JOURNAL OF ENVIRONMENTAL ECONOMICS AND MANAGEMENT **29**, S-34–S-42 (1995)

Stochastic Trends and Structural Breaks in the Intensity of Metals Use

B. STEPHEN LABSON

Department of Energy and Minerals, 115 Victoria Parade, Fitzroy, Victoria 3065, Australia

Received February 3, 1994; revised August 18, 1994

This research examines whether innovations in the relationship between metals demand and economic activity are of a deep nature, such that they have persistence, or whether such innovations are transitory, conditional on a break point resulting from the 1973 oil price shock. Evidence was found to suggest that, at least for some of the metals studied in this research, intensity of use is well represented as a stationary process after accounting for a break point at 1973. One interpretation of this result is that technological shocks are not as pervasive as one might have thought and that only extraordinary events have a measurably long-lasting influence on metals demand. © 1995 Academic Press, Inc.

I. INTRODUCTION

The relationship between demand for industrial materials and economic activity has been of perennial concern, even though the nature of the concern has varied considerably over time. The debate of the early 1970s was over the perceived constraint to economic growth implied by what was thought by some researchers as a lock-step relationship between demand for exhaustible resources and economic growth. More recently, the debate has been focused on the potential burden on the environment that economic growth may incite through further processing, use, and ultimately disposal of industrial materials.

In studying the relationship between metals demand and economic activity, researchers (see, for example, Auty [1] and Tilton [11]) have examined the intensity of metals use, which is simply defined as the ratio of metals consumption to aggregate production within an economy. While the evaluation of intensity of use is not generally based on an explicit theoretical structure, researchers have found it to be a useful tool with which one can decompose a complex system into something more manageable. Observations on this summary measure have been used to identify some general characteristics related to the underlying nature of metals demand, such as its relationship to general economic activity, the affect of changing sectoral balances within an economy and the role of technological change. Often, such analysis has been in the form of trend analysis, based on the presumption of stationarity about a deterministic trend.

In a similar vein, macroeconomists have been quite interested in the time series properties of various macroeconomic aggregates. Much of this work has been influenced by the seminal work of Nelson and Plosser [6], in which they considered various macroeconomic aggregates in terms of whether they are best represented as a stochastic or deterministic trend. The primary implication being that random innovations impart a permanent influence on a variable best described as following a stochastic trend, and that there is no tendency for the variable to revert to a stable mean. Following the general theme of this literature, Labson and Crompton

0095-0696/95 $12.00

[5] examined the stochastic nature of metals demand and its relationship with aggregate income. One of their conclusions was that intensity of use in metals demand is best represented as a stochastic trend.

Perron [7] and others have extended unit root tests to consider a system which is stationary around a trend function which contains a one-time break. More specifically, this work is generally based on the presumption that certain time series may contain a shock which is unrelated to the underlying data-generating mechanism. In effect, the exogenous shock is filtered out of the data in order to determine whether the series is stationary after accounting for a one-time break in the mean of the series. As Perron [7] has demonstrated, if the system is affected by an exogenous break in mean, standard Dickey–Fuller-type unit root tests will be biased toward acceptance of the null of nonstationarity. The possibility of a one-time break in mean seems to be particularly relevant to intensity of use in metals demand. Given the link of both production and consumption activities between most metals and energy, it seems quite reasonable to presume that the oil price shock of 1973, as a case in point, may have significantly altered the relationship between metals demand and economic activity. For example, Tilton [11, 12] argued that 1973 represented a turning point in metals demand due in part to the changing product composition of end use products, brought about by materials substitution and innovation in energy-saving technologies.

