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Manuel Frondel, Peter Grabarczyk, Stephan Sommer, Martin Wagner

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A Cointegrating Polynomial Regression Analysis of the Material Kuznets Curve Hypothesis

Manuel Frondel,* Peter Grabarczyk,† Stephan Sommer,‡ Martin Wagner§

Employing consumption data for aluminum, lead and zinc for eight OECD countries spanning from 1900 to 2006, this paper tests the hypothesis underlying the notion of the Material Kuznets Curve (MKC), which postulates an inverted U-shaped relationship between a country's level of economic development and its intensity of metal use. Applying the tests and estimation techniques for nonlinear cointegration developed by Saikkonen and Choi (2004), Wagner (2013) as well as Wagner and Hong (2016), we find that the MKC hypothesis is less strongly supported by the data than when employing the standard methods that have been used in the empirical Environmental Kuznets Curve (EKC) literature so far. The evidence for a cointegrating MKC is mixed, at best.

Keywords: Intensity of Use, Metals, Nonlinear Cointegration.

JEL codes: C12, C13, C22, Q32.

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1 Introduction

Investigating the nexus between economic growth and environmental degradation, caused for example by the emission of greenhouse gases and other pollutants, has been at the heart of a great deal of empirical studies. Inspired by the seminal work of Grossman and Krueger (1991, 1995), as well as Holtz-Eakin and Selden (1995), a prominent topic of this strand of the literature is the so-called Environmental Kuznets Curve (EKC) hypothesis,[1] postulating an inverted U-shaped relationship between a country's economic activity, typically measured by

*RWI – Leibniz Institute for Economic Research.

†Technical University Dortmund

‡RWI – Leibniz Institute for Economic Research.

§Technical University Dortmund, Institute for Advanced Studies, Vienna, and Bank of Slovenia, Ljubljana.

[1]The term EKC hypothesis was coined in analogy to the inverted U-shaped relationship between the level of economic development and the degree of income inequality that was postulated by Kuznets (1955) in his presidential address to the American Economic Association.

Table 1: Overview on Selected Recent Studies on the MKC Hypothesis

	Estimation Methods	Unit Root Tests	Cointegration Tests	Support of MKC Hypothesis
Bringezu et al. (2004)	OLS, FGLS, FE, RE	–	–	Yes
Canas et al. (2003)	OLS, FE, RE	–	–	Yes
Crompton (2015)	FE	Pesaran, Im-Pesaran-Shin, Choi	–	Yes
Focacci (2005)	OLS	–	–	No
Guzmán et al. (2005)	FGLS, NLLS	Augmented Dickey-Fuller test	Augmented Dickey-Fuller	Yes
Huh (2011)	VECM, VAR	Augmented Dickey-Fuller, Philips-Perron	Johansen cointegration likelihood ratio	Yes
Jaunky (2012)	GMM, VECM	Augmented Dickey-Fuller, Zivot-Andrews, Narayan-Popp, Levin-Lin-Chu, Im-Pesaran-Shin, Pesaran, Chang-Song	Nyblom-Harvey, Pedroni, Westerlund	Yes
Jaunky (2013)	VECM	Augmented Dickey-Fuller, Zivot-Andrews, Narayan-Popp, Levin-Lin-Chu, Im-Pesaran-Shin, Pesaran, Chang-Song	Pedroni, Westerlund, Westerlund-Edgerton, Di Iorio-Fachin	Yes
Wårell (2014)	OLS, FE	Pesaran	Westerlund	for middle-income countries

Note: FE: Fixed Effects, FGLS: Feasible Generalized Least Squares, GMM: Generalized Methods-of-Moments, NLLS: Non-Linear Least Squares, OLS: Ordinary Least Squares, RE: Random Effects, VAR: Vector Autoregression Model, VECM: Vector Error Correction Model.

gross domestic product (GDP) per capita, and per-capita measures of various kinds of pollutants as dependent variables. In econometric terms, the hypothesized inverted U-shape of this relationship requires that in addition to (log) GDP per capita, we must include the square of this explanatory variable, and maybe also higher powers, in any specification employed to test the EKC hypothesis.

The reasoning underlying such specifications and the EKC hypothesis is that in early stages of economic development, environmental degradation and pollution increase with economic development, but beyond some welfare level the positive trend reverses and further economic growth may lead to environmental improvement (Stern, 2004). This level may vary for both countries and environmental indicators.

A similar reasoning is adopted for the nexus between economic development and the use of materials, for which Focacci (2005) coined the notion Material Kuznets Curve (MKC). While

Malenbaum (1978) was the first to analyze the MKC hypothesis for a large set of metals, this strand of the literature enjoys growing popularity – see Table 1 for recent examples and its continuation in Table A.1 in the appendix. In line with large parts of the empirical EKC literature, the table shows that some MKC studies do not use unit-root and cointegration techniques at all. Equally disconcerting is that those studies that employ unit-root and cointegration tests, use *linear*, rather than nonlinear techniques, thereby ignoring the fact that powers of an integrated process, e.g. log GDP per capita, are not integrated processes of any order – for more details on this fact see Müller-Fürstenberger and Wagner (2007) and Wagner (2008, 2012). To prevent misplaced conclusions with respect to the existence of an MKC, both unit-root and cointegration tests, as well as cointegration estimation techniques, need to be modified to suit to the, in the words of Wagner and Hong (2016), *cointegrating polynomial regression* (CPR) context, thereby accounting for the fact that the MKC hypothesis necessitates powers of economic indicators as regressors.[2]

