence has been also been widely discussed in macroeconomic theory and tested via empirical analyses. This literature, which covers both economics and economic history, is too large to be survived here, but includes such seminal work as the study by Barro and Sala-i Martin (1992), who were testing a neoclassical growth model for convergence across 48 US states. They regressed the average growth rates over the entire sample (and over various periods between 1840 and 1988) on initial income levels, showing that the whole sample converged in terms of economic growth when sectoral composition and region variables were controlled for.

Environmental convergence research is inspired by previous economic convergence literature and uses similar methodologies to inspect cross-country emissions convergence for various samples and different time spans. The idea stems from the fact that the evolution of income and pollution are both determined simultaneously. This is a consequence of the macro-economic model suggested by Kriström (2000), in which environmentally harmful pollution and incomes are the outcome of a joint production faction, and where society seeks to find the optimal mix of the two, maximizing welfare. This, in turn, is a reasonable assumption since most, if not all, economic activity requires energy use and energy is usually generated via the extraction of natural resources at the expense of various negative environmental effects. This was a fundamental scientific theoretical proposition in Georgescu-Roegen’s (1971) seminal work on the entropy law and the economic process. In a post-industrial revolution time frame, and for England even before that (Warde, 2007), one effect of this has been the emissions of carbon dioxide through the combustion of fossil fuels. Needless to say, the relationship between economic growth and emissions depends on the decisions of households, firms and governments as well as the underlying institutional and policy frameworks. Moreover, the relationship is also depending on the characteristics of what can be described as technological regimes, and with that, the social capability of different countries to embrace new technologies, which means that the basic relationship is dynamic, rather than static Panayotou (1993). In terms of catch-up growth, the role of social capabilities was suggested as a decisive precondition for convergence by Abramowitz (1986), but would, as we argue, in principle apply also to environmental dimensions of convergence.

Pettersson et al. (2014) undertakes a comprehensive review of the literature on convergence of carbon dioxide emissions among countries. According to the review, empirical research provides evidence for convergence among developed (OECD) countries, while relatively persistent gaps (or in some cases, divergence) are explored at the global level. One of the potential reasons for the latter evidence is that “countries globally differ a lot in terms of fossil fuel reserves, fuels which historically have been relatively costly to transport over long distances (e.g., coal)" (Pettersson et al., 2014: 172). The authors attribute varying results for different subsets of countries (such as convergence among OECD countries) to spill-over effects and environmental policies. Previous studies fall short of explaining carbon convergence (or divergence) patterns with respect to the type of energy fuel mix that dominates in a certain economy or in a certain historical period. One of the few studies that investigate carbon convergence according to the type of energy consumed is Herrerias (2013), which examines a large group of developed and developing countries from 1980 to 2009 and finds evidence against the convergence hypothesis for the whole sample, regardless of the source of emissions (coal, natural gas and petroleum). Once the sample is categorized with respect to geographical area, symptoms of convergence in emissions from coal are discovered in South America. Conducting club convergence tests, the study arrives at four convergence clubs in the case of emissions from coal, while 24 countries experience divergence. Additionally seven convergence clubs in terms of natural gas emissions and nine convergence clubs in terms of emissions from petroleum were traced in the study. This motivates the focus in this specific study, to separately study oil convergence. Additionally, this is an especially important case, since the price shocks of 1973 and 1979 manifested a powerful transformation pressure on the energy system in the oil consuming countries of the world. A central issue is whether the reduction of oil consumption can basically be explained by a roughly similar economic transformation pressure across countries, or if the discretion of country-specific energy policy was crucial for the transformation of the energy systems. A response to a similar transformation pressure would be consistent with clear evidence for β-convergence in terms of oil intensity, while the opposite would be true in the case of a high degree of energy political discretion. In principle, these two outcomes are relevant in the perspective of future climate policy, concerning the prospects for individual countries to move ahead, pushing the technological frontier and encourage other counties to follow suit.

3. Model and data

We investigate cross-sectional β-convergence where the period growth rate of emission intensity between time 0 and time *t* is regressed on initial emission intensity for each country. A standard cross-sectional convergence model regresses the growth rate of emissions, $\ln(y_{it} / y_{i0})$, on the *initial* level of emissions, $\ln y_{i0}$, for country or region *i*. The general form of the model is as follows:

$$\ln(y_{it} / y_{i0}) = \alpha + \beta \ln(y_{i0}) + \varepsilon_i \tag{1}$$

where ε_i is the error term for country or region *i*. This model tests the null hypothesis of divergence, H_0: $\beta = 0$ for all *i*; against the alternative hypothesis of convergence: H_1: $\beta < 0$ for all *i*. Thus, if $\beta < 0$, we have convergence. With a slight modification in the model, we investigate the percentage changes between base years and comparison years using a balanced data set, covering oil consuming countries. The dependent variable is the change in carbon intensity, with respect to carbon emitted from the combustion of oil products only (*COILINT*), i.e. oil related carbon emission per GDP in fixed PPP-adjusted prices. The main independent variable is carbon intensity (*OILINT*), also with respect to carbon emitted from the combustion of oil products, in the base year. In addition we also include the following control variables:

