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Internal Validity of Estimating the Carbon Kuznets Curve by Controlling for Energy Use

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Abstract

The carbon Kuznetz curve (CKC) hypothesis assumes that carbon dioxide emissions initially increase in tandem with output but start decreasing at higher levels of output. This paper considers the internal validity of estimating the CKC in an integrated framework of carbon dioxide emissions, energy consumption, and output, as done in recent literature. We argue that, first, the research question and the feasible conclusions differ from the standard CKC-framework. Second, the estimates are biased to overstate the compatibility of development and environmental policy goals. In a more realistic model carbon dioxide emissions rise quicker, peak later, and decrease slower as output increases.

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Keywords: Energy consumption, carbon dioxide emissions, environmental Kuznets curve.

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1. Introduction

As concerns for climate change and the need for global mitigation action have gained more awareness, also the long-standing debate on the environmental Kuznets curve (EKC) has received novel attention. The EKC depicts a relationship between emissions and output: at low levels of economic development growth increases emissions, but at higher levels of output the relationship is reversed. Graphically this implies an “inverted U” shape for the function of output to emissions (see Figure 1). When the focus is particularly on carbon dioxide emissions, the relationship is referred to as the carbon Kuznets curve (CKC).

The CKC-hypothesis has substantial relevance to development and climate change mitigation policies. Under the CKC-hypothesis, economic growth would ultimately contribute to the reduction of emissions, implying synergy between development and mitigation policy goals. Typically the alternative is to assume that emissions grow as output grows. This would imply a conflict between development and mitigation goals.

Over the last few decades the EKC-hypothesis has generated an enormous amount of literature. A recent strand of literature has attempted to merge the CKC literature (emissions-output-nexus) with a related topic concerning the relationship between energy consumption and output (energy-output-nexus)(See Figure 2). In a precursory study, Richmond and Kaufmann (2006) attempt to estimate the tipping point of the CKC with various model specifications. Some of these model specifications use the consumption shares of different fuel types to explain carbon dioxide emissions levels. The seminal work by Ang (2007) examines the relationship between emissions, energy

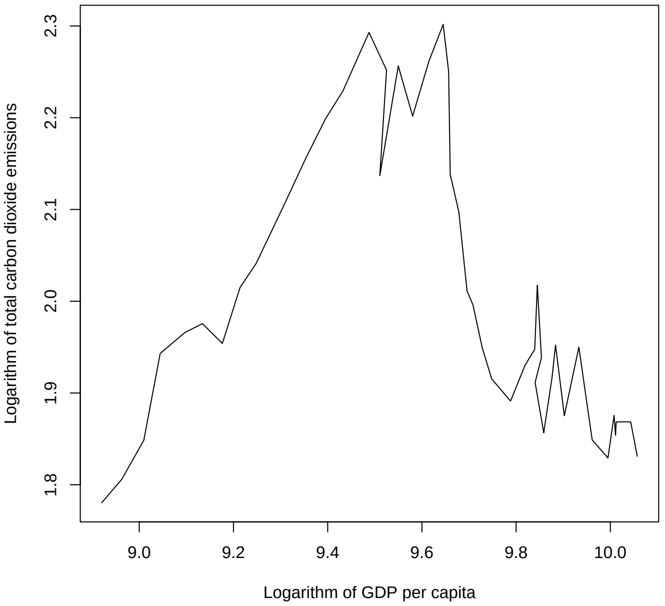

Figure 1: Relationship between the logarithm of per capita CO_2 emissions per capita and the logarithm of per capita GDP in France, 1960-2006.

consumption, and output in France using cointegration methods and a vector error correction model. Total energy consumption is included as an explanatory variable to tackle omitted variable bias. Apergis and Payne (2009, 2010) extend and apply this method for panel data on South American countries and for the countries of the Commonwealth of Independent States. Soytas et al. (2007) use emissions, energy consumption, and output among others variables in a vector autoregression model for the United States. Soytas and Sari (2009) apply a similar method for Turkey. Jalil and Mahmud (2009) use an autoregressive distributed lag model for data on China and also add foreign trade as an additional explanatory variable.

