Measuring Global Economic Activity*

James D. Hamilton
Department of Economics
University of California at San Diego
9500 Gilman Drive, 0508
La Jolla, CA 92093
jhamilton@ucsd.edu

August 15, 2018
revised: April 18, 2019

Abstract

A number of economic studies have used a proxy for world real economic activity derived from shipping costs. This measure turns out to depend on a normalization that has substantive consequences of which users of the index had been unaware prior to this paper. This paper further evaluates this and alternative measures in terms of treatment of trends, coherence with world output, and ability to predict commodity prices. I conclude that measures derived from world industrial production offer a better indicator of global real economic activity.

*I thank the editor and anonymous referees for comments on an earlier draft of this paper, and thank the JP Morgan Center for Commodities for financial support as a JPMCC Distinguished Visiting Fellow.

Keywords: world economic activity, shipping costs, commodity prices
Applied economists often want a monthly measure of the level of global economic activity in empirical models of variables like commodity prices, exchange rates, and interest rates. One popular measure that has been used in dozens of studies\textsuperscript{1} was developed by Kilian (2009) based on the cost of shipping.

In this paper I review the mechanical details behind Kilian’s index and evaluate its appropriateness as a measure of global real economic activity.

1 Details behind Kilian’s index.

The market for shipping services is governed by supply and demand, just like any other market. In a typical year, increasing global economic activity increases the demand for shipping, which by itself would lead to an increase in the cost of shipping. On the other hand, increases in shipping capacity and improvements in shipping productivity also shift the supply curve out, leading to lower prices. The trend in real shipping costs has been downward over time, meaning that in most years the second effect is bigger than the first. If the growth in shipping capacity, improvements in shipping productivity, and growth of potential real GDP could be characterized by deterministic time trends, then we might interpret the residuals from a regression of the real cost of shipping on a time trend as the cyclical component of global real economic activity.

As a first step in constructing his index of real economic activity, Kilian (2009) developed a monthly measure $x_t$ of the nominal cost of shipping. This was calculated by initializing $x_{1968:1} = 1$ and for each subsequent month through 2007:12 adding an average of the change in the natural logarithm across a set of different freight rates to the previous month’s value $x_{t-1}$,

$$x_t = x_{t-1} + \frac{\sum_{i=1}^I \delta_{it} \Delta \log p_{it}}{\sum_{i=1}^I \delta_{it}} \tag{1}$$

where $p_{it}$ is the cost of shipping a particular bulk dry cargo $i$ from monthly issues of Drewry’s Shipping Insight and $\delta_{it} = 1$ if that cost is known for $t$ and $t-1$. For data since 2008, Kilian and Murphy (2014) updated $x_t$ using the Baltic Dry Index ($BDI$) of shipping costs:

$$x_t = x_{t-1} + \Delta \log (BDI_t) \quad \text{for } t \geq 2008:1. \tag{2}$$

Kilian continued through 2018 to update $x_t$ using equation (2) and reported on his website a measure of real economic activity described in equation (3) below.

Kilian converted his nominal index $x_t$ into a real index by dividing $x_t$ by the U.S. consumer price index ($CPI_t$). He then took the log of this ratio,

$$\log(x_t/CPI_t) = \log(x_t) - \log(CPI_t),$$

and regressed the result on a linear time trend:

$$\log(x_t) - \log(CPI_t) = \alpha + \beta t + \varepsilon_t. \quad (3)$$

The residuals $\varepsilon_t$ from this regression are the Kilian index of real economic activity that has been used by the studies cited in footnote 1 and many others. This index is plotted in the top panel of Figure 1.