GDP per capita (*GDPC*) controls for the effects of per capita income in the base year. Such effects can be expected if income is systematically related to the capacity to introduce flexible responses to the oil price shock. Given Abramowitz's original proposal and the New Growth Theory in more recent times, higher incomes are expected to be positively correlated with a higher social capacity, or technical capacity, to embrace new technology or even to lead the development of such technology. Another possibility is, however, as suggested by Olson (1982), that high income countries, and in his case not the least the Nordic countries during the 1980s, tended to fall victim to what came to be known as "institutional sclerosis", i.e. vested interests trying to block various institutional reforms. This could possibly also be the case of energy policy. We do not expect environmental effects from GDP per capita, apart from perhaps the post 1990-period, the reason being that carbon per se was not considered an environmental issue at the time, and since pollution such as sulphur was avoided through other means than a down right downsizing of oil consumption.

We also control for the effects of change in GDP per capita (*CGDPC*), which in this context could be expected if growth automatically tends to lower the oil carbon intensity through structural change, as suggested by Khan (1979).

Coal intensity (*SOLIDINT*) controls for effects of a large proportion of coal in the energy system, which could provide a relatively straightforward substitute for oil, since a high proportion of coal would also indicate that the proper infrastructure for coal would already have been established.

An even more straightforward control in this respect is the change of coal intensity (*CSOLIDINT*) over the investigated sub-period, as an indicator of coal being actually used as a significant substitute for oil.

The investigation is based on a combined data set comprising of Angus Maddison's historical GDP data and Oak Ridge Laboratories carbon emissions dates, divided into emissions from liquid and solid fuels. The motivation for using the Maddison data is that it is especially designed for historical growth analyses, with a certain consideration of changing national borders. For instance, Germany is analyzed as the contemporary German state, including former BRD and DDR. This is also true for former USSR and Yugoslavia. It is worthy of note that Maddison's African GDP figures are often considered as of high quality.

The following countries were excluded from the analyses, motivated by the following:

- Former oil-producing COMECON countries: Bulgaria, Romania and the USSR:
- Countries associated with the former eastern bloc with extensive USSR oil imports in exchange for i.e. political support: Cuba, Mongolia, Syria, Angola
- Oil producing countries: Mexico, Venezuela, Bahrein, Iran, Iraq, Kuwait, Oman, Qatar, Saudi Arabia, United Arab Emirates, Algeria, Djibouti, Libya
- Countries with a comparatively large oil industry and/or bunkering facilities for international shipping: Jamaica, Singapore, Lebanon
- Countries with missing data: Malawi, Mali, Mauretania, Namibia, Swaziland, Zimbabwe

The period of analysis is divided into the following sub-periods. First, 1973-1979 represents the period after the first oil crisis in late 1973. In several Western countries, the OPEC I crisis triggered a political process with the aim to reduce oil dependency. The second period is 1979-1991, starting with the second oil crisis and ending with the emergence of climate policy as indicated by the United Nations Framework Convention on Climate Change (UNFCCC) in 1992. The final period therefore includes the era of climate policy, and ends with the latest update (2004) of the Maddison dataset.

Table 1 exhibits descriptive statistics for CO_2 emissions in order to provide a first picture of the base year oil intensities of the Western economies under consideration. Accordingly, the average share of CO_2 emissions from oil combustion in GDP decreased significantly from 1973 to 1991. This brought together the fact that the maximum level of oil intensity among the countries also decreased in time, although it belonged to Canada in all the three years reported. The variation among the countries with respect to oil intensity also decreased as shown by their standard deviation and coefficients of variation below.

Table 2. Summary statistics using the observations from the Western country sample

Variable	Mean	Median	Minimum	Maximum
OILINT1973	0.14	0.14	0.07	0.21
OILINT1979	0.12	0.12	0.07	0.17
OILINT1991	0.08	0.07	0.06	0.11
Variable	Std. Dev.	C.V.	Skewness	Ex. kurtosis
OILINT1973	0.04	0.28	0.01	-1.13
OILINT1979	0.03	0.25	0.11	-1.15
OILINT1991	0.01	0.18	0.67	-0.32

4. Results

The model described above is estimated using a simple Ordinary Least Squares (OLS) approach. Since cross-sectional data may suffer from the problem of heteroskedasticity, the standard errors in our models are corrected for this problem to arrive at robust errors. All the results are displayed in Table 2.