By applying the cointegration tests of Wagner (2013), together with estimation techniques from Saikkonen and Choi (2004) as well as Wagner and Hong (2016), and employing metal use data spanning from about 1900 to 2006 for aluminum, lead and zinc, this paper tests the MKC hypothesis between a country's GDP per capita and the ratio of metal consumption to GDP (intensity of use, IOU) for eight OECD countries, including highly industrialized countries such as the US, Japan, and Germany. Our empirical analysis demonstrates that, similar to the conclusions drawn from the EKC analysis by Wagner (2015), the evidence for a MKC relationship is strongly diminished compared to that resulting from applying standard tests for linear cointegration. In those cases in which the MKC hypothesis cannot be rejected, we find the expected inverted-U-shaped relationship between log per-capita GDP and log intensity of use for the majority of this subset of countries.

The subsequent section describes the data used for our analysis, while Section 3 discusses the empirical results. The final section summarizes and concludes.

2 Data and MKC Hypothesis

It is well known that long time series are beneficial for valid estimation and inference in cointegration analysis. As a consequence, when empirically analyzing the nexus between a

[2] In terms of econometric analysis, the present paper is similar in scope for the empirical MKC literature as Wagner (2015) for the empirical EKC literature.

country's economic development and its metal use, long time series for these variables are required. Consequently, data availability is a crucial determinant of both the depth and width of any such analysis. While exploiting data on metal use from a variety of sources, such as the World Bureau of Metal Statistics (WBMS), we have opted for making use of the longest time series on metal use, which are available for aluminum, lead, and zinc for eight OECD countries: Australia, France, Germany, Italy, Japan, Switzerland, UK and the US – for an overview on the available data, see Table A.2 in the appendix.

In addition, any investigation of the MKC hypothesis necessitates data on a country's economic performance. To this end, data on GDP per capita is retrieved from the so-called Maddison Project and measured in Geary-Khamis Dollar (henceforth abbreviated by $) with base year 1990 (Bolt and Zanden, 2014).

A casual inspection of Figures 1 to 3 on the existence of a MKC yields some substance in the case of aluminum for countries such as Australia, France and USA. The MKC hypothesis appears to fit even better for lead, for which consumption declines for the majority of these countries upon reaching fairly low individual threshold values. This decline, however, may be due to the fact that the toxic character of lead eventually forced these countries to reduce their lead use. Although a similar explanation does not apply to zinc, its consumption per unit of GDP shrank in all countries alongside with increasing GDP per capita.

Figure 1: Log Aluminum Use per GDP (in metric tons per million $) versus Log GDP per Capita (in 1990$)

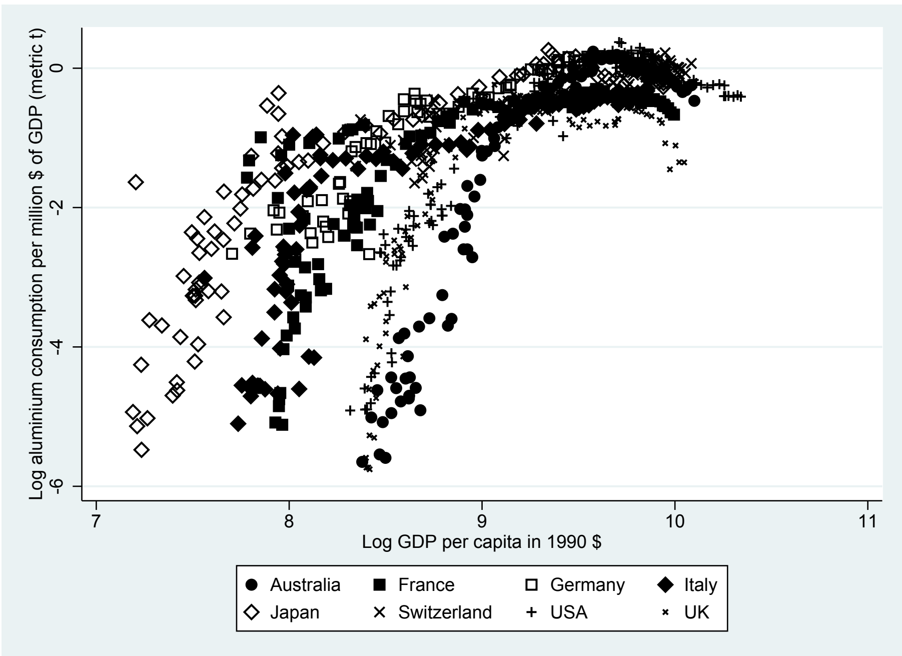

Figure 2: Log Lead Use per GDP (in metric tons per million $) versus Log GDP per Capita (in 1990 $)