One feature of this construction that appears not to have been understood by the many users of this index is the following. Equation (2) implies that for $t \geq 2008:1$,

$$x_t = x_{2008:1} + \log(BDI_t) - \log(BDI_{2008:1}) \quad (4)$$

for $c_0 = x_{2008:1} - \log(BDI_{2008:1})$. No one before me had noticed the simple identity in (4), and Kilian has never made public his data for the underlying index $x_t$. However, it turns out to be possible to uncover the underlying series for $x_t$ from publicly available data. For $t \geq 2008:1$, the unknown value for $x_t$ is related to the observed value of $BDI_t$ according to equation (4) which involves a single unknown constant $c_0$. We further know that $z_t = \log(\log(BDI_t) + c_0) - \log(CPI_t) - \alpha - \beta t$ should be exactly equal to the value for $\varepsilon_t$ reported by Kilian for $t \geq 2008:1$ for some values of $c_0$, $\alpha$, and $\beta$. The values of $c_0$, $\alpha$, and $\beta$ can be estimated by a nonlinear least squares regression\(^2\) of the reported $\varepsilon_t$ on the value of $z_t$ using data after 2008 and $CPI$ of the appropriate vintages.\(^3\) The resulting estimated values for $c_0$, $\alpha$, and $\beta$ give the fitted regression an $R^2$ of unity in explaining $\varepsilon_t$, confirming that we have exactly replicated Kilian’s procedure. With $\alpha$ and $\beta$ thus known, the pre-2008 values of $x_t$ are then obtained by adding back in the time trend to $\varepsilon_t$.\(^4\)

The uncovered series for $x_t$ is plotted in the bottom panel of Figure 1. The value for $c_0$ turns out to be $-5.236$ when $x_{1968:1}$ is normalized to be unity. However, if the sequence $x_t$ had been generated with some initial value for $x_{1968:1}$ other than unity (corresponding to choosing

\(^2\)One could also find essentially the same answer using any arbitrary 3 data points. However, because of rounding errors in the reported data, a more accurate reconstruction of the original series is obtained by pooling all the observations in a nonlinear regression.

\(^3\)When matching Kilian and Murphy (2014), the CPI as reported in October 2009 was used (in order to match their data exactly), and when matching the data as downloaded from Kilian’s website in July 2018, the CPI as reported in April 2018 was used.

\(^4\)Data and code for all calculations and series produced in this paper are available at http://econweb.ucsd.edu/~jhamilto/REA.zip.
some month other than 1968:1 to be normalized to unity), the value of \( c_0 \) would be a different number. For example, if we started the recursion from a value of \( x_{1968:1} \) that results in a value for \( x_{1973:1} \) of 1, the value of \( c_0 \) would be \(-5.694\).

The implications of this can be seen when we substitute (4) into (3):

\[
\log[\log(BDI_t) + c_0] - \log(CPI_t) = \alpha + \beta t + \varepsilon_t. \tag{5}
\]

Taking logs twice is an uncommon procedure for economic data, but no one noticed prior to my paper that this is what the Kilian index used in the papers referenced in footnote 1 was in fact doing. One consequence of taking double logs in this context is that the resulting series for real economic activity \( \varepsilon_t \) would be different depending on the value of \( c_0 \), that is, different depending on whether we normalize \( x_{1968:1} \) to be 1, \( x_{1973:1} \) to be 1, or choose some other month to normalize to be 1. Figure 2 shows how different normalizations affect the resulting measure of real economic activity.

After seeing an initial draft of this paper, Kilian (forthcoming) revised his index, and bases it now on the residuals of the regression

\[ x_t - \log(CPI_t) = \alpha + \beta t + \varepsilon_t. \tag{6} \]

The original index based on (3) and the revised index based on (6) are compared in Figure 3. Kilian (forthcoming) wrote that the revised index “differs only slightly from the original index.” However, statistical tests in the following section find significant differences.

2 Evaluating alternative measures of real economic activity.

A primary motivation given by Kilian (2009, p. 1057) for the validity of his index as a measure of global real economic activity came from an anecdotal review of global developments over 1970-2007. He concluded, “Figure 1 is fully consistent with the anecdotal evidence on the relative importance and timing of these fluctuations in global real economic activity.” Applying that same standard to the more recent values of either of the indexes in Figure 3 raises substantial doubts about the measures’ continuing reliability. The series would lead us to conclude that the cyclical component of world economic activity reached a far lower level in 2016 than was seen in either the financial crisis of 2008-2009 or the 1974-75 global recession. That conclusion seems hard to justify on the basis of GDP data for any major country, and certainly does not square with the assertion in Kilian (2009, p. 1056) that “the level of global real economic activity as it relates to industrial commodity markets is proportionate to this index.” In later work, Kilian and Zhou (2018) stressed the index’s potential usefulness as a
leading indicator of global real economic activity. But we now have several years of data from
which we know that no great global collapse followed the indexes’ extreme bearish signal in
2016.