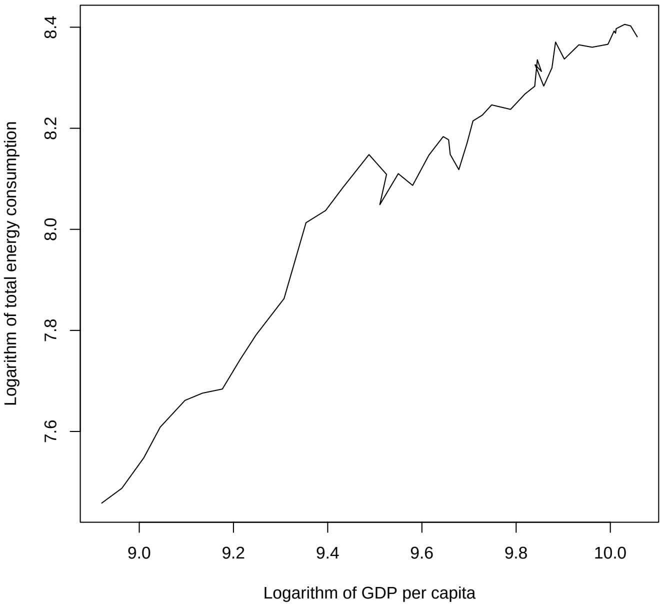

Figure 2: Relationship between the logarithm of total energy consumption per capita and the logarithm of per capita GDP in France, 1960-2006.

The aforementioned articles only briefly comment the rationale for including energy consumption as a explanatory variable. Most argue that it helps to tackle with omitted variable bias, but this notion is left without any justification or discussion.

Nevertheless, this is not a trivial matter. The inclusion of energy consumption as an explanatory variable for carbon dioxide emissions causes a significant problem for the interpretation and estimation of the model, undermining the internal validity of these studies. First, an essential claim of the CKC-hypothesis is that, as output grows, the growth of energy use is compensated by a shift to cleaner fuel sources. When total energy consumption is included as a regressor, the focus of the study is bounded to changes in the fuel mix. The other route of causality, emission growth through growth in energy use, is disregarded. Second, emissions are not measured directly in data sets that are used by the referred articles. Carbon dioxide emissions are defined by a linear function of different fuel commodities. The amount of emissions that each fuel commodity causes is determined by its chemical composition. Because total energy use, an explanatory variable, is also a linear combination of different fuel commodities, there is a possibility for endogeneity when output also affects energy use. This interlink can cause bias in the estimates.

In this paper we discuss the problems related to the new approach by focusing on the seminal work by Ang (2007). Apergis and Payne (2009, 2010) use a very similar methodology. Richmond and Kaufmann (2006) could face different complications as they explain emissions with fuel proportions, not total energy use. Soytas et al. (2007) and Soytas and Sari (2009) use a time series technique known as the Toda-Yamamoto procedure, which does not explicate a long run model, as do vector error correction models. As the problems manifest in different ways, we restrict our analysis to the first-mentioned case. We aim to clarify, in the context of Ang's model, how the problems arise. To do this, we study the model analytically and use the framework introduced by Simon and Rescher (1966) to assess rigorously the causal relationships between the variables.

In the next section we shortly describe the data sources used in the literature and discuss the statistical methodology to specify the locus of the problem. In the third section we describe how the CKC-hypothesis consists of declining carbon intensity and increasing energy use, and how they relate to the misspecification in Ang (2007). In the fourth section we conclude.

2. The data and methodology

It is important to take into account how the carbon dioxide emissions data is produced in the data sets that are used in the literature. Ang (2007), Apergis and Payne (2009, 2010), Soytas et al. (2007), Soytas and Sari (2009), and Jalil and Mahmud (2009) use data from the World Bank's World Development Indicators (WDI) data set, which in turn uses carbon dioxide emission data calculated by the U.S. Department of Energy's Carbon Dioxide Information Analysis Center (CDIAC) (Boden et al., 2009). In the CDIAC data set carbon dioxide emissions are calculated from consumed quantities of different fuel commodities and cement manufacturing. The CDIAC data set uses energy statistics by the United Nations Statistics Division (UNSD).[1]

The WDI data set uses energy statistics compiled by the International Energy Agency (IEA). Richmond and Kaufmann (2006) use data compiled by the IEA on energy use, and calculates the carbon dioxide emissions by multiplying fuel use by the appropriate carbon content factor.

