

# Oil-Consumption-Weighted GDP: Description, Calculation, and Comparison

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May 2016

This paper is released to encourage discussion and critical comment. The analysis and conclusions expressed here are those of the authors and not necessarily those of the U.S. Energy Information Administration. Our thanks to Vinay Tripathi, summer intern from Stanford University, for his background research on this project.

## Summary

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We outline an alternative measure of gross domestic product (GDP) for regional country groupings that accounts for the relative level of oil consumption within each of the component countries. This analysis specifically focuses on aggregate oil-weighted GDP indices for the OECD (Organization for Economic Cooperation and Development), non-OECD, and world. We detail the calculation of this oil-weighted GDP index and compare growth rates for the OECD, non-OECD, and world with those from GDP series based on purchasing power parity (PPP) and market exchange rates (MER). We then explore these differences by showing how oil intensity—oil consumption as a share of GDP—varies for these groups based upon the GDP series used.

## Introduction

For many people across Alabama and Louisiana, up into Ohio and way out in California, the release of preseason college football rankings marks the end of summer and the transition to the best time of year. As the fall season creeps closer—traffic picks up, the kids start to dread the upcoming school year—various outfits order the best teams in the country from 1 to 25, before a single game has been played. As strange as it seems, the formation of these rankings has some similarities to forecasts of oil consumption.

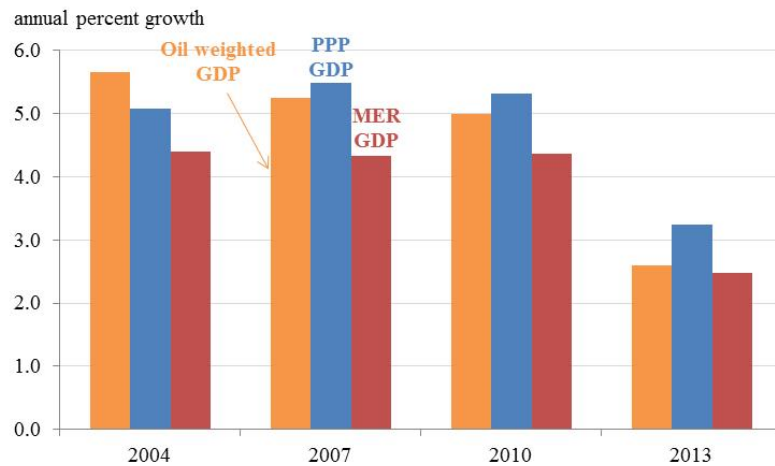
For both preseason rankings and oil consumption forecasts, estimates must be made based on old information and the extension of that data to the future. College football pollsters invariably modify their extrapolations of past performance based on other things, including the quality of returning players, “intangibles”, and the like. Those forecasting oil consumption do so as well: they generally use predictions of future growth in real [inflation-adjusted] gross domestic product (GDP), consider the implications of national policies and technologies on oil demand, and factor in geopolitical risks.

Because it is available for most countries, GDP is often used in forecasting models of international oil consumption. However, in order to calculate world [or regional] GDP growth rates, individual country GDPs must first be converted from their local currencies to a common one. There are two standard ways to do this: (1) using exchange rates determined by national authorities or in legally-sanctioned markets where currencies are traded (i.e., market exchange rates (MER)), or (2) using purchasing power parities, sometimes called PPP exchange rates.<sup>1</sup> The country values can then be aggregated to a world or regional total for growth rate calculations.

One element that most crude oil forecasters ignore when using standard world GDP measures is its distribution among oil consumers. Yet, it matters for total oil consumption whether economic growth is occurring in countries that use oil heavily [with respect to their total economic output], or is concentrated among those countries that consume relatively little. In this paper, we outline one modification to account for this: a GDP index and growth rate weighted by oil consumption. The oil-weighted index still uses GDP as a measure of economic activity, but relates it to oil consumption through weights tied to each country’s share of total world oil consumption. Such an adjustment can have a significant effect on observed world GDP growth rates [Figure 1].