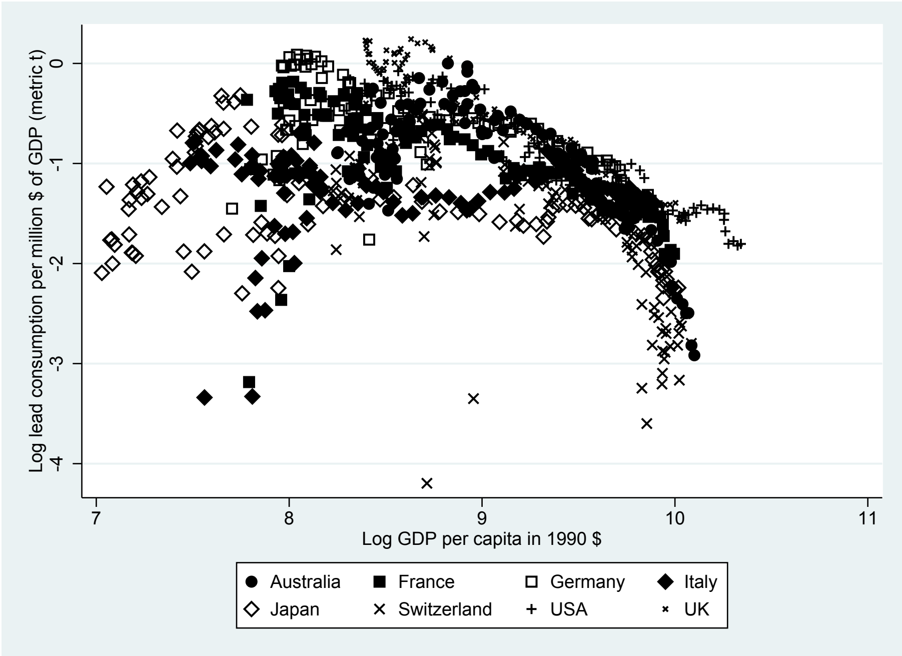

Figure 3: Log Zinc Use per GDP (in metric tons per million $) versus Log GDP per Capita (in 1990$)

These figures suggest that a quadratic specification of the MKC hypothesis

$$m_t = c + \delta \cdot t + \beta_1 \cdot y_t + \beta_2 \cdot y_t^2 + u_t, \quad (1)$$

may suffice. Here m_t denotes the natural logarithm of the intensity of use of metal m in year t, measured in metric tons per million Geary-Khamis \$, y_t denotes log GDP per capita, t is a linear time trend, u_t denotes the error term and c, δ, β_1 as well as β_2 are the parameters to be estimated. The hypothesis of an inverted U-shaped MKC requires β_1 to be positive and β_2 to be negative. Apart from the time trend, Equation 1 is the usual quadratic equation used for studying the MKC hypothesis (Jaunky, 2012, p. 298). Based on Equation 1, the per-capita GDP value of the turning point from which on the intensity of metal use shrinks is given by $\exp\left(-\frac{\beta_1}{2\beta_2}\right)$.

Inspired by Figures 1 - 3, which suggest country-specific MKCs with individual turning points, we have opted for individually analyzing the MKC hypothesis for each country, thereby refraining from the use of panel data estimators. Among other assumptions, their application would impose the restriction that all countries exhibit the same income elasticity at any given income level (Stern, 2004).

3 Empirical Analysis

Since the seminal work of Granger and Newbold (1974), researchers increasingly pay attention to the unit root properties of macroeconomic time series, such as GDP and resource consumption. These variables are frequently found to be integrated of order one ($I(1)$). Hence, before assessing the existence of any nexus between metal use and economic growth, it is imperative to individually test for each country (i) whether (log) GDP per capita is an $I(1)$ process using unit-root tests and, if this holds true, (ii) whether the error term in Equation 1 is stationary using, e.g., tests for nonlinear cointegration developed by Wagner (2013) and Wagner and Hong (2016), rather than standard cointegration tests. In contrast to these tests for nonlinear cointegration, classical cointegration tests are based on the assumption that all stochastic regressors appearing in Equation 1, i. e. y_t and y_t^2, as well as the dependent variable m_t, are $I(1)$. It is, however, known (see, e.g., Wagner, 2012) that y_t being $I(1)$ implies that y_t^2 cannot be $I(1)$; and is in fact not integrated of any integer order.

Table 2: Test Statistics of the Phillips-Perron (PP) and the Augmented Dickey-Fuller (ADF) Unit-Root Test for log GDP per capita (y_t)

	Intercept		Intercept and linear trend	
	PP	ADF	PP	ADF
Australia	0.67	2.73	-2.02	-1.57
France	-0.14	0.77	-2.38	-1.71
Germany	-0.41	0.59	-2.76	-2.56
Italy	-0.19	1.39	-1.76	-1.87
Japan	0.01	1.53	-1.89	-1.30
Switzerland	-0.43	1.63	-1.91	-1.77
USA	-0.28	2.01	-3.14	-2.95
UK	1.37	1.34	-2.17	-0.50

*Note: Bartlett kernel and Newey and West (1994) bandwidth for long-run covariance estimation. The optimal number of lags for the ADF test is based on the sequential t method (Ng and Perron, 1995), but it is omitted for the sake of expositional simplicity. Asterisks * and ** indicate rejection of the null hypothesis at the 10% and 5% significance level, respectively.*

3.1 Unit Root Tests

Applying both the unit-root test of Phillips and Perron (1988) and the Augmented Dickey-Fuller (ADF) test of Dickey and Fuller (1981) to log GDP per capita (y_t), the null hypothesis of y_t being $I(1)$ cannot be rejected throughout (Table 2). In what follows, we therefore employ cointegration tests, that is, we examine the stationarity of the error term in Equation 1. Due to the above mentioned fact that powers of an integrated process, such as log GDP per capita, are not integrated processes of any order, testing whether Equation 1 is a cointegrating relationship requires modified tests for a cointegrating polynomial regression setting, which have not been applied in the MKC literature so far. These tests, applied in the following section, are modifications of the (non-)cointegration test of Phillips and Ouliaris (1990) and the cointegration test of Shin (1994) to investigate cointegration in a polynomial regression setting, such as that underlying the MKC hypothesis.