Table 2. Convergence in CO_2 emissions (from oil) intensity for sub-samples

	1973-1979		1979-1991		1991-2004	
	(1a) West	(1b) Global	(2a) West	(2b) Global	(3a) West	(3b) Global
	COILINT7379	COILINT7379	COILINT7991	COILINT7991	COILINT9104	COILINT9104
OILINT_base	-0.89**	-1.86*	-0.82***	-0.23***	-0.45	3.10
	(-2.43)	(-1.84)	(-6.95)	(-3.41)	(-0.16)	(0.90)
SOLIDINT_base	-0.41	0.56	0.05	0.02	-1.01	-0.15
	(-1.40)	(1.30)	(0.34)	(0.84)	(-1.27)	(-0.16)
CSOLINT	0.02	-0.06	0.00005***	0.000008	0.05	0.05**
	(0.71)	(-1.30)	(2.95)	(0.39)	(0.49)	(2.25)
GDPC_base	-0.19**	0.02	-0.008	-0.01*	-0.20	-0.22*
	(-2.79)	(0.05)	(-0.53)	(-1.75)	(-1.56)	(-1.90)
CGDPC	-0.01	-0.39*	-0.003	-0.08***	0.07	-0.89**
	(-0.04)	(-1.82)	(-0.07)	(-2.86)	(0.33)	(-2.04)
_cons	1.82**	0.08	-0.87***	-0.89***	1.83	1.90**
	(2.71)	(0.24)	(-5.56)	(-17.49)	(1.46)	(2.09)
N	22	86	22	85	22	86
="* p<0.10	** p<0.05	*** p<0.01				
Adjusted R-squared	0.56	0.15	0.78	0.30	0.05	0.18

Note: t statistics in parentheses. Heteroskedasticity-robust standard errors.

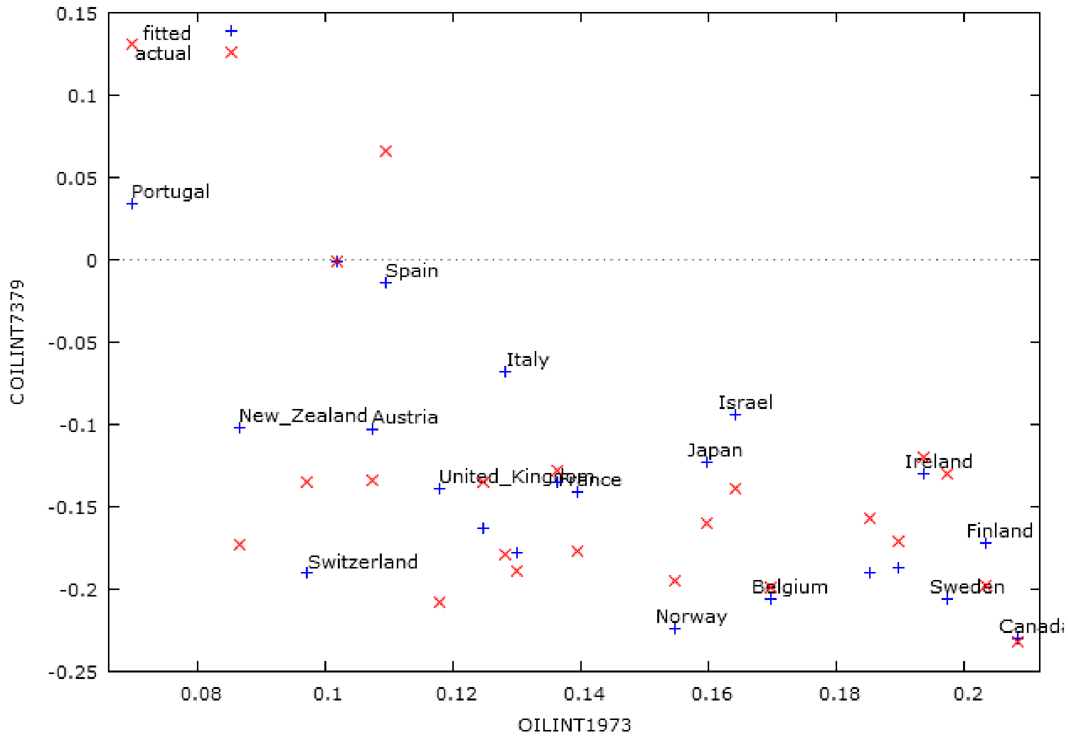
The period 1973-1979

As shown by Model (1a) in Table 2, there is evidence for oil intensity convergence among the Western economies in the period 1973-1979. Higher oil intensity led to a large reduction of the oil intensity implying, as expected, that the transformation pressure increased with intensity. This confirms the hypothesis of convergence in terms of emissions from oil combustion. There is also evidence indicating that higher GDP per capita in 1973 led to a reduction of the change in oil intensity over the period. Growth rate of GDP per capita instead of its level has a similar effect for the global sample. Model (1b) also provides evidence for carbon convergence in the global sample, not as strong as in the Western countries though.