The question examined in this paper is whether intensity of metals use has gone from one stationary mean to another, or if each new innovation imparts a permanent influence on the series. This paper extends previous research by Labson and Crompton [5] by treating the oil price shock of 1973 as an extraordinary event. When the oil price shock is treated as an extraordinary event, the relevant question then becomes: does intensity of use exhibit mean-reverting behavior over important segments of time, where only the relatively infrequent extraordinary events have true persistence? If this is indeed the case, metals demand would be expected to follow in lock-step with economic activity, with this relationship only affected by rather large and infrequent shocks.[1]

II. TESTING FOR A UNIT ROOT CONDITIONAL ON A ONE-TIME MEAN BREAK

To determine whether intensity of metals use is mean-reverting about a one-time break, the innovational-outlier model reported by Perron [7] was employed. Within this framework, one tests whether a data series is best represented as following a unit root process. The alternative being that the series is stationary about a one-time mean break.[2] Under the specification of the innovational-outlier model, the change in the mean is not instantaneous, but rather gradually adjusts to a new

[1] The matter of stationarity in intensity of use is also of importance from a methodological standpoint. Regression-based evaluation of intensity of use in terms of behavioral relationships or forecasting procedures may be deficient if the matter of stationarity is not properly accounted for.

[2] It is important to note that I have not considered reversion about a deterministic trend function. This choice was made since it is suspected that deviations in intensity of use are generally caused by factors such as technological shocks, which are not likely to be of a deterministic nature. Of course, time trends are used often in applied research as an approximation of the outcome of such random factors, however, since this is the essence of the study at hand, such a crude approximation seems inappropriate.

level.[3] Operationally, Perron's specification of the innovational-outlier is based on the presumption that the dynamics of the mean change are directly related to the dynamics of the specified error process. The model under the null hypothesis of a unit root with one-time break is

$$y_t = y_{t-1} + A^*(L)^{-1}B(L)[v_t + \gamma D(TB)_t], \quad (1)$$

where an ARMA(p, q) process is specified for the ω_t in the form $A^*(L)\omega_t = B(L)v_t$, with $A^*(L)$ and $B(L)$ p- and q-order polynomials in L, and v_t is i.i.d. $(0, \sigma_v^2)$. $D(TB)_t = 1$ if $t = T_B + 1$ and 0 otherwise, with T_B the year in which the break in mean occurs.

Under the alternative hypothesis, in which the series does not contain a unit root, the process is described as

$$y_t = \mu + A(L)^{-1}B(L)[v_t + \gamma DU_t], \quad (2)$$

where $DU_t = 0$ if $t \leq T_B$ and 1 otherwise, and e_t is an ARMA process of the form $A(L)e_t = B(L)v_t$. The two competing models, as presented by Eq. (1) and (2), are nested following Said and Dickey [10] and represented by an autoregressive model of the form

$$y_t = \mu + \gamma DU_t + dD(TB)_t + \alpha y_{t-1} + \sum_{j=l}^{k} c_j \Delta y_{t-j} + v_t, \quad (3)$$

where the Δy_{t-j} are the lagged first differences of the series, with k being of suitable length to ensure the validity of the asymptotic distribution.

To test for a unit root, conditional on the existence of a one-time mean break, Eq. (3) is estimated by OLS. The null hypothesis is that $\alpha = 1$, in which case the series is characterized as following a stochastic trend. Similar to the standard unit root case studied by Dicky and Fuller [3], the t statistic on $\hat{\alpha}$ ($t_{\hat{\alpha}}$) is not distributed as a Student t. However, the Dicky–Fuller critical values are not appropriate either, since they are not independent of additional deterministic components, which in this case are DU and $D(TB)$.

Perron [7] has calculated critical values which incorporate these deterministic components, based on the presumption that the time of break in mean is known. However, depending on the series under study, such as presumption may be controversial. Christiano [2] among others has argued that the identification of break points in economic time series is often data dependent. If the break point is data dependent, tests for unit roots need to account for what can be characterized as pretest estimation. Since the focus of this study is on the oil price shock and intensity of metals use, it seems that the presumption of exogeneity in the break point is appropriate, given the presumably important link between use of industrial metals and energy sources. The main point being that the purpose of this study is not to search for a break point but simply to test for a unit root around a very specific break point—the 1973 oil price shock.

[3] Perron [7] and Perron and Vogelsang [8] have also described an additive-outlier model in which the change in mean is presumed to be instantaneous. The more flexible innovational-outlier model which allows for gradual change in the mean has been used in this study since it is likely to be robust as compared to the more restrictive additive-outlier model.