Essentially this means that there are no actual measurements of carbon dioxide emissions. They are simply calculated from energy statistics. In the next section we specify the calculation formula in relation to the model.

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[1] UNSD data is used for the time period analyzed in this paper.

Next we present the model introduced by Ang (2007). The CKC-hypothesis is examined using cointegration and vector error correction (VECM) modelling techniques, applied to data on France between 1960 and 2000. The time series on emissions, energy use, and output are assumed to include a stochastic trend, therefore most traditional time series methods are not applicable.

A long run relationship between the time series can exist if the stochastic trend is common to all the variables. A common stochastic trend implies that that there is a linear combination of the time series such that the combination is stationary. In which case, the time series are said to be cointegrated.

This relationship is specified by Ang (2007) as a long run steady-state model, such that

$$\ln c_t = \beta_0 + \beta_1 \ln e_t + \beta_2 \ln y_t + \beta_3 (\ln y_t)^2 + u_t, \tag{1}$$

where c_t is carbon dioxide emissions, e_t is total energy use, y_t is real GDP measured in local currency, all measured in per capita terms, and u_t is a stationary error term.

As in a typical CKC-model, the square of output is included to capture the nonlinearity in the CKC. The CKC-hypothesis implies that parameter β_2 is positive and β_3 is negative to form an upside-down parabola. The novel feature is the included regressor $\ln e_t$.

In addition to the long run model, Ang (2007) studies the dynamic causal relationship between the time series by specifying a vector error correction model that incorporates model (1). The VECM describes how the variables vary around the steady-state model.

In this paper our focus is strictly on the long run model, which however is also the basis for short run variations.

3. The misspecification

3.1. Recognizing the definitions

Next we examine the problems caused by the definition of emissions in the model introduced by Ang (2007). We begin by introducing the conceptualization in the literature and the definitions that need attention. In the subsequent sections we analyze the problems that arise from this setting.

To explore this problem rigorously, we use the framework introduced by Simon and Rescher (1966).[2] Ang's (2007) model specification can be represented as a *self-contained structure.* The structure is a set of equations consisting of model equation (1) and equations determining the value of the exogenous variables e_t, y_t, and u_t. The structure is self-contained when the number of equations equals the number of variables. The ordering of solving this structure determines the causal relationships between the variables. In this simple case, it seems that the dependent variable is the carbon emissions level c_t. This can be depicted by a diagram:

$$\begin{tikzcd}
e_t \arrow[dr] & \\
y_t \arrow[r] & c_t \\
u_t \arrow[ur] &
\end{tikzcd},$$

where the arrows indicate the direction of causality. The diagram simply

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[2] This proves to be extremely convenient in the more complex cases to follow.

expresses that carbon dioxide emissions c_t are jointly caused by energy use e_t, output y_t, and omitted variables captured by the error term u_t.

In model (1), a naive interpretation of the partial marginal effect of y_t on c_t,

$$\frac{\partial \ln c_t}{\partial \ln y_t} = \beta_2 + 2\beta_3 \ln y_t, \tag{2}$$

would be that it quantifies the causal relationship between emissions and output.[3] However, this interpretation does not take into account that, for the most part, carbon dioxide emissions are calculated from energy use.[4] The conceptual relationship between emissions and energy use is made evident by the following two identities.

First, the data set in use defines carbon dioxide emissions as a linear function of fossil fuel combustion and cement manufacturing. The amount of carbon dioxide emissions caused by combustion is determined by the chemical composition of the fuel. The emitted amount of carbon dioxide can be calculated by multiplying the amount of fuel usage by a constant factor prescribed by the chemical properties of the fuel. Thus, the total carbon dioxide emissions c_t is a linear combination of the usage of oil e_t^{oil}, solid fuels e_t^{solid}, natural gas e_t^{gas}, and gas flaring e_t^{flare}, in addition to emissions from cement manufacturing s_t, that is

$$c_t \equiv \alpha_{oil} e_t^{oil} + \alpha_{solid} e_t^{solid} + \alpha_{gas} e_t^{gas} + \alpha_{flare} e_t^{flare} + s_t, \tag{3}$$

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[3] To be exact, this is of course an expected conditional partial derivative, but to ease notation, we do most of the analysis as if it was a deterministic model.