3.2 Cointegration Tests

To test whether Equation 1 is a cointegrating polynomial relationship, we use the tests developed by Wagner (2013) and Wagner and Hong (2016). First, we employ the extension of the non-cointegration test of Phillips and Ouliaris (1990) to cointegrating polynomial regressions (CPRs) of Wagner (2013), denoted here by $P_{\hat{u}}$. Second, we use a cointegration test for CPRs, denoted here by CT, with the flipped null hypothesis of cointegration discussed in Wagner

Table 3: Results of the $P_{\hat{u}}$ Non-Cointegration Test and the *CT* Cointegration Test

	Aluminum		Lead		Zinc	
	$P_{\hat{u}}$	CT	$P_{\hat{u}}$	CT	$P_{\hat{u}}$	CT
Australia	49.97*	0.10*	49.56*	0.05	16.67	0.08
France	12.18	0.07	61.03**	0.07	81.11**	0.05
Germany	57.71**	0.11**	67.88**	0.07	74.76**	0.06
Italy	34.81	0.08	41.13	0.04	51.17*	0.05
Japan	53.61**	0.07	34.97	0.12**	29.45	0.07
Switzerland	61.13**	0.06	70.20**	0.06	62.42**	0.06
USA	30.52	0.05	55.06**	0.09*	52.82*	0.09*
United Kingdom	11.72	0.09*	37.32	0.05	43.86	0.06

Bartlett kernel and Newey and West (1994) bandwidth for long-run covariance estimation. Asterisks * and ** indicate rejection of the null hypothesis at the 10% and 5% significance level, respectively.

and Hong (2016).[3]

Table 3 presents the results based on the $P_{\hat{u}}$ non-cointegration test and the CT cointegration test. For aluminum, the combined evidence originating from both tests suggests that only for Japan and Switzerland there may be a cointegrating MKC. For these two countries, the $P_{\hat{u}}$ test rejects the null and the CT test does not reject the null. With respect to lead, the MKC hypothesis is supported for four countries (Australia, France, Germany, and Switzerland), while in case of zinc there is statistical support France, Germany, Italy and Switzerland.

In addition, for comparative purposes, we have also applied the Phillips and Ouliaris (1990) non-cointegration test and the Shin (1994) cointegration test, with the results reported in Table A.3 in the appendix. The results obtained from these tests for the null hypothesis of linear cointegration respectively the absence of linear cointegration lead to seemingly stronger evidence of the MKC hypothesis than the CPR evidence reported here. This is a similar finding to Wagner (2015), who also finds "too strong" evidence for the prevalence of an EKC (for CO_2 and SO_2 emissions) when using inappropriate tests.

[3] The CT test uses critical values that differ from those of the Shin (1994) test and that depend upon the specification of the deterministic component, the number of integrated regressors and the included powers of the integrated regressors. In case of only a single integrated regressor present in the regression with powers larger than one as given in Equation 1, the limiting distribution is nuisance parameter free. The $P_{\hat{u}}$ non-cointegration test is an extension of the variance-ratio test of Phillips and Ouliaris (1990) and involves a long-run variance estimate based on the residual of a VAR(1) regression for $[m_t, y_t]'$ including deterministic components, see Wagner (2013) for more details.

3.3 Estimation Results

For the countries with evidence of a cointegrating MKC relationship, we next estimate Equation 1. To allow for asymptotic standard inference, the OLS estimator, consistent in the cointegration case despite regressor endogeneity and error serial correlation, needs to be suitably modified. The literature provides several such modifications originally considered for linear cointegrating relationships: the Fully Modified OLS (FM-OLS) estimator of Phillips and Hansen (1990), the dynamic OLS (D-OLS) estimator of Saikkonen (1991) or the Integrated Modified OLS estimator of Vogelsang and Wagner (2014). The FM-OLS approach rests upon a two-step transformation: first, the dependent variable is modified to wipe out the dependence of the error term u_t on the errors that generate the integrated regressors. Second, an additive bias term is removed by a suitable additive correction factor. The dynamic OLS (D-OLS) approach as suggested by Saikkonen (1991) tackles the nuisance parameter dependencies of the OLS limiting distribution via augmenting the regression by leads and lags of the first differences of the integrated regressor. These estimation approaches have been extended for the CPR context by, e.g., Wagner and Hong (2016) for the FM-OLS estimator and Saikkonen and Choi (2004) for the D-OLS estimator.[4] In the following tables, we label these extended estimators by FM-OLS and D-OLS. Both procedures require estimates of long-run variances, which are based on the OLS residuals. For long-run variance estimation in our analysis, we use the Bartlett kernel in conjunction with the data-dependent bandwidth rule of Newey and West (1994). Furthermore, lead and lag choices are according to Choi and Kurozumi (2012). As a benchmark, we include in addition the OLS estimator.