III. THE APPLICATION AND EMPIRICAL RESULTS

Equation (3) was used to test for a unit root in intensity of metals use, conditional on a mean break in 1973.[4] Postwar, annual observations were used. The metals examined were aluminum, copper, lead, steel, tin, and zinc. Metals consumption is defined in terms of weight. Four industrialized regions were examined, Japan, the United Kingdom, and the United States, as well as the Organisation for Economic Co-operation and Development (OECD) countries as an aggregate. The country specific data was used primarily due to the extended data coverage available, rather than due to any presumptions regarding possible differences between regions. However, since metal consumption is reported at the level of semi-finished products, rather than final demand, trade in end products may distort interpretation of the results. To get an idea of whether the results are robust to this distortion, aggregate OECD metals intensity of use is also examined. The OECD data set is an updated version of that reported in Tilton [12]. The sample period is shorter than that of the country series, but will likely present a clearer picture of the relationship between final demand and economic activity, since OECD net trade in metals is relatively small. Aggregate production, as measured by real gross domestic production (GDP) or gross national production (GNP) is used as a general measure of economic activity. The value of the truncation parameter, k, was chosen following Perron [7] by setting it to the highest value (starting at $k = 5$) for which the t-statistic on the estimated coefficient, $\hat{c}_k$, is statistically significant at the 10% level. The results for Japan, the United Kingdom, and the United States are reported in Table I, along with the results of the standard Dickey–Fuller-type unit root test, which does not allow for a one-time break in mean.

The columns under "No mean break" in Table I refer to the results of a standard Dickey–Fuller-type test for a unit root (not allowing for a mean break) in the intensity of use for the various metals studied.[5] In this case, the unit root is not generally rejected, with only U.S. and U.K. tin intensities found to be stationary over the full sample period at the 5% level, and U.S. steel intensity at the 10% level. The implication is that there is little or no tendency for intensity of use to revert to a single, stable mean for five of the six metals studied.

The columns under "1973 mean break" in Table I contain the relevant statistics related to the presumption that the 1973 oil price shock was an extraordinary event. The estimated autoregressive coefficients ($\hat{\alpha}$) are generally smaller than in the no mean break case, and, for U.S. copper intensity, Japanese and U.S. tin intensity, and Japanese and U.S. lead intensity, they are significantly different from 1 (rejection of the unit root) at the 5% level. Furthermore, at the 10% level a unit root in U.K. aluminum intensity is rejected. As such, if one is willing to consider

[4] An anonymous referee has commented that, strictly speaking, a unit root cannot be present in the intensity of use series since there is zero probability of ever reaching a negative value. Of course, this basic argument holds for the evaluation of many economic variables. Ultimately, the dichotomy of the unit root versus stationary process must be seen as a hopefully useful approximation for the particular purpose at hand. In this case, the framework serves to focus attention on whether the series is mean reverting (after accounting for a break point) or if the basic structure of the process is ever changing.

[5] The tests for a unit root under no mean break correspond to that reported in Labson and Cromptom [5], however, the results in some cases are slightly different due to the slightly expanded sample period and the use of a different selection criterion for the value of the truncation parameter, k.

the 1973 oil price shock as an event unrelated to the date-generating process, evidence was found to suggest that intensity of use is stationary about a one-time mean break, at least for some of the metals studied. The implication being that a fairly lock-step relationship between metals demand and economic activity may exist, at least for "normal" shocks and that only extraordinary events such as the oil price shock have persistence.

Notice that in all three countries, steel and zinc intensity is best represented as a nonstationary series even under the presumption of a meanbreak at 1973. This may be a case in which trade in final goods (thus metal consumption) is not captured by the data set used for this study. Particularly in the case of steel and zinc, where significant trade in end-use products such as automobiles and white good exists, a more aggregate examination may be more appropriate. The results of unit root tests using OECD data, without and with mean break, are reported in Table II.