[4] With the given definition, approximately 99% of emissions in France are produced by energy use.

where α_{oil}, α_{solid}, α_{gas}, $\alpha_{flare} > 0$ are the related ratios of emissions to fuel quantity. (See Boden et al., 2009)

Gas flaring and cement manufacturing amount only to a percent of total carbon emissions in the data, so they will be omitted in some of the following analyses.

Second, total energy use e_t can be defined as the sum of usage oil e_t^{oil}, solid fuels e_t^{solid}, natural gas e_t^{gas}, and other energy sources e_t^{other}, such as nuclear energy and renewable fuels, which do not cause emissions in the aforementioned sense. Gas flaring does result in energy production. Therefore

$$e_t \equiv e_t^{oil} + e_t^{solid} + e_t^{gas} + e_t^{other}. \tag{4}$$

To clarify the notation we define two sets of variable: the set of energy commodities affecting carbon dioxide emissions, $C = \{oil, solid, gas, flare\}$, and the set of energy commodities that amount to total energy use, $E = \{oil, solid, gas, other\}$.

Recognizing the dependencies in identities (3) and (4) has serious implications on the interpretation of the marginal effect (2). To see this, first let's define the the proportion of fuel commodity in terms of total energy use,

$$q_t^i \equiv \frac{e_t^i}{e_t},$$

where $q_t^i \geq 0$ for all $i \in E$ and $\sum_{i \in E} q_t^i = 1$ for any t. By rearranging and plugging this into identity (3) to eliminate e_t^i for all i, we get

$$c_t \equiv e_t \sum_{i \in C \cap E} q_t^i \alpha_i + \alpha_{flare} e_t^{flare} + s_t$$

By interpreting the sum term as the average emissions rate of energy consumption, we can identify it as *carbon intensity*[5] and denoted it by a_t, so that

$$c_t \equiv e_t a_t + \alpha_{flare} e_t^{flare} + s_t. \tag{5}$$

Since the partial derivative (2) requires that total energy use e_t is held constant, we notice that, in this case, the level of carbon dioxide emissions c_t can only change through changes in carbon intensity a_t, gas flaring emissions e_t^{flare}, and cement manufacturing emissions s_t.

With these definitions we can express two problems that arise from model specification (1). First, we study the problem of declining carbon intensity of fuel consumption, and in the subsequent section we analyze the bias caused by an endogeneity problem.

3.2. Carbon intensity

It can be shown that the marginal effect (2) has a much more narrow interpretation than implied. The marginal effect (2) can be interpreted only as the causal effect of output y_t on emissions c_t through carbon intensity a_t. This ignores the effect of y_t on c_t through energy use e_t. As a result, the model is actually a regression analysis of carbon intensity.

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[5] Note that here carbon intensity refers to the ratio of carbon emissions to energy consumption. This is not to be confused with carbon intensity of output which is the ratio of carbon emissions to output.

To show this, we form a set of equations consisting of equations

$$\begin{aligned}\ln c_t &= \beta_0 + \beta_1 \ln e_t + \beta_2 \ln y_t + \beta_3 (\ln y_t)^2 + u_t, \\ c_t &= e_t a_t + \alpha_{flare} e_t^{flare} + s_t,\end{aligned}$$

and equations determining the value of the exogenous variables e_t, y_t, and u_t, which compose a self-contained structure, when we hold e_t^{flare} and s_t constant. Solving the set of equations reveals the causal relationships between the variables, which can be depicted as

$$\begin{tikzcd}
e_t \arrow[dr] \arrow[drr] & & \\
y_t \arrow[r] & c_t \arrow[r] & a_t \\
u_t \arrow[ur] & &
\end{tikzcd}.$$

Regarding the whole structure, carbon intensity a_t is the ultimate dependent variable. In other words, if a change in output y_t causes a change in emissions c_t, this means that carbon intensity a_t must have changed.