Starting the discussion with the estimation results for aluminum (for Japan and Switzerland), we find significantly positive coefficient estimates for β_1 and significantly negative estimates for β_2 in case of Japan, indicating an inverted-U shape (Table 4). While the estimates do not differ strongly across methods, for Japan, the estimated MKC curves and fitted values, given in Figure A1, show a much better adjustment on the basis of FM-OLS than based on D-OLS. For Switzerland, the coefficient estimate for β_2 is not significantly different from zero. This leads to large GDP per capita values of the turning points, notably for the OLS and the D-OLS estimates.

For lead, we find inverted U-shaped relationships for all four considered countries Australia, France, Germany, and Switzerland (see Figure A2). Again, all per-capita GDP values of

[4] Similar extensions of the IM-OLS principle are currently investigated.

Table 4: Estimation Results for Aluminum

	$\hat{\delta}$	t-values	$\hat{\beta}_1$	t-values	$\hat{\beta}_2$	t-values	$\exp\left(-\hat{\beta}_1/2\hat{\beta}_2\right)$
Japan							
OLS	0.039	(4.61)	17.976	(7.88)	-1.021	(-7.46)	6,657.6
D-OLS	0.061	(10.32)	19.872	(13.09)	-1.161	(-13.45)	5,200.8
FM-OLS	0.042	(4.86)	20.524	(9.79)	-1.173	(-9.77)	6,296.3
Switzerland							
OLS	0.004	(0.50)	1.453	(0.44)	-0.041	(-0.21)	4.176×10^7
D-OLS	0.004	(0.46)	1.453	(0.36)	-0.041	(-0.18)	4.176×10^7
FM-OLS	0.006	(0.79)	4.150	(0.10)	-0.191	(-0.81)	51,469.7

the turning points are within sample, with the exception of Germany and the FM-OLS estimator (see Table 5). Finally, in qualitative terms, the results for zinc for France, Germany, Italy and Switzerland are similar to those for aluminum and lead. As shown in Table 6, all coefficient estimates exhibit the expected signs and are significantly different from zero, except for Germany (FM-OLS and D-OLS).

Table 5: Estimation Results for Lead

	$\hat{\delta}$	t-values	$\hat{\beta}_1$	t-values	$\hat{\beta}_2$	t-values	$\exp\left(-\hat{\beta}_1/2\hat{\beta}_2\right)$
Australia							
OLS	0.016	(2.97)	23.837	(8.87)	-1.390	(-9.82)	5,279.4
D-OLS	0.023	(3.38)	22.287	(6.46)	-1.325	(-7.59)	4,503.5
FM-OLS	0.019	(3.47)	23.718	(8.78)	-1.391	(-9.99)	5,043.3
France							
OLS	-0.033	(-4.86)	9.103	(3.72)	-0.460	(-3.67)	19,693.7
D-OLS	-0.034	(-8.48)	8.711	(4.56)	-0.437	(-4.11)	21,459.2
FM-OLS	-0.033	(-8.58)	8.049	(4.55)	-0.402	(-4.06)	22,367.5
Germany							
OLS	-0.023	(-9.23)	6.587	(3.02)	-0.340	(-2.75)	16,209.5
D-OLS	-0.023	(-6.82)	5.601	(2.96)	-0.287	(-2.69)	17,311.4
FM-OLS	-0.026	(-9.17)	4.072	(2.69)	-0.191	(-2.22)	42,613.1
Switzerland							
OLS	-0.035	(-2.26)	19.565	(4.48)	-1.024	(-3.81)	14,121.9
D-OLS	-0.035	(-3.01)	22.328	(4.82)	-1.176	(-4.58)	13,322.1
FM-OLS	-0.030	(-2.55)	20.425	(4.52)	-1.086	(-4.31)	12,129.0

In sum, we find a cointegrating MKC relationship for only a subset of countries. For all countries and metals with the exception of aluminum for Switzerland $\hat{\beta}_2$ is significantly negative implying an inverted U-shape. For given combination of country and metal furthermore the estimates do not differ strongly across methods. However, the individual estimates of the slope parameters differ across countries, in line with the evidence for heterogeneity visible in Figures 1–3; remarked upon already at the end of Section 2. This implies that estimation methods that assume parameter homogeneity across countries, such as panel data estimation methods, should be used with great care, if at all.

Table 6: Estimation Results for Zinc

	$\hat{\delta}$	t-values	$\hat{\beta}_1$	t-values	$\hat{\beta}_2$	t-values	$\exp\left(-\hat{\beta}_1/2\hat{\beta}_2\right)$
France							
OLS	-0.022	(-4.91)	10.819	(6.13)	-0.573	(-6.20)	12,504.3
D-OLS	-0.023	(-7.16)	10.735	(7.29)	-0.567	(-6.95)	12,951.3
FM-OLS	-0.022	(-7.73)	10.069	(7.90)	-0.532	(-7.45)	12,904.7
Germany							
OLS	-0.023	(-7.46)	4.793	(3.73)	-0.229	(-3.03)	34,325.1
D-OLS	-0.023	(-6.30)	2.624	(1.27)	-0.110	(-0.95)	144,565.1
FM-OLS	-0.024	(-7.14)	2.606	(1.46)	-0.105	(-1.04)	243,419.0
Italy							
OLS	0.002	(0.21)	11.373	(4.77)	-0.620	(-5.06)	9,674.3
D-OLS	0.013	(2.12)	5.895	(2.29)	-0.334	(-2.35)	6,892.6
FM-OLS	0.008	(1.31)	10.025	(4.54)	-0.557	(-4.51)	8,129.4
Switzerland							
OLS	-0.016	(-1.22)	22.852	(2.73)	-1.203	(-2.54)	13,354.2
D-OLS	-0.013	(-0.86)	23.684	(2.43)	-1.256	(-2.28)	12,471.4
FM-OLS	-0.017	(-1.62)	22.546	(3.19)	-1.185	(-2.99)	13,493.1