None of the other variables appear to be significant, showing that neither the initial dependency on coal nor the changes in coal intensity were influential for oil intensity changes. The R-squared is fairly high, but still shows that roughly 44 percent of the variations remain unexplained. This demonstrates a comparatively high degree of national energy policy discretion, in other words, responses that can potentially be attributed to country specific policy, business life and consumer responses.

The OECD countries with the largest reductions of oil intensity include Canada, Switzerland, Norway and Belgium, which are shown in Figure 1. The countries experiencing the highest transformation pressure, given GDP per capita and oil intensity in 1973, include Canada, Sweden, Ireland and Finland. Among these countries especially Sweden and Canada underwent substantial decreases in their oil intensity, while it was still on the same scale as the previously mentioned countries. It is worth to notice that Finland benefited from favorable bilateral agreements with the USSR concerning manufactured goods for cheap oil during this period, which may explain a less pronounced decrease of her oil intensity, despite the high transformation pressure.

Figure 1. Oil intensity in 1973 versus changes in oil intensity during 1973-1979



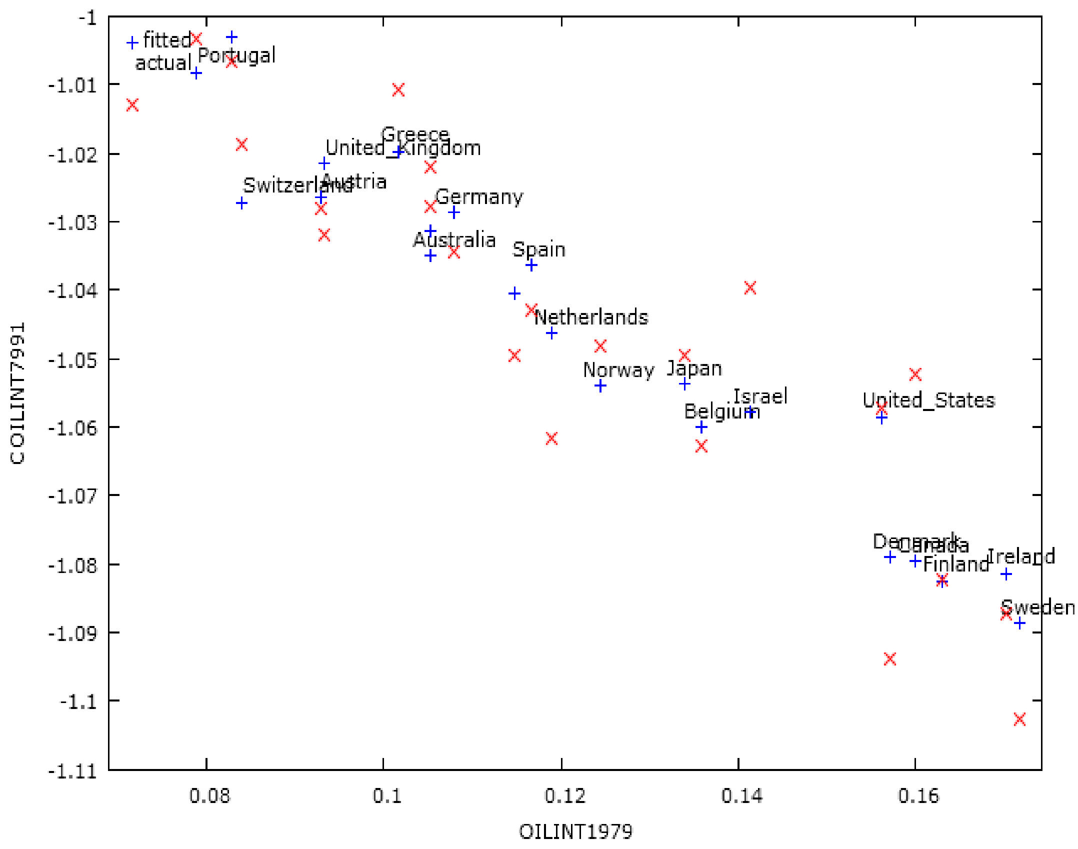
The period 1979-1991

The second oil crisis in 1979 probably constituted a higher transformation pressure, as compared to OPEC I. Not only did oil prices rise even higher, but the geo-political events, including the Iranian revolution, the conflict between Iran and the U.S.A, the Iraq-Iran War and the U.S.S.R invasion of Afghanistan, probably led to an even more severe situation from the point of view of Western national security.