A more explicit regression equation can be formulated when the negligible effects of gas flaring and cement manufacturing are ignored. Now identity (5) is simplified to $c_t = a_t e_t$. This can be applied into equation (1) to eliminate c_t. Rearranging gives the equation

$$\ln a_t = \beta_0 + (\beta_1 - 1) \ln e_t + \beta_2 \ln y_t + \beta_3 (\ln y_t)^2 + u_t. \tag{6}$$

By supplementing this with equations determining the exogenous variables e_t, y_t, and u_t, we have a self-contained structure, which can be depicted by a diagram:

$$\begin{tikzcd}
e_t \arrow[dr] & \\
y_t \arrow[r] & a_t \\
u_t \arrow[ur] &
\end{tikzcd}.$$

In this case, it is clear that the true dependent variable is a_t and that the model parameters in expression (2) describe the marginal effect on carbon intensity a_t, not on emissions c_t.

The problem can be also seen by comparing the marginal effect (2) and the derivative of identity (5). To simplify, assume gas flaring and cement manufacturing emissions are constants. Now partially derivating identity (5) with respect to y_t gives

$$\frac{\partial c_t}{\partial y_t} = e_t \frac{\partial a_t}{\partial y_t} + \frac{\partial e_t}{\partial y_t} a_t. \tag{7}$$

If emissions level e_t is held constant, as is required to calculate the marginal effect (2), the second term on the left hand side of (7) is omitted. This means that Ang (2007) only investigates the first term.

Variations in both carbon intensity and energy use are essential for the CKC. This can be seen from Figure 3. Here the development of carbon emissions in France (curve A) has been decomposed in to growth of energy consumption (B) and decline of carbon intensity(C).[6] This shows that without the growth of energy consumption emissions in 2006 would be 60% less compared to 1960. On the other hand, without the shift to cleaner fuels emissions would be 150% higher in 2006.

Carbon intensity a_t has decreased in France because of a decline in the

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[6] To be more specific, $A = \frac{c_t}{c_{1960}}$, $B = \frac{e_t}{e_{1960}}$, and $C = \frac{c_t}{c_{1960}} / \frac{e_t}{e_{1960}}$.

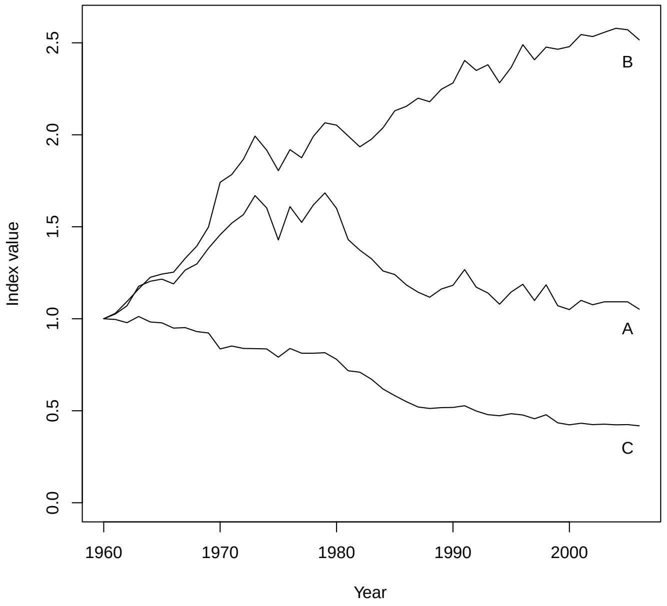

Figure 3: Curve A is the index of carbon emissions, B is a index energy consumption, and C is the carbon intensity. By definition $A = BC$.

share of heavily polluting fuels like coal and oil. They have been replaced or outgrown by the use of natural gas and nuclear energy. Especially in the case of France, is seems that nuclear energy has had a significant impact (See Iwata et al., 2010).

If the decline in carbon intensity is a result of economic growth, as the CKC-hypothesis implies, we should expect to see a negative relationship between carbon intensity and output. Figure 4 suggests such a relationship for France in the period 1960-2006.