4 Summary and Conclusions

Using consumption data for aluminum, lead, and zinc spanning from about 1900 to 2006, this paper has examined the MKC hypothesis for eight OECD countries, including highly industrialized countries such as the US, Japan, and Germany. Since the logarithm of GDP per capita is found to be an $I(1)$ process for the countries under scrutiny, we individually test for each country whether there is a cointegrating polynomial relationship between the logarithm of the intensity of metal use and the logarithm of GDP per capita, as well as its square. Based on the tests for (non-)linear cointegration introduced by Wagner (2013) and Wagner and Hong (2016), we find support for a cointegrating MKC relationship only for a subset of these countries, such as Japan and Switzerland in case of aluminum. Similar to the findings originating from empirical EKC analyses, e.g. by Wagner (2015), we find that the MKC hypothesis is less strongly supported by the data than when employing standard tests developed for linear cointegrating relationships.

The reduced-form approach pursued here (given by Equation 1) is only a first step to analyze the MKC hypothesis. To obtain more insights into the relationship between the intensity of use and GDP per capita, more general specifications and the inclusion of further relevant economic explanatory variables are necessary. Changes of relative metal prices, for instance, can be expected to impact the intensity of metal use via substitution effects (see, e.g., Stuermer, 2016). However, as relative metal prices are often found to be stationary, rather than integrated, the employed estimation and testing techniques have to be extended to accommodate also stationary regressors. Furthermore, the presence of relevant substitution effects hints at the usefulness of system estimation considering several metals jointly. These extensions are, however, beyond the scope of the present paper.

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Appendix

Table A.1: Continued Overview on Selected Recent Studies on the MKC Hypothesis

	Metal	Countries	Time Period	Support of MKC Hypothesis
Bringezu et al. (2004)	Direct material input	26 countries and EU-15	1960-2000	Yes
Canas et al. (2003)	Direct material input	16 industrialized countries	1960-1998	Yes
Crompton (2015)	Steel	26 OECD countries	1970-2012	Yes
Focacci (2005)	Aluminum, copper, lead, nickel, tin, zinc	5 industrialized countries	1960-1995	No
Guzmán et al. (2005)	Copper	Japan	1960-2000	Yes
Huh (2011)	Steel	South Korea	1975-2008	Yes
Jaunky (2012)	Aluminum	20 high-income countries	1970-2009	Yes
Jaunky (2013)	Copper	16 rich countries	1966-2010	Yes
Wårell (2014)	Steel	61 countries	1970-2011	Only for middle-income countries

Table A.2: Data Range for the Countries under Scrutiny

Country	GDP	Aluminum	Lead	Zinc
Australia	1900-2006	1920-2006	1900-2006	1911-2006
France	1900-2006	1900-2006	1900-2006	1900-2006
Germany	1900-2006	1920-2006	1900-2006	1900-2006
Italy	1900-2006	1908-2006	1900-2006	1900-2006
Japan	1900-2006	1911-2006	1900-2006	1911-2006
Switzerland	1900-2006	1920-2006	1900-2006	1927-2006
UK	1900-2006	1900-2006	1900-2006	1900-2006
USA	1900-2006	1900-2006	1900-2006	1900-2006

Table A.3: Results of the PO Non-Cointegration Test of Phillips and Ouliaris (1990) and the Cointegration Test of Shin (1994)

	Aluminum		Lead		Zinc	
	PO	Shin	PO	Shin	PO	Shin
Australia	-5.87**	0.10*	-5.52**	0.05	-3.11	0.09*
France	-3.93*	0.07	-4.78**	0.06	-4.29**	0.05
Germany	-6.62**	0.09*	-5.43**	0.08	-6.31**	0.06
Italy	-4.30**	0.08*	-4.22**	0.04	-6.04**	0.05
Japan	-4.28**	0.07	-3.76	0.13**	-6.17**	0.06
Switzerland	-6.24**	0.06	-5.72**	0.06	-6.14**	0.06
USA	-3.44	0.12**	-4.69**	0.31**	-5.18**	0.26**
United Kingdom	-3.26	0.11**	-3.62	0.05	-4.32**	0.06

Note: Bartlett kernel and Newey and West (1994) bandwidth for long-run covariance estimation. Numbers with one asterisk denote rejection of the null hypothesis at the 10% significance level and numbers with two asterisks indicate rejection of the null at the 5% significance level.