It is therefore not surprising to learn that Model (2a) shows even stronger evidence for oil intensity convergence during the period 1979-1991 as compared to the period 1973-1979. The coefficient for base year oil intensity is weaker, but significant at an even higher level. The only control variable that is significant is the base year *CSOLINT* (1979), while GDP per capita is not significant during this period. the positive correlation btw CSOLINT and COILINT means that a change in coal intensity necessitates same-directional change in oil intensity. This means that coal was, generally speaking, not substituting for oil.

The overall explanatory power of the model is also considerably higher than the previous model, with only 22 percent of the variation being attributed to country specific characteristics. The cross plot in Figure 2 also reveals that Sweden, Ireland, Finland, Denmark and Canada experienced the highest transformation pressure and that their high level of response was in accordance with the international pattern of responses, given the exceptionally high transformation pressure. This implies that we can expect a combination of strong political and economic responses to the second oil crisis in these countries. It is, however, unlikely that they managed to develop responses that implied major technological breakthroughs, or fundamentally changed economic structures, simply because they are still on the regression line.

Figure 2. Oil intensity in 1979 versus changes in oil intensity during 1979-1991

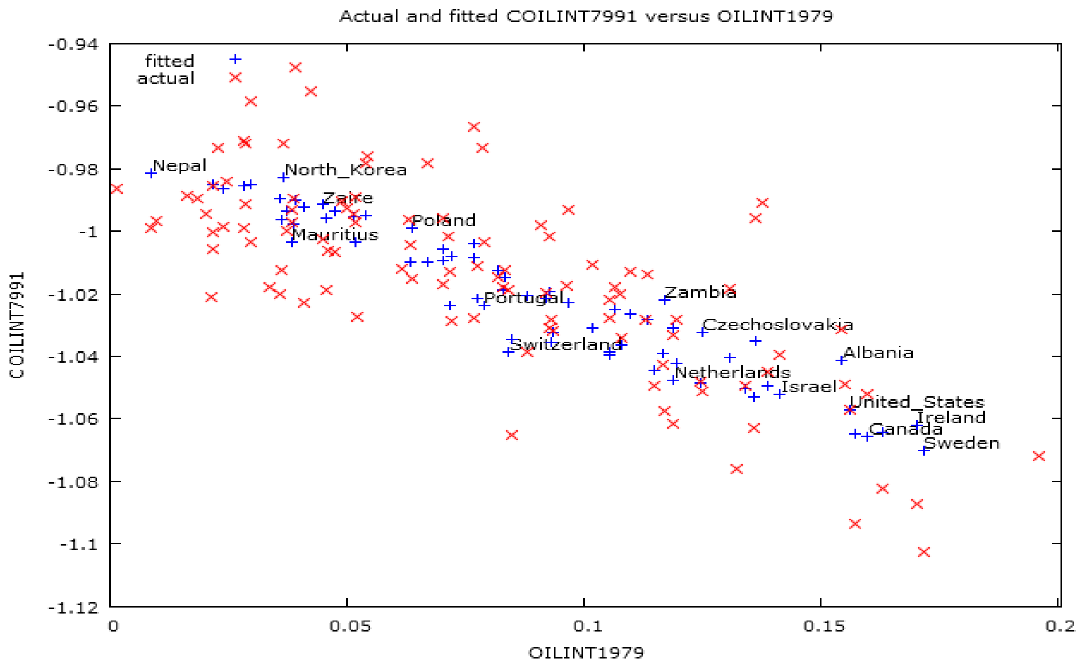


Turning to the global sample, there is again evidence for convergence during the period 1979-1991, as seen from Model (2b). Again, we notice that the oil intensity in 1979 is significant, while the elasticity is lower than for the Western countries. We can therefore conclude that the Western countries reacted more sharply to the second oil crisis than other non-oil producing, non-COMECON associated countries. Besides, the base year per capita income level (*GDPC*) and the changes in it (*CGDPC*) are significant and negative in this model, showing that a higher income level and growth tended to increase the transformation pressure or was affecting the capacity to lower the oil intensity.

The R-square is also much lower than for the Western sample, suggesting that approximately 70 percent of the variation can be attributed to country specific responses.