It is noteworthy that the curve in Figure 4 does not seem like a parabola.

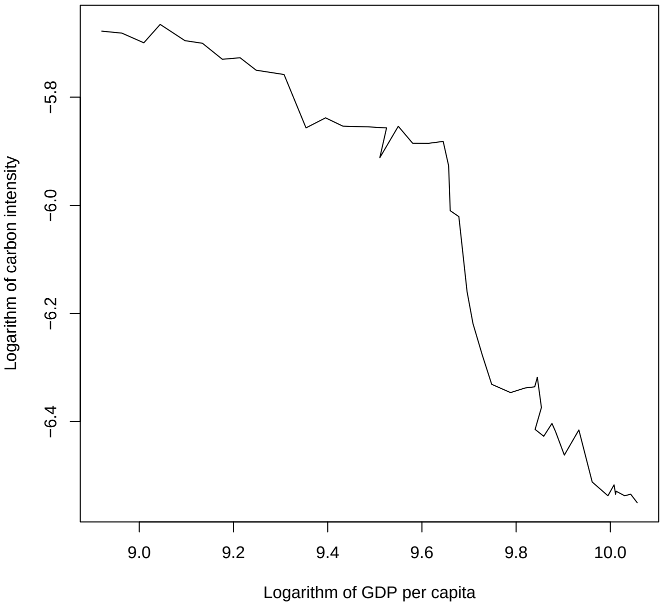

Figure 4: The logarithm of Carbon intensity of energy use, measured in kilograms of carbon dioxide emissions per kilogram of oil equivalent energy, and the logarithm of per capita GDP.

Suppose that model (1) only explains changes in carbon intensity a_t, as we claim, and that the model parameters are consistent with the CKC-hypothesis. Then a_t should rise at low output levels and decline when output is high, assuming energy use is fixed. However this does not seem to be the case in Figure 4.

The delusive fit of the parabola can be explained by inspecting the fitted model in Ang (2007). Ang reports the parameter estimates $\beta_0 = -161.38$, $\beta_1 = 2.25$, $\beta_2 = 31.11$, and $\beta_3 = -1.67$. By using these in model (1), rearranging, and taking the conditional expected value we get equation

$$\ln c_t + 161.38 - 2.25 \ln e_t = 31.11 \ln y_t - 1.67(\ln y_t)^2. \tag{8}$$

The left hand side of equation (8) is the part that is left for output to explain. Because β_3 is negative, the value of the right hand side as a function of $\ln y_t$ is an upside-down parabola. Suppose β_3 truly is negative, as Ang (2007) claims. Then, to satisfy equation (8), also the left hand side should be a parabola. The value of the left side term (interpreted as a time series) is plotted against time series $\ln y_t$ in Figure 5. It is easy to observe that Figure 5 (like Figure 4) gives no cause to assume a polynomial shape with a tipping point in the near past.

The misleading goodness of the fit of the "inverted U"-shaped curve found by Ang (2007) can be explained by observing, that most of the observations lie on the right hand side of the parabola.[7] However, this does not give reason to suspect the existence of a tipping point in the carbon intensity.

3.3. Energy use

The second problem is of endogeneity, rising because energy use e_t is dependent on output y_t. As a result, the estimate for the CKC is biased.

This can be shown in the framework of Simon and Rescher (1966) by first noting the three mechanisms dictated by the CKC-hypothesis and our knowledge of the definitions. These mechanisms describe how the variables relate to each other and allow us to construct a structure, to analyze the problem rigorously.

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[7] One could plot the parabola of right hand side of equation (8) in Figure 5, but probably due to strong sensitivity to the rounding of the parameter values, the curve fits very poorly.