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<sup>1</sup> The PPP exchange rate is the number of units of a country’s currency required to buy the same amount of goods and services in domestic markets as a U.S. dollar would buy in the United States. For more on converting GDP to a common currency see Vipin Arora (2015), “Currency Conversion and Energy Projections: Some Questions and Answers,” EIA Working Paper. URL: [https://www.eia.gov/workingpapers/pdf/mer\\_ppp\\_arora.pdf](https://www.eia.gov/workingpapers/pdf/mer_ppp_arora.pdf).

**Figure 1: Comparison of growth in real world GDP for select years**

Source: EIA, Oxford Economics

The oil-weighted index shows higher annual growth in real world GDP than MER-based estimates over the last decade, especially before 2010. It is also higher than the PPP growth rate in 2004, but below it thereafter. This is because economic growth in the OECD countries slowed more than in the non-OECD countries during and following the 2008 recession that occurred in many advanced economies. One major benefit of the index—implicit in the figure, but explicit in its calculation—is that it places a heavier emphasis on economic growth occurring in countries that are large oil consumers relative to those that are not. Moreover, the oil-weighted index is conceptually simple and straightforward to calculate.

The remainder of this paper reviews the oil-weighted GDP index in detail. We begin by outlining some reasons for its use, describe its calculation, and then compare historical and forecast growth rates from the index with those from GDP converted at MER or PPP rates. We then explore the shortcomings in the oil-weighted index, such as the differences in the elasticity of consumption with respect to GDP across countries and over time, which is partly reflected in changing energy intensities, and conclude with a general discussion of the oil-weighted index, including its strengths and weaknesses along with potential areas for further research.

## Comparing World GDP Growth Rates

Standard methods of aggregating and calculating GDP growth in country groups—using MER or PPP exchange rates—have no specific tie to energy consumption. Rather, they convert GDP from local currency units to a common one, usually the U.S. dollar, based on exchange rates that take account of many goods and services. Yet for those concerned with understanding and forecasting oil consumption, the distribution of oil consumption—in addition to economic growth—within and between country groups can be important. It is for this reason that the oil-weighted GDP index is a useful addition to GDP series based on PPP or MER exchange rates.

A simple two-country world, which includes only China and the United States, is a useful example for understanding the differences in the calculation of world GDP using the three different methods [see Appendix A for detailed calculations]. In 2010, the real GDP of China and the United States were 53.4

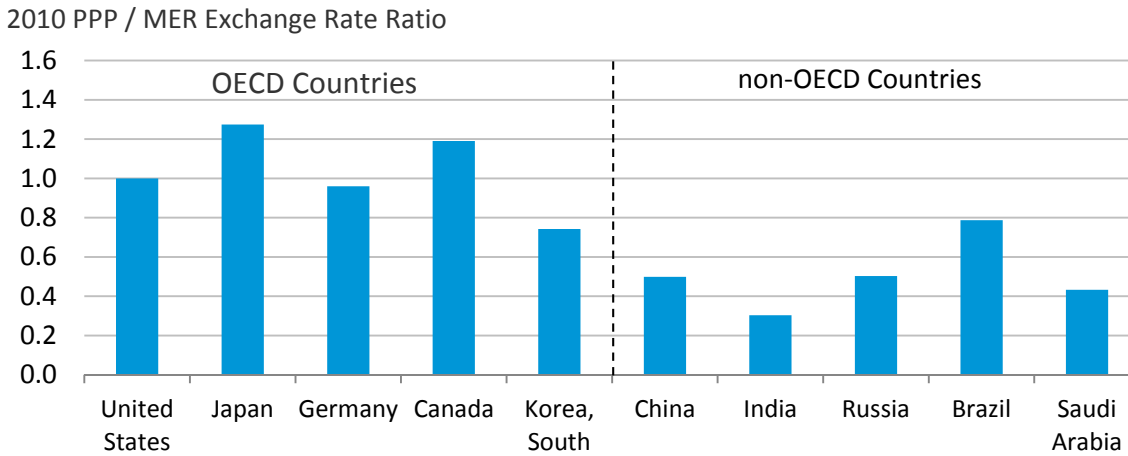
billion yuan and 15.0 billion dollars, respectively. That year, China's yuan-to-dollar exchange rates were 3.38 for the PPP and 6.77 for the MER.<sup>2</sup> Based on the PPP exchange rate, China's real GDP in 2010 accounted for 45% of the two-country world total. The MER exchange rate, on the other hand, resulted in a conversion of China's real GDP so that it was only 29% of the world total. Consequently, China's GDP gets more weight in the calculation of world GDP using the lower PPP exchange rate. Moreover, because of China's higher GDP growth rate [9.5% from 2010 to 2011 compared with the 1.6% growth in U.S. real GDP], the aggregated world GDP growth rate is also higher [5.2% based on the PPP compared with 3.9% using the MER]. China's share of oil consumption in 2010 was 32% of the two-country total and the calculated oil-consumption-weighted GDP growth rate in 2011 was 4.1%, close to that of the MER-based world GDP growth rate.