In the global sample, we also find the Western world countries among the most oil intensive; again with Sweden, Ireland, Finland, Denmark and Canada experiencing the highest transformation pressure (see Figure 3). The sample certainly includes countries with vastly different institutional capacity to mobilize their resources such as political power to implement various oil intensity reducing strategies. The general uniform response and convergence therefore shows that purely market forces, reducing the relative demand for oil, were important in all the investigated countries.

Figure 3. Oil intensity in 1979 versus changes in oil intensity during 1979-1991 (global sample)



The period 1991-2004

For the last period, no variables are found to be significant in the Western sample, showing no evidence for oil intensity convergence (see Model (3a)). The only general conclusion is that most countries continued to decrease their oil intensity, while this happened independently of the previous type of transformation pressure given by base year intensities or any other factors investigated here. Neither does the world sample reveal any evidence for oil convergence during the period 1991-2004 (see Model (3b)). Some of the control variables are, however, significant in the case of the global sample, while the overall explanatory power of the model is weak. This means that the 1990s clearly marked a structurally different era as compared to the 1970s and 1980s and that the lack of systematic patterns is the remaining mystery of this period. We therefore expect that the degree of national discretion was much higher in this period, even though it marked the beginning of coordinated international efforts to reduce carbon emissions. This may be understood in terms of the difficulties in negotiating an internationally uniform transformation pressure. This situation stands in contrast to the previous periods with an externally created transformation as seen from the perspective of the West.

5. Conclusions

This study is an attempt to shed light on the dynamics of (CO_2) emissions caused by oil combustion in three recent sub-periods within 1973-2004. Needless to say, emissions are released based on the type of resource endowments as well as the production technology a country is dependent on. Owing to the fact that oil and other fuels such as coal have different technologies and that they have been used as substitutes in different times, we believe that such a distinction is between energy resources deserves attention.

A cross-section of 86 countries and a developed country sample from the OECD have been examined in search of β-convergence in CO_2 emissions due to oil combustion as a share of GDP (emissions intensity) controlling for factors like combustion of solid fuels, GDP per capita and the period changes in these variables. The results reveal evidence in support of β-convergence for the sub-periods 1973-1979 and 1979-1991, whereas no evidence is found for convergence for the post-1991 period. These results are valid when both the restricted global sample and the sub-sample of western economies are considered.

The strong convergence with respect to oil during the periods 1973 to 1979 and during the period 1979 to 1991, combined with the lack of convergence with respect to coal related carbon emissions opens for a tentative discussion with relevance to cotemporary climate strategies. First, we notice that convergence occurred as a consequence of a high internationally uniform transformations pressure, which was experienced by net oil consuming market economies. This transformation pressure was, from the perspective of these countries, externally imposed upon them through the actions of e.g. OPEC. This stands in contrast to the present situation, where countries through negotiations attempt to create an internal transformation pressure. The lack of external forces obviously makes this a difficult task, which explains the lack of convergence, or weak convergence if other studies are considered. Also, the historical experience of oil convergence indicates convergence with respect to as to how oil is used in the economy, with respect to technology and economic structures. Here, we point at the possibility of an emerging Leontief technology, from a more diversified situation. The same seems, not to be true for coal, which also to some extent may have substituted for oil on a systemic level. One possible interpretation of the results is that international carbon taxes or permit trading schemes may first be introduced for oil only. As the burden sharing, due to the previous convergence, had been more uniform internationally speaking, as compared to an overall carbon tax which also includes non-converging coal, it would be easier to negotiate the institutional infrastructure for oil. With such an institutional framework in place, the next step would be to implement the tax for coal and other carbon sources.

Acknowledgement

Financial support for this research has been provided by the Swedish Energy Agency (STEM)

References

Abramovitz, M. (1986). “Catching Up, Forging Ahead, and Falling Behind,” *Journal of Economic History* 46, 386-406.

Aldy, J. E. (2006). Per capita carbon dioxide emissions: convergence or divergence? *Environmental and Resource Economics*, Vol. 33, pp. 533–555.

Barro, R. J., and Sala-i-Martin, X. (1992). Convergence. *Journal of Political Economy* 100(2): 223-251.

Boden, T.A., G. Marland, and R.J. Andres. (2013). *Global, Regional, and National Fossil-Fuel CO_2 Emissions*. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A.

Brännlund, R., Karimu, A., Söderhplm, P. (2014). *Convergence in carbon dioxide emissions and the role of growth and institutions. A parametric and nonparametric analysis*. CERE Papers

Brock, W. A., and Taylor, M. S. (2005). Economic growth and the environment: a review of theory and empirics, In Aghion, P., and Durlauf, S. N. (Eds.), *Handbook of Economic Growth,* Elsevier, pp. 1750–1821.