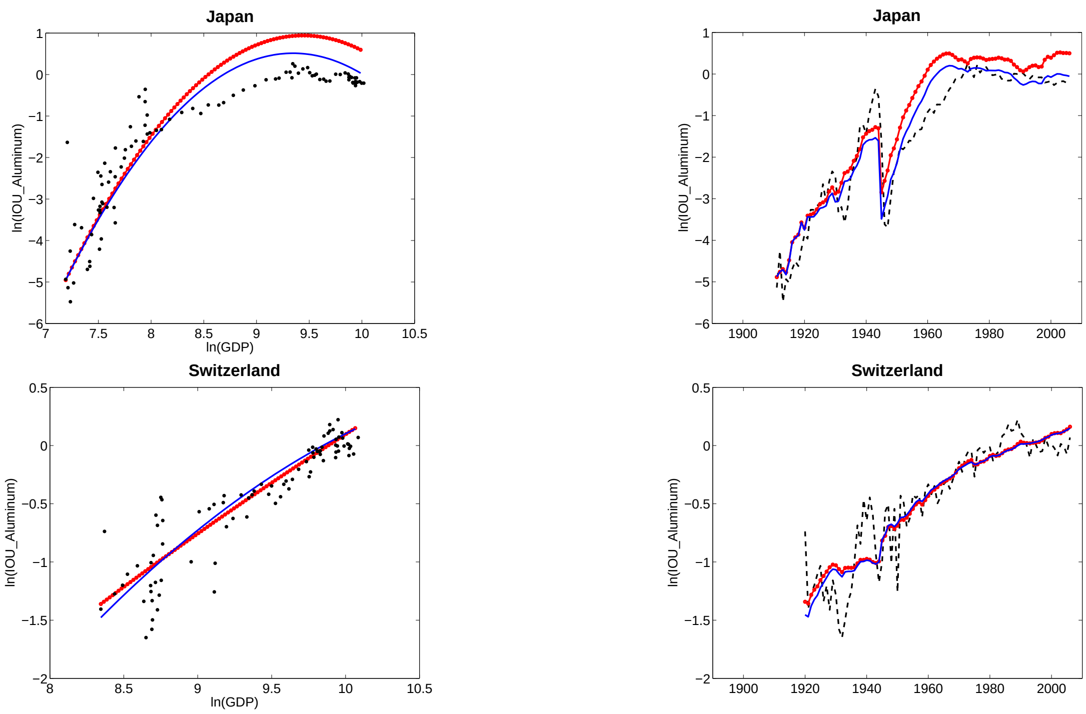

Figure A1: Estimated aluminum MKC curves and fitted values plots for Japan and Switzerland. On the left-hand side the dots show the pairs of observations of log GDP per capita and log intensity of use. The curves show a line that is the result of inserting equidistantly spaced points from the sample range of log GDP per capita, with corresponding values of the trend given by $t = 1, \ldots, T$, in the estimated relationship (1) using the coefficient estimates obtained by FM-OLS (solid – blue) and D-OLS (dotted – red). The right-hand side shows the actual log intensity of use values (dashed – black) together with fitted values obtained by FM-OLS (solid – blue) and D-OLS (dotted – red).