In this section I follow up with formal statistical tests, looking at evidence on stationarity,
coherence with known data on global real GDP, usefulness for modeling real commodity prices,
and other issues.

2.1 Deterministic time trends.
The implicit, but never tested, assumption behind the use of residuals from these time-trend
regressions is that either \( \log(x_t) - \log(CPI_t) \) for Kilian’s original index or \( x_t - \log(CPI_t) \) for
the revised index can be characterized as a stationary process around a deterministic linear
time trend. Letting \( s_t = x_t - \log(CPI_t) \) and using the sample of observations for \( t = 1968:1 \)
through 2018:6, an augmented Dickey-Fuller test (with 3 lags of \( \Delta s_t \)) of the null hypothesis
that \( s_t \) can be characterized as a unit-root process fails to reject the null at the 10% significance
level.\(^5\) Alternatively, the test of Kwiatkowski et al. (1992) takes the null hypothesis to be
that \( s_t \) is stationary around a linear time trend. This test leads to rejection of the null at the
1% significance level.\(^6\) Thus the assumption behind Kilian’s index is not supported by the
data.

If real shipping costs in reality contain a unit root, fitting a linear time trend causes the
residuals for date \( t \) to incorporate information about values observed through the end of the
sample. This could cause the residuals to perform spuriously well at in-sample forecasting
evaluations. In practice, we observe that the coefficients characterizing the time trend continue
to change as more data are added. For example, Figure 4 compares the time trend when
estimated through 2009:8 (the sample period used by Kilian and Murphy (2014)) with the
trend estimated through 2018:6.

2.2 Coherence with world economic activity.
The results in Section 2.1 suggest that a better way to obtain a stationary series is by differ-
cencing rather than regressing on a time trend. If we want the cyclical component, Hamilton
(2018) proposed that the two-year difference

\[ c_t = s_t - s_{t-24} \tag{7} \]

\(^5\) The \( t \)-statistic is \(-2.46\) with \( T = 603 \), which falls short of the 10% critical value of \(-2.57\) from Hamilton
(1994, Table B.6, Case 2).

\(^6\) Here I used 4 lags to obtain a test statistic of 0.321 which exceeds the 1% critical value of 0.216.
is often a robust way to isolate the cyclical component of most economic time series.\footnote{Hamilton (2018) proposed that we could isolate the cyclical component more generally using an OLS regression. Given the evidence of a unit root noted above, here we use the simple and more robust alternative in equation (7). This also simplifies interpretation of forecasting regressions below as it is a true real-time measure.} Kilian’s revised index is compared with (7) in the top two panels of Figure 5. The reason that Kilian’s measure regards 2016 as the worst downturn in record is in part because a linear trend was used to construct it. The measure in the second panel, which does not assume a linear time trend, would still describe 2016 as a severe contraction, but not worse than the global financial crisis. Notwithstanding, a big factor in the record low shipping prices in 2016 was overbuilt shipping capacity, not a severe global economic contraction.

OECD Main Economic Indicators published an estimate of monthly industrial production for the OECD plus 6 other major countries (Brazil, China, India, Indonesia, the Russian Federation and South Africa). The OECD series begins in 1958:1 and ends in 2011:10.\footnote{Kilian and Zhou (2018, Table A1a) mistakenly assert that the series is only available since 1973:1. Kilian and Zhou (2018, p. 66) also give the mistaken impression that this series only included China beginning in 2006. In fact, China has been included in the world industrial production index at least since 1999.} Baumeister and Hamilton (2019) reproduced the methodology by which the original index was constructed to extend the series through 2018:7.\footnote{This series is regularly updated at https://sites.google.com/site/cjsbaumeister/research.} The bottom panel of Figure 5 plots the cyclical component of the log of this series again using the two-year difference (7). Unlike the Kilian index, the industrial production data imply that the 1974-75 and 2008-2009 recessions were clearly the most significant downturns in global real activity during this period. The series also suggests that there was a period of strong growth following the recovery from the 2008-2009 downturn, and characterizes 2015-2016 as sluggish global growth rather than a separate severe global contraction. All of this accords well with what is commonly understood about global economic activity.