Differences between the MER and PPP exchange rates are generally greatest for the non-OECD countries. For example, five OECD and five non-OECD countries make up the top 10 oil-consuming countries in the world (representing almost 60% of total world consumption). In 2010, the average PPP/MER exchange rate ratio of the five OECD countries was 1.03 while the average ratio of the five non-OECD countries was 0.50 [Figure 2]. Because of the lower PPP/MER exchange rate ratios for the non-OECD countries, the GDP growth rates in these countries make smaller contribution to the MER-based world GDP growth rate compared with the PPP-based world GDP growth rate. Further, because the GDP growth rates of non-OECD countries have generally been much stronger than those in the OECD in recent years, the calculated MER-based world GDP growth rates have been lower than the PPP-based world growth rates [Figure 1].

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<sup>2</sup> The PPP/MER ratio (0.51 for China in the example above) is often referred to as the national price level. It tells how many dollars are needed to buy a dollar's worth of goods in the country as compared with the United States. For example, based on the PPP, you could purchase 1 unit of goods and services for 3.38 yuan. On the other hand, if you had 1 dollar, you could exchange that for 6.77 yuan on the currency exchange market and purchase 2 units of goods and services in China.

**Figure 2: 2010 PPP/MER Exchange Rate Ratios of 10 Largest Oil Consuming Countries**

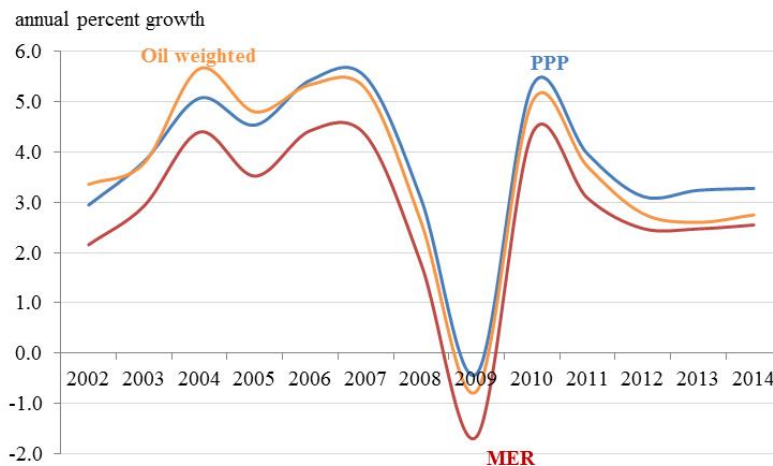


Source: EIA, Oxford Economics

**Figure 3**, **Figure 4**, and **Figure 5** compare 2002-14 annual growth rates of real GDP for the world, OECD, and non-OECD from our oil-consumption-weighted index, with series based on MER and PPP exchange rates.<sup>3</sup> **Figure 6** compares forecasts of GDP growth in 2016.