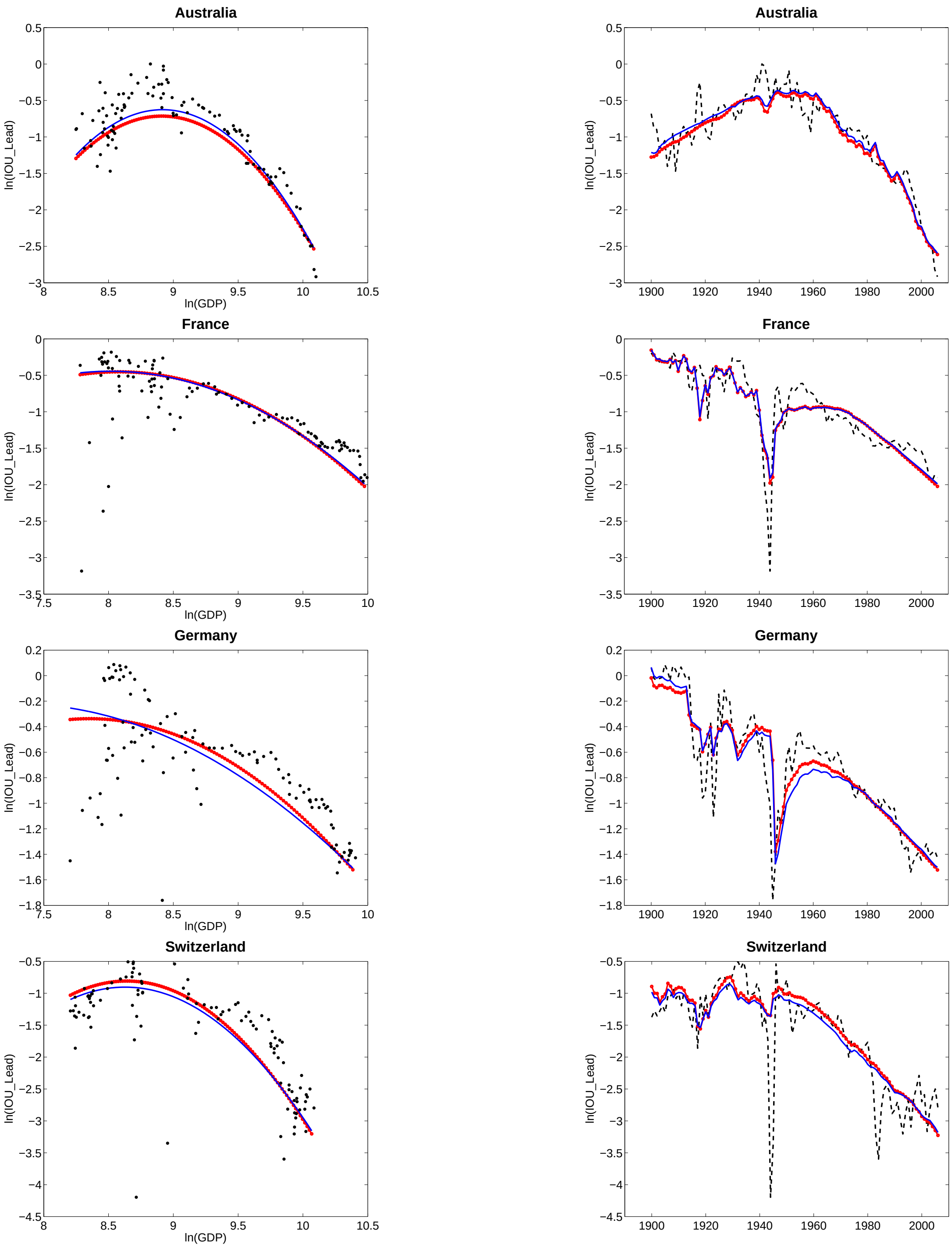

Figure A2: Estimated lead MKC curves and fitted values plots for Australia, France, Germany and Switzerland. For further explanations, see Figure A1.

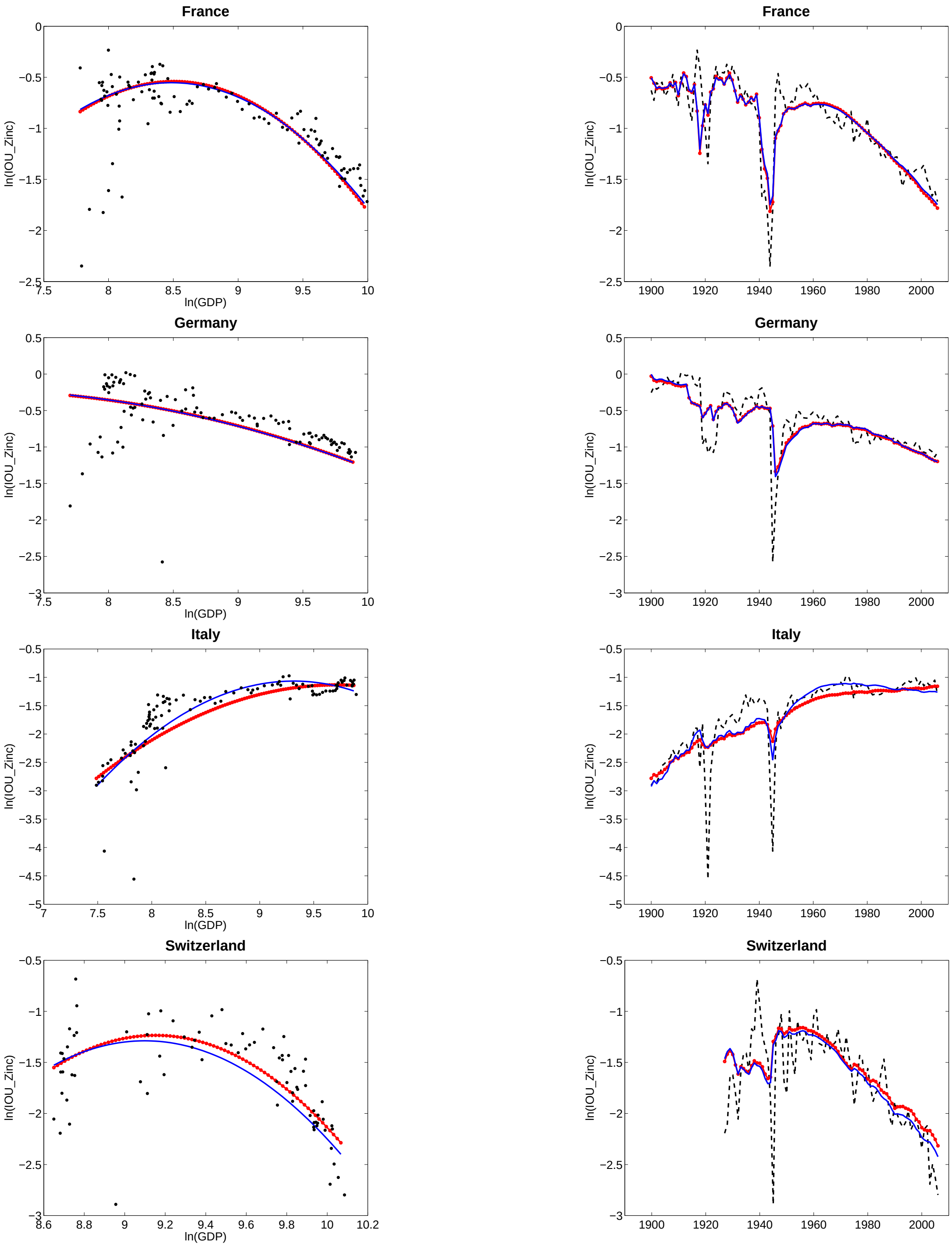

Figure A3: Estimated zinc MKC curves and fitted values plots for France, Germany, Italy and Switzerland. For further explanations, see Figure A1.