Kilian and Zhou (2018) argued that one drawback to using world real GDP is that researchers often want to estimate higher frequency models, and they state that quarterly real GDP is only available since 1990. However, the World Bank has published estimates of annual world real GDP going back to 1960. One obvious check is to look at the correlation between these annual figures and alternative proposed monthly measures of the cyclical component of real economic activity. Consider an OLS estimation of

\[
g_t = \alpha + \beta c_t + v_t
\]

where \(g_t\) is the growth rate of world real GDP in year \(t\), \(c_t\) is a proposed cyclical measure as of the last month of year \(t\), and \(t\) runs from 1971 to 2017. Row 1 of Table 1 shows that the cyclical component of industrial production is very strongly correlated with observed annual GDP growth. By contrast, the correlation between GDP growth and either of Kilian’s measures is not statistically significant at conventional levels (rows 2 and 3). The cyclical
component of real shipping costs (row 4) does somewhat better than Kilian’s measures but is not nearly as strongly related to GDP as is world industrial production.

Kilian and Zhou (2018) also noted that delays in obtaining the GDP or industrial production numbers undermines their usefulness for real-time assessment. For example, as of January of year \( t+1 \) we would know the value of the BDI and CPI for December of year \( t \) (and thus could construct any of the measures in rows 2-4 of Table 1 as of January) but would typically only know the value for industrial production through June of year \( t \) at that time. Kilian and Zhou (2018, p. 58) asserted that another advantage of their approach is that “the Kilian index [is] a leading indicator with respect to global real output, unlike global industrial production, which is a coincident indicator,” though they provided no statistical evidence in support of this claim.

One obvious way to evaluate both concerns is to base the industrial-production measure \( c_t \) for year \( t \) on the June value of industrial production rather than December, evaluating equation \( (8) \) as a possible tool for purposes of nowcasting. Row 5 of Table 1 shows that the June value is still quite useful. Indeed, one gets a far better picture of world GDP growth for year \( t \) by looking at industrial production through June of that year rather than shipping costs through December. Interestingly, either of Kilian’s measures based on shipping costs through June actually have a slight negative correlation with what world GDP growth for that year turned out to be.

### 2.3 Forecasting commodity prices.

Another argument given by Kilian and Zhou (2018) in favor of their measure is based on its purported usefulness for modeling commodity prices. Here I investigate this claim using a number of different commodity prices. Let \( p_t \) be the change in the logarithm of the real price of a particular commodity or index of commodities between month \( t-1 \) and \( t \) and \( z_t \) either the growth rate of industrial production or one of the two Kilian measures. Consider forecasting regressions of the form

\[
p_t = \alpha + \sum_{j=1}^{3} \phi_j p_{t-j} + \sum_{j=1}^{3} \beta_j z_{t-j} + v_t. \tag{9}
\]

Table 2 reports \( p \)-values for the \( F \)-test of the null hypothesis \( H_0 : \beta_1 = \beta_2 = \beta_3 = 0 \) that the measure of real economic activity is of no use for forecasting the commodity price \( p_t \). The commodity prices considered are the World Bank’s two broad commodity price indexes (energy and non-energy), two more specialized indexes (agriculture and base metals), and prices of four important individual commodities (crude oil, soybeans, aluminum and copper). The

---

10 An alternative option is to use the production-weighted index of world industrial production that is included in the World Trade Monitor Database reported by CPB Netherlands Bureau for Economic Policy Analysis. This series begins in January 2000 and is reported with only a two-month delay. Its growth rate is similar to the OECD+6 index and appears to be a good way to update the OECD+6 index.
regression (9) was estimated for $t = 1968:4$ to 2018:2. Industrial production has statistically significant coefficients for purposes of forecasting every commodity except aluminum. The Kilian-Zhou index does not give statistically significant predictions of any of these prices. The Kilian (forthcoming) index gives better forecasts than Kilian-Zhou, and is statistically significant for purposes of predicting the agricultural price index, the base-metals price index, and copper prices. But it is never as good as industrial production.