Brock, W. A., and Taylor, M. S. (2010). The green Solow model. *Journal of Economic Growth,* Vol. 15, pp. 127–153

Camarero, M., Picazo-Tadeo, A. J., and Tamarit, C. (2008). Is the environmental performance of industrialized countries converging? A 'SURE' approach to testing for convergence. *Ecological Economics*, Vol. 66, No. 4, pp. 653-661.

Camarero, M., Picazo-Tadeo, A. J., and Tamarit, C. (2013). Are the determinants of CO_2 emissions converging among OECD countries? *Economics Letters*, Vol. 118, No. 1, pp. 159-162.

Carlsnäs, W. (1988). *Energy Vulnerability and National Security,* Pinter Publishers, London

Ezcurra, R., (2007). Is there cross-country convergence in carbon dioxide emissions? *Energy Policy*, Vol. 35, pp. 1363-1372.

Georgescu-Roegen, N. (1971). *The Entropy Law and the Economic Process* (1971). Harvard University Press: Cambridge, Massachusetts

Herrerias, M.J. (2013). The Environmental Convergence Hypothesis: CO2 Emissions according to source of energy, *Energy Policy,* 61, pp. 1140–1150

Kahn, H., (1979). *World economic development*. Westview Press, Boulder Colorado.

Kriström, B. (2000). Growth, employment and the environment. *Swedish Economic Policy Review* 7, pp. 155–184.

Nguyen-Van, P. (2005). Distribution dynamics of CO_2 emissions. *Environmental and Resource Economics*, Vol. 32, No. 4, pp. 495-508

Maddison A (2007). *Contours of the World Economy I-2030AD*, Oxford University Press. The Maddison-Project, http://www.ggdc.net/maddison/maddison-project/home.htm, 2013 version

Olson, M. (1982). *The Rise and Decline of Nations: Economic Growth, Stagflation, and Social Rigidities,* Yale University Press.

Panayotou, T. (1993). *Empirical tests and policy analysis of environmental degradation at different stages of economic development*, Working paper WP238, Technology and Employment Programme, International Labour Office, Geneva.

Panopoulou, E. and Pantelidis, T. (2009). Club convergence in carbon dioxide emissions. *Environmental and Resource Economics*, Vol. 44, No. 1, pp. 47-70.

Pettersson, F., Maddison, D., Acar, S., and Söderholm, P. 2014. Convergence of Carbon Dioxide Emissions: A Review of the Literature, *International Review of Environmental and Resource Economics*, 7(2), 141-178.

Solow, R. M.(1956). Technical change and the aggregate production function, *Review of Economics and Statistics*, vol. 39, 312-320

Strazicich, M. C., and List, J.A. (2003). Are CO_2 emission levels converging among industrial countries? *Environmental and Resource Economics,* Vol. 24, No 3, pp. 263-271.

Warde, P. (2007). *Energy Consumption in England and Wales 1560-2000*, Consiglio Nazionale delle Ricerche, ISSM

Westerlund, J., Basher, S.A. (2008). Testing for convergence in carbon dioxide emissions using a century of panel data, *Environmental & Resource Economics* 40(1):109-120

APPENDIX

Western sample:

Model 1a: OLS, using observations 1-22
Dependent variable: COILINT7379
Heteroskedasticity-robust standard errors, variant HC1

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	1.81536	0.669915	2.7098	0.01546	**
OILINT1973	-0.889025	0.365194	-2.4344	0.02700	**
SOLIDINT1973	-0.414654	0.296376	-1.3991	0.18088	
CSOLINT7379	0.0244391	0.033999	0.7188	0.48262	
l_GDPC1973	-0.192196	0.0688482	-2.7916	0.01307	**
CGDPC7379	-0.0130161	0.328078	-0.0397	0.96884	

Mean dependent var	-0.134969	S.D. dependent var	0.088960
Sum squared resid	0.055733	S.E. of regression	0.059020
R-squared	0.664641	Adjusted R-squared	0.559842
F(5, 16)	3.234963	P-value(F)	0.033051
Log-likelihood	34.54377	Akaike criterion	-57.08753
Schwarz criterion	-50.54128	Hannan-Quinn	-55.54543

Model 2a: OLS, using observations 1-22
Dependent variable: COILINT7991
Heteroskedasticity-robust standard errors, variant HC1

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	-0.870192	0.15638	-5.5646	0.00004	***
OILINT1979	-0.816234	0.117362	-6.9549	<0.00001	***
SOLIDINT1979	0.0486836	0.0492351	0.9888	0.33748	
CSOL7991	5.47519e-05	1.8531e-05	2.9546	0.00932	***
l_GDPC1979	-0.00834665	0.0157651	-0.5294	0.60377	
CGDPC7991	-0.00307557	0.0448752	-0.0685	0.94621	