Intensity of use in the OECD data series seems to follow the same general pattern as found in the country series. A unit root is not generally rejected for intensity of use (except for aluminum at the 10% level) without the inclusion of a mean break. If, however, the persistent effect of the oil price shock is accounted for via the presumed mean break, some evidence is found to reject the null

TABLE I
Unit Root Tests for Intensity of Metals Use (Japan, UK, US)

	No mean break				1973 mean break		
	T	k	$\hat{\alpha}$	$t_{\hat{\alpha}}$	k	$\hat{\alpha}$	$t_{\hat{\alpha}}$
Aluminum							
Japan	34	3	0.82	−2.12	2	1.21	1.68
UK	34	3	0.92	−0.69	2	0.58	−3.35*
US	34	0	0.76	−2.02	4	0.82	−1.46
Copper							
Japan	41	2	0.70	−2.45	2	0.88	−0.92
UK	45	1	1.01	0.22	1	0.88	−1.14
US	47	2	0.90	−1.72	2	0.54	−4.33**
Lead							
Japan	41	2	0.83	−1.09	0	0.29	−4.95**
UK	45	2	0.98	−0.55	2	1.01	0.03
US	47	2	0.91	−2.78†	4	0.74	−5.71**
Steel							
Japan	39	3	0.91	−1.41	4	0.96	−0.84
UK	45	5	0.99	−0.28	2	0.89	−1.62
US	43	1	0.98	−0.32	1	0.72	−2.26
Tin							
Japan	38	2	0.96	−0.90	5	0.65	−3.71**
UK	45	3	0.93	−3.67††	3	0.90	−2.43
US	47	4	0.85	−5.01††	4	0.72	−5.86**
Zinc							
Japan	41	2	0.98	0.20	5	0.81	−2.11
UK	45	4	1.03	0.72	4	0.88	−1.38
US	43	1	0.98	−0.20	5	0.81	−3.00

Note. † and †† denote that the statistic is significant at the 10 and 5% level, respectively, based on critical values reported in Fuller [4]. * and ** denote that the statistic is significant at the 10 and 5% level, respectively, based on critical values reported in Perron [7].

TABLE II
Unit Root Tests for Intensity of Metals Use (OECD)

		No mean break			1973 mean break		
	T	k	$\hat{\alpha}$	$t_{\hat{\alpha}}$	k	$\hat{\alpha}$	$t_{\hat{\alpha}}$
Aluminum	33	0	0.72	$-2.66^{\dagger}$	4	0.86	−0.85
Copper	33	2	0.96	−0.54	2	0.70	−2.04
Lead	33	0	0.96	−0.77	0	0.96	−0.64
Steel	33	0	0.99	−0.25	2	0.74	−3.22*
Tin	31	1	0.94	−2.29	2	0.72	−5.70**
Zinc	33	0	0.95	−0.78	4	0.48	−4.67**

Note. † denotes that the statistic is significant at the 10 and 5% level, respectively, based on critical values reported in Fuller [4]. * and ** denote that the statistic is significant at the 10 and 5% level, respectively, based on critical values reported in Perron [7].

hypothesis of a unit root. The estimated autoregressive coefficients are, except for aluminum and lead, much lower than in the no mean break case, in the case of tin and zinc they are significantly different from 1 (rejection of the unit root) at the 5% level, and at the 10% level they are significant for steel. As such, it appears that there is some evidence to suggest that at least for several important metals studied here, innovations in intensity of use are largely transitory, and only extraordinary events have a persistent effect.

IV. A DATA-DEPENDENT BREAK POINT

A premise of this paper has been that the oil price shock of 1973 represented an extraordinary event. While this presumption is often made by applied economists, it is also true that it may be a bit arbitrary for the purpose at hand. Several anonymous reviewers of a previous draft have commented to the effect that a data-dependent choice of break point might be more reasonable. To motivate this idea, first consider the graph of OECD intensity of use over 1960 to 1992 (Fig. 1).

While it is difficult to ascertain exactly what constitutes a reasonable break point from a casual view of the data (especially given the fact that I have used Perron's model which allows for a dynamic transition in the break function, rather than a sudden shift), it does appear that 1973 is an arguably reasonable choice of break point. Still, it is also reasonable to explore whether the results of the previous section are robust to a data-dependent choice of break point.