2.4 Additional considerations.

Finally I offer some observations on the nominal shipping index $x_t$ itself. One notices in the bottom panel of Figure 1 that this series seems to behave differently before and after 2008. This was the date at which Kilian switched from updating the index using equation (1) to updating it based purely on the BDI as in equation (2). Odom (2010) noted that changes in the methodology behind BDI may have contributed to its volatility. Figure 6 compares Kilian’s nominal index $x_t$ with the path it would have taken since 2008 if he had continued to update it using equation (1). The series would exhibit less of a downward trend, less of a drop in 2016, and less volatility.

If in spite of the many issues raised above one still wanted to use the BDI as a measure of global real economic activity, it has the appealing feature that it is actually available daily.\footnote{Daily values for the BDI were obtained from TradingEconomics.com.} To use the daily BDI as a cyclical indicator, the evidence in Sections 2.1 and 2.2 argues strongly for using a two-year difference rather than residuals from a linear time trend.\footnote{Bruno, Büyükşahin, and Robe (2016) used residuals from a regression of the BDI on a linear time trend to construct a weekly indicator of economic activity. They did not propose solutions to how to develop this into a practical real-time estimator.} A daily indicator could thus be obtained from

$$c_t = \log(BDI_t/CPI_t) - \log(BDI_{t-(2 \times 247)}/CPI_{t-(2 \times 247)})$$

where $t$ now denotes daily data with 247 the number of business days in a year and $CPI_t$ is a value for the consumer price index associated with day $t$. Constructing the latter raises two modest technical challenges. First, the $CPI$ is only available with a lag, and second, the $CPI$ only changes at monthly intervals. To solve these issues, I associated the value of the BDI for the first business day in March with the $CPI$ for January,\footnote{Alternatively, if the goal is to develop a daily index for use in historical academic research rather than for real-time nowcasting, one could logically associate the value of the BDI for the 11th business day in March with the $CPI$ for March and linearly interpolate using the $CPI$ for April to fill in subsequent days in March and the first 10 business days in April.} and linearly interpolated between the January and February $CPI$ to fill in each subsequent day in March.\footnote{An alternative would be to use daily nowcasts of the CPI developed by Knotek and Zaman (2017) and updated by the Federal Reserve Bank of Cleveland. A drawback of this is that the series would exhibit discrete jumps at release dates, unlike the procedure developed here.} The resulting
series, plotted in Figure 7, might in the spirit of Kilian (2009) be viewed as a daily indicator of the cyclical component of global real economic activity.

3 Conclusions.

This paper made publicly available for the first time details that allow researchers to investigate the properties of popular measures of global real economic activity based on shipping costs. Doing so uncovered significant problems in a widely-used index and established that alternative approaches to handling the trend in shipping costs offer both a better description of the shipping data and better coherence with world GDP. Notwithstanding, monthly estimates of world industrial production are far better than measures based on shipping costs at describing world GDP or predicting commodity prices.
References


Table 1. Results from regressions of year $t$ world real GDP growth on alternative measures of global economic activity as of December or June of year $t$.

<table>
<thead>
<tr>
<th>Measure of real economic activity</th>
<th>$t$-statistic</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>December</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1) Industrial production</td>
<td>12.21</td>
<td>0.77</td>
</tr>
<tr>
<td>(2) Kilian-Zhou (2018)</td>
<td>1.45</td>
<td>0.04</td>
</tr>
<tr>
<td>(3) Kilian (forthcoming)</td>
<td>1.27</td>
<td>0.03</td>
</tr>
<tr>
<td>(4) Real shipping cost</td>
<td>3.68</td>
<td>0.23</td>
</tr>
<tr>
<td><strong>June</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(5) Industrial production</td>
<td>5.23</td>
<td>0.38</td>
</tr>
<tr>
<td>(6) Kilian-Zhou (2018)</td>
<td>-0.52</td>
<td>0.01</td>
</tr>
<tr>
<td>(7) Kilian (forthcoming)</td>
<td>-0.53</td>
<td>0.01</td>
</tr>
<tr>
<td>(8) Real shipping cost</td>
<td>0.77</td>
<td>0.02</td>
</tr>
</tbody>
</table>