Mean dependent var	-1.046363	S.D. dependent var	0.027404
Sum squared resid	0.002601	S.E. of regression	0.012749
R-squared	0.835088	Adjusted R-squared	0.783553
F(5, 16)	26.06039	P-value(F)	3.71e-07
Log-likelihood	68.25667	Akaike criterion	-124.5133
Schwarz criterion	-117.9671	Hannan-Quinn	-122.9712

Model 3a: OLS, using observations 1-22
Dependent variable: COILINT9104
Heteroskedasticity-robust standard errors, variant HC1

	Coefficient	*Std. Error*	*t-ratio*	*p-value*
const	1.82661	1.24715	1.4646	0.16240
OILINT1991	-0.450278	2.76597	-0.1628	0.87272
SOLIDINT1991	-1.01023	0.79757	-1.2666	0.22342
CSOL9104	0.0508151	0.103907	0.4890	0.63145
l_GDPC1991	-0.199164	0.12793	-1.5568	0.13907
CGDPC9104	0.0673172	0.201765	0.3336	0.74298

Mean dependent var	-0.184347	S.D. dependent var	0.122119
Sum squared resid	0.226117	S.E. of regression	0.118879
R-squared	0.277987	Adjusted R-squared	0.052358
F(5, 16)	1.406613	P-value(F)	0.274421
Log-likelihood	19.13855	Akaike criterion	-26.27710
Schwarz criterion	-19.73085	Hannan-Quinn	-24.73500

Global sample:

Model 1b: OLS, using observations 1-140 (n = 86)
Missing or incomplete observations dropped: 54
Dependent variable: COILINT7379

Heteroskedasticity-robust standard errors, variant HC1

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	0.0836318	0.34545	0.2421	0.80933	
OILINT1973	-1.85644	1.00713	-1.8433	0.06899	*
SOLIDINT1973	0.555674	0.426473	1.3030	0.19633	
CSOLINT7379	-0.0579737	0.0446232	-1.2992	0.19761	
l_GDPC1973	0.0224772	0.0525494	0.4277	0.66999	
CGDPC7379	-0.391797	0.214814	-1.8239	0.07190	*

Mean dependent var	0.055682	S.D. dependent var	0.367593
Sum squared resid	9.178715	S.E. of regression	0.338724
R-squared	0.200849	Adjusted R-squared	0.150902
F(5, 80)	2.504454	P-value(F)	0.036935
Log-likelihood	-25.81793	Akaike criterion	63.63586
Schwarz criterion	78.36194	Hannan-Quinn	69.56243

Model 2b: OLS, using observations 1-140 (n = 85)
Missing or incomplete observations dropped: 55
Dependent variable: COILINT7991
Heteroskedasticity-robust standard errors, variant HC1

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	-0.891928	0.0509985	-17.4893	<0.00001	***
OILINT1979	-0.23196	0.06811	-3.4057	0.00104	***
SOLIDINT1979	0.0241781	0.028759	0.8407	0.40305	
CSOL7991	8.32095e-06	2.14913e-05	0.3872	0.69967	
l_GDPC1979	-0.0105041	0.00600679	-1.7487	0.08423	*
CGDPC7991	-0.0762871	0.0267012	-2.8571	0.00546	***

Mean dependent var	-1.012163	S.D. dependent var	0.059879
Sum squared resid	0.197395	S.E. of regression	0.049987
R-squared	0.344597	Adjusted R-squared	0.303116
F(5, 79)	18.70329	P-value(F)	3.22e-12
Log-likelihood	137.1611	Akaike criterion	-262.3222
Schwarz criterion	-247.6663	Hannan-Quinn	-256.4272

Model 3b: OLS, using observations 1-140 (n = 86)
Missing or incomplete observations dropped: 54
Dependent variable: COILINT9104

Heteroskedasticity-robust standard errors, variant HC1

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	1.90638	0.910678	2.0934	0.03948	**
OILINT1991	3.10016	3.44792	0.8991	0.37128	
SOLIDINT1991	-0.146934	0.924658	-0.1589	0.87414	
CSOL9104	0.0517944	0.023033	2.2487	0.02728	**
l_GDPC1991	-0.216111	0.113492	-1.9042	0.06048	*
CGDPC9104	-0.894417	0.437895	-2.0425	0.04439	**

Mean dependent var	0.219083	S.D. dependent var	1.505439
Sum squared resid	147.9884	S.E. of regression	1.360094
R-squared	0.231785	Adjusted R-squared	0.183772
F(5, 80)	2.988380	P-value(F)	0.015927
Log-likelihood	-145.3685	Akaike criterion	302.7371
Schwarz criterion	317.4631	Hannan-Quinn	308.6636