Perron and Vogelsang [8] have computed critical values for testing for a unit root under the alternative of a one-time mean break, where the time of the break point is unknown. It is important to understand that this particular test is not meant to determine whether a break point actually exists. Rather, it is meant to accommodate the fact that the distribution of the t-statistic in the unit root test is dependent on the manner in which one chooses the break point. Intuitively speaking, the critical values are adjusted for what could be considered "data mining." Operationally, the choice of break point is determined by finding the minimum value of the t-statistic on α in Eq. (3) over all possible break points while holding the truncation parameter, k, fixed. The critical values computed by Perron and Vogelsang [8] are then used to account for this procedure. The results of the unit

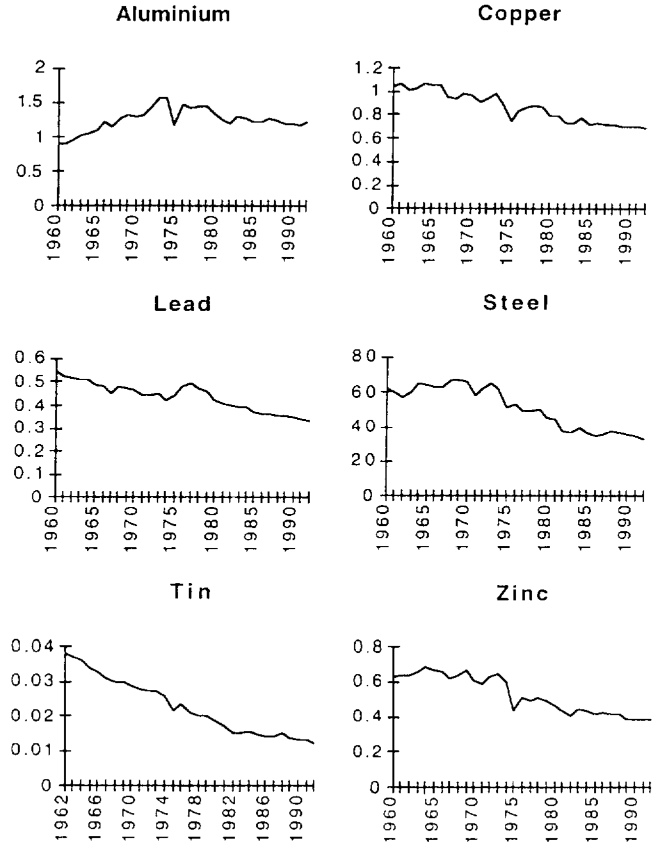

FIG. 1. OECD intensity of use of aluminum, copper, lead, steel, tin, and zinc (metric tons per million dollars GDP).

root test of OECD intensity of metals use[6] within Perron's framework of an unknown break point are reported in Table III.

Apparently, 1973 is reasonably consistent with a data-dependent choice of break point. Under this framework, the break point for steel, tin, and zinc is 1973.[7] However, in those cases which obtained a different break point, the unit root was still not rejected. That is, even under the relatively more flexible test allowing for an unknown break point, no additional evidence was found to suggest that intensity of use is stationary about a one-time mean break. On the other hand, the results of this study seem to be robust to the manner in which one chooses the time of break.

[6] I have also evaluated the Japanese, U.K., and U.S. data within this framework. The results were not very different from the results shown in Table I, and for the sake of brevity, they are not reported here. These results will be provided on request.

[7] The results are slightly different from those reported in Table II even in the case where the break is 1973, since for this framework, $k = 5$ for all tests. Perron and Vogelsang offer an alternative test procedure whereby the truncation parameter is data-dependent as well. I performed this test following the advise of a referee and found the qualitative results reported above unchanged.

TABLE III
Unit Root Tests for Intensity of Metals Use (OECD) under Data Dependent Break Point

	Break	$\hat{\alpha}$	$t_{\hat{\alpha}}$
Aluminum	1979	0.37	−3.21
Copper	1972	0.71	−2.23
Lead	1978	0.69	−2.58
Steel	1973	0.73	−2.97
Tin	1973	0.70	$-4.48^{\dagger\dagger}$
Zinc	1973	0.41	-5.20^{**}

Note. †† denotes that the statistic is significant at the 5% level, based on critical values reported in Perron and Vogelsang [8].

V. CONCLUSION

In this paper, the relationship between metals demand and economic activity has been examined. Following previous research in applied minerals economics, this relationship was evaluated in terms of the intensity of use. Intensity of use is simply a definitional identity, however, it is an often-used summary measure which allows for a simple description of a complex economic system. The idea of a unit root process in intensity of use and the implicit lack of mean reversion seem to be useful in the examination of if, after accounting for extraordinary events, metals consumption and economic activity fall in lock-step, or if the relationship is constantly changing due to innovational persistence or to what might be loosely defined as technological change.