Notes to Table 1. The table reports the $t$-statistic on $\beta$ and the $R^2$ from OLS estimation of equation (8) for $c_t$, the cyclical component of the log of world industrial production in December (row 1) or June (row 5) of year $t$; the index used by Kilian and Zhou (2018) (as obtained by downloading from Kilian’s webpage July 2018) for December (row 2) or June (row 6) of year $t$; the index proposed by Kilian (forthcoming) (as obtained by downloading from Kilian’s webpage April 2019) for December (row 3) or June (row 7) of year $t$; and the cyclical component of real shipping costs (from equation (7)) for December or June.
Table 2. *P*-values for tests of null hypothesis that alternative measures of real economic activity are no help in forecasting real commodity prices.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>0.02</td>
<td>0.33</td>
<td>0.16</td>
</tr>
<tr>
<td>Non-energy</td>
<td>&lt; 0.01</td>
<td>0.15</td>
<td>0.06</td>
</tr>
<tr>
<td>Agriculture</td>
<td>&lt; 0.01</td>
<td>0.10</td>
<td>0.05</td>
</tr>
<tr>
<td>Base metals</td>
<td>0.01</td>
<td>0.12</td>
<td>0.02</td>
</tr>
<tr>
<td>Crude oil</td>
<td>0.05</td>
<td>0.52</td>
<td>0.27</td>
</tr>
<tr>
<td>Soybeans</td>
<td>0.05</td>
<td>0.14</td>
<td>0.08</td>
</tr>
<tr>
<td>Aluminum</td>
<td>0.06</td>
<td>0.38</td>
<td>0.08</td>
</tr>
<tr>
<td>Copper</td>
<td>0.01</td>
<td>0.06</td>
<td>0.02</td>
</tr>
</tbody>
</table>
Figure 1. Kilian’s original monthly index of real economic activity and underlying nominal index, 1968:1 to 2018:6.

Notes to Figure 1. Top panel: calculated by the author as 100 times the residuals from regression (3) when $x_{1968:1}$ is normalized at 1. Bottom panel: constructed by the author as described in the text. Shaded regions denote NBER U.S. recession dates.
Figure 2. Residuals from regression (3) for two different normalizations for the level of $x_i$. 
Figure 3. Comparison of the measures used by Kilian and Zhou (2018) and Kilian (forthcoming).

Notes to Figure 3. Black: series downloaded from Kilian’s webpage July 2018. This is the measure used by Kilian and Zhou (2018), and corresponds to 100 times the residuals from regression (3). Dotted red: series downloaded from Kilian’s webpage April 2019. This is the measure used by Kilian (forthcoming) and corresponds to 100 times the residuals from regression (6).
Figure 4. Real cost of shipping and time trends estimated over two different samples.

**Real shipping cost with different time trends**

Figure 5. Alternative measures of global real economic activity.

Notes to Figure 5. Top panel: measure used by Kilian (forthcoming), 1968:1-2018:6, obtained by downloading the real activity measure from Kilian’s webpage in April 2019. Middle panel: cyclical component of real shipping costs, as calculated by equation (7) with $s_t = 100[x_t - \log(CPI_t)]$. Result is plotted for 1970:1-2018:6. Bottom panel: cyclical component of world industrial production, as calculated by equation (7) with $s_t$ 100 times the log of the industrial production index for OECD plus 6 major countries. Result is plotted for 1960:1-2018:6. Shaded regions denote NBER U.S. recession dates.
Figure 6. Alternative measures of nominal shipping costs.

Notes to Figure 6. Solid black: nominal index $x_t$ underlying Kilian’s real activity index; constructed by the author as described in the text. Beginning 2008:1 the change in $x_t$ is simply the change in the log of the BDI. Dotted red: results of extending $x_t$ after 2008:1 using equation (1).
Figure 7. Daily cyclical component of real shipping cost, March 16, 2011 to July 16, 2018.