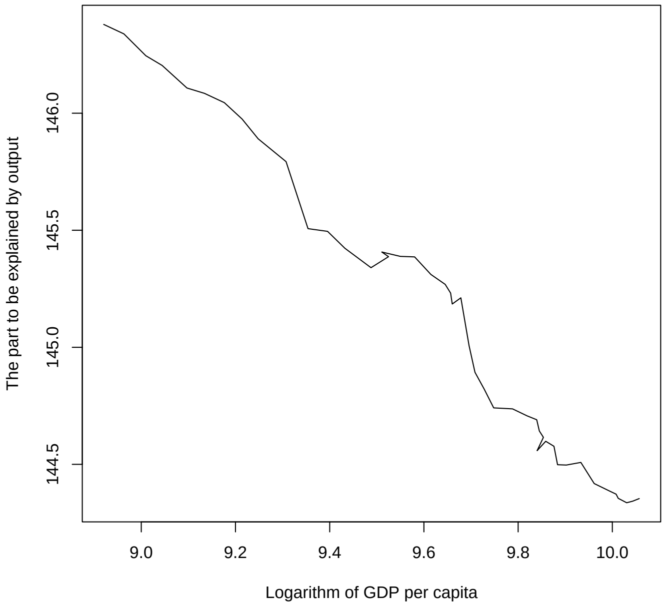

Figure 5: Relationship between the logarithm of per capita CO_2 emissions unexplained by energy use and per capita and the logarithm of per capita GDP.

First, we take into count the definition of carbon emissions in identity (5). To clarify the results, we omit emissions from gas flaring and cement manufacturing, and take a logarithm of the equation. This states that carbon emissions can be decomposed into carbon intensity a_t and energy use e_t.

Second, output y_t is a cause of carbon intensity a_t according to the CKC-hypothesis. This is also implied by Ang (2007) as shown in the previous section. Because we want to assess the bias in Ang's model, we assume that Ang correctly formulates the mechanism that defines carbon intensity a_t. In other words, we assume that equation (6) is satisfied.[8]

Third, we note that also energy use e_t depends on output y_t. This is essential to the CKC-hypothesis, nonetheless it is neglected in the strand of literature initiated by Ang (2007). Although this basic claim is fairly evident, the details are the subject of the immense energy-output-nexus literature. To capture this relationship, we simply assume that there is a differentiable and monotonically increasing function e for which $\ln e_t = e(\ln y_t)$.

These three notions form a set of equations, a self-contained structure,

$$\ln c_t = \ln a_t + \ln e_t \tag{9a}$$

$$\ln a_t = \beta_0 + (\beta_1 - 1)\ln e_t + \beta_2 \ln y_t + \beta_3 (\ln y_t)^2 + u_t \tag{9b}$$

$$\ln e_t = e(\ln y_t), \tag{9c}$$

when $\ln y_t$ and u_t, are set as exogenous variables. Now $\ln c_t$, $\ln a_t$, and $\ln e_t$ are clearly dependent variables. The structure can also be interpreted as a simultaneous equations model. In this context, we regard it as the unbiased model.

Note that we do not argue that this model is empirically valid in all respects. To the contrary, as we argued, carbon intensity is not a parabola. The model is constructed to compare with the faulty model in Ang (2007).

Also note that we could, for example, form the structure from equations (1), (5) and (9c), but this would alter the causal ordering. As Simon and Rescher (1966) show, this would be empirically indistinguishable from structure (9), even if it is theoretically invalid. We choose the structure (9), from a

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[8] Note that also equation (1) could be chosen but this would result in an unfounded causal ordering without affecting the bias.

set of empirically equivalent structures, because the resulting causal ordering that not unrealistic.

The causal ordering of the structure (9) can be depicted as a diagram

$$\begin{tikzcd}
y_t \arrow[r] \arrow[ddr] & e_t \arrow[dr] \arrow[dd] & \\
 & & c_t \\
u_t \arrow[r] & a_t \arrow[ur] &
\end{tikzcd}.$$

The reasoning in the diagram can also be expressed less formally. First, suppose y_t and u_t are determined by an external process, the economy for example. Now also e_t is determined by y_t through the mechanism e. When e_t, y_t, and u_t are known, using equation (9a), also a_t is determined. Now e_t and a_t are set, carbon emissions c_t is known by definition.