The country results offer evidence with which to reject the presence of the unit root conditional on a 1973 break point in intensity of use of aluminum in the United Kingdom, copper in the United States, lead in Japan and the United States, and tin in Japan and the United States. On a country basis in a unit root in intensity of use in steel and zinc could not be rejected. Unfortunately, it is not clear why the results are not uniform across metals or regions. One explanation, particularly in the case of steel and zinc, may rest in the fact that the available data is in terms of semifinished product and does not capture trade in end products such as automobiles and other consumer durables.

The results of the more aggregate study, which should be relatively unaffected by trade-related distortions in the data, indicate that in the OECD, steel, tin, and zinc intensity of use can be represented as a stationary, albeit segmented, process. That is, outside of extraordinary events, OECD steel, tin, and zinc demand does follow in lock-step with economic activity, as defined by rejection of the unit root in intensity of use at the 5% level (10% level for steel). As such, it appears that some evidence has been found which suggests that under normal circumstances, metals consumption and economic activity tend to follow in lock-step, and that for the

[8] An anonymous referee has suggested that one is likely to find a persistent decline in intensity of metals use if one looks at the last 100 years or so. This may well be the case and, given a suitably accurate data set, merits further research. Nevertheless, the postwar period represents a period of sufficient innovation as to make this evaluation nontrivial.

most part, innovations are not of such a deep nature as to impart a permanent influence on intensity of use over reasonably interesting time horizons.[8] Metals consumption (at least in those cases where the null of nonstationarity was rejected) is a concomitant of economic activity, and this relationship seems to be relatively unaffected by all but the most extraordinary events. One interpretation of this result is that technological shocks are not as pervasive as one might have thought and that only the relatively large, but sporadic events have a measurably lasting influence on metals demand. This is not to lend credence to a "limits to growth" type argument though. Quite the contrary, the presumption of a mean break implies a lack of such loosely defined limits. Still, the results of this study should be of some use for the more mundane purpose of understanding the relationship between metals demand and economic activity over more normal circumstances.

Admittedly, the conclusions of this study should probably be characterized as preliminary since the results at this stage are rather mixed. Hopefully this paper has developed a framework in which to form a clearer view of the relationship between metals demand and economic activity in future research.

REFERENCES

1. R. Auty, Materials intensity of GDP: Research issues on the measurement and explanation of change, *Resour. Policy* **11**, 275–283 (1985).
2. L. J. Christiano, Searching for a break point in GNP, *J. Business Econom. Statist.* **10**, 237–250 (1992).
3. D. A. Dickey and W. A. Fuller, Distribution of estimates for autoregressive time series with unit root, *J. Amer. Statis. Assoc.* **74**, 427–431 (1970).
4. W. Fuller, "Introduction to Statistical Time Series," Wiley, New York (1976).
5. B. S. Labson and P. L. Crompton, Common trends in economic activity and metals demand: Cointegration and the intensity of use debate, *J. Environ. Econom. Management* **25**, 147–161 (1993).
6. C. R. Nelson and C. I. Plosser, Trends and random walks in macroeconomic time series: Some evidence and implications, *J. Monetary Econom.* **10**, 139–162 (1982).
7. P. Perron, Testing for a unit root in a time series with a changing mean, *J. Business Econom. Statist.* **8**, 153–162 (1990).
8. P. Perron and T. J. Vogelsang, Nonstationarity and level shifts with an application to purchasing power parity. *J. Business Econom. Statist.* **10**, 301–320 (1992).
9. P. Perron and T. J. Vogelsang, Testing for a unit in a time series with a changing mean: corrections and extensions, *J. Business Econom. Statist.* **10**, 467–469 (1992).
10. S. E. Said and D. A. Dickey, Testing for unit roots in autoregressive-moving average models of unknown order, *Biometrika* **71**, 599–607 (1984).
11. J. E. Tilton, The new view of minerals and economic growth, *Econom. Record* **65**, 265–278 (1989).
12. J. E. Tilton, "World Metal Demand: Trends and Prospects," Resources for the Future, Washington DC (1990).