The magnitude of the marginal effect of output y_t on carbon emissions c_t in structure (9) can be assessed applying the implicit function rule to get the total derivative

$$\frac{\mathrm{d}\ln c_t}{\mathrm{d}\ln y_t} = -\frac{\begin{vmatrix} -(\beta_2 + 2\beta_3 \ln y_t) & 1 & 1-\beta_1 \\ 0 & -1 & -1 \\ -e' & 0 & 1 \end{vmatrix}}{\begin{vmatrix} 0 & 1 & 1-\beta_1 \\ 1 & -1 & -1 \\ 0 & 0 & 1 \end{vmatrix}},$$

where we denote $e' = \frac{\partial e_t}{\partial y_t}$. By calculating the determinants, we get expression

$$-\frac{(\beta_2 + 2\beta_3 \ln y_t) - e'(-1 + (1-\beta_1))}{-1},$$

which can be simplified to determine the (total) marginal effect

$$\frac{\mathrm{d}\ln c_t}{\mathrm{d}\ln y_t} = (\beta_2 + 2\beta_3 \ln y_t) + e'\beta_1. \tag{10}$$

Now marginal effect (10) can be compared to the biased interpretation in expression (2). We see clearly, that the model specification of Ang (2007) is biased by the term $-e'\beta_1$, which is negative in the plausible case. First, e' is positive when larger output implies more energy use. Second, the parameter β_1 should also be positive, as energy use has positive effect on carbon emissions.

The negative bias has two implication for the shape of the CKC.

First, we show that the tipping point of CKC is at a higher level of output when bias exists. In the unbiased case the tipping point y_t^* is such that the marginal effect (10) equals zero. This is equivalent to

$$y_t^* = e^{\frac{-\beta_2 - e'\beta_1}{2\beta_3}}.$$

Similarly, in the biased case the tipping point y_t^{**} satisfies

$$y_t^{**} = e^{\frac{-\beta_2}{2\beta_3}}.$$

Now, when $e'\beta_1 > 0$, adding β_2 to both sides gives $\beta_2 + e'\beta_1 > \beta_2$. Because β_2 is positive and β_3 is negative according to the CKC-hypothesis, we see that

$$\frac{-\beta_2 - e'\beta_1}{2\beta_3} > \frac{-\beta_2}{2\beta_3}.$$

As the exponent function function is strictly increasing, we get

$$y_t^* = e^{\frac{-\beta_2 - e'\beta_1}{2\beta_3}} > e^{\frac{-\beta_2}{2\beta_3}} = y_t^{**}.$$

A second implication for the shape is that the unbiased CKC grows quicker and declines more slowly, than the biased one. This is simply due to the fact that, for all levels of output y_t the biased marginal effect is smaller than the unbiased one. When $y_t < y_t^{**}$, (i.e. before the tipping point of the biased CKC), carbon emissions are actually growing faster. When $y_t^{**} < y_t < y_t^{*}$, the biased CKC has tipped, even though emissions are actually still growing. And when $y_t^{*} < y_t$, emissions are declining, but slower then the biased CKC implies.

The unbiased shape draws a more pessimistic view regarding the conflict between development and climate change policy goals.

4. Conclusions

We have shown that including total energy consumption as a control variable causes critical problems for estimating the carbon Kuznets curve.

First, we have shown that neglecting changes in energy use alters the interpretation of the model parameters significantly. As a result, the strand of literature in question answers a very different question compared to conventional CKC-literature. The estimated relationship is not the CKC as a whole. For the most part, it just estimates the relationship between carbon intensity and output, which neglects the causal effect through energy use.

Second, there is no curve in the shape of an “inverted U”. The carbon intensity, which is actually being fitted, has been declining very steadily in France over the time period (see Figure 4). The fitted upside-down parabola has most observations on the right hand side of the curve, which explains the delusive fit.

Third, we have shown that energy use is a cause of endogeneity, when change in output implies a change in the level of energy use. As a result, the studied model specification gives an overly optimistic view of the compatibility of development and environmental policy goals. If there is a tipping point, it occurs later than expected. Before tipping, output increases emissions faster, and afterwards, emissions drop slower than anticipated.

To answer any relevant questions about the CKC-hypothesis, one can not simply combine the energy-output and carbon-output nexuses in to one equation. However the analysis shows, that it might be useful to divide the emissions-output nexuses into energy-output and carbon-intensity-output nexuses, and analyze them simultaneously.

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