In terms of world GDP, year-over-year MER-based growth rates are lower than both the oil-weighted index and PPP-based series for almost every year in the sample [**Figure 3**]. The oil-weighted world GDP grows faster than the PPP series through about 2006, but slower thereafter. The less developed countries—which have grown faster—are relatively more important in the PPP and oil-weighted series, compared with the MER-based ones until the last couple of years.

**Figure 3: Comparison of annual growth in real world GDP**

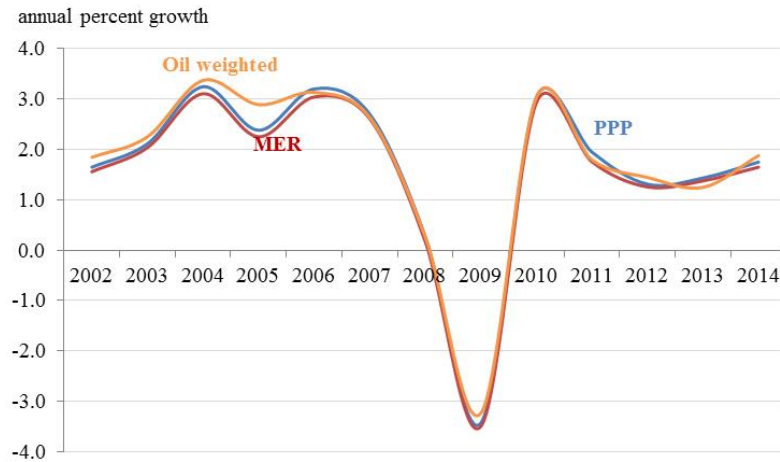


Source: EIA, Oxford Economics

<sup>3</sup> The historical MER and PPP data shown in **Figure 1-Figure 13** are from Oxford Economics, the oil consumption weighted GDP and oil consumption values are from EIA calculations based on EIA and IHS Global Insight data.

Figure 4 shows that, unlike the world, historical GDP growth rates for OECD countries across the three GDP series are generally similar when looking at year-over-year growth. However, the OECD oil-weighted index growth rates are higher than the MER and PPP-based ones in 2005, reflecting the stronger growth in the United States relative to most other OECD countries, which pushes up oil-weighted growth because the United States is such a large oil consumer.

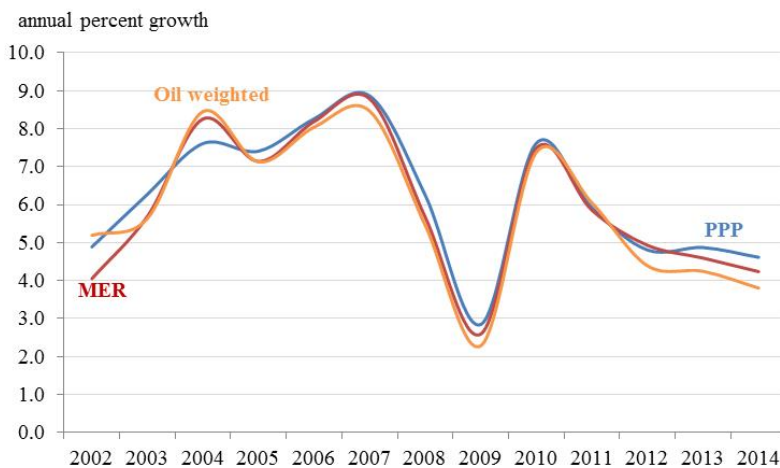
Figure 4: Comparison of annual growth in OECD real GDP



Source: EIA, Oxford Economics

Growth rate differences in the three GDP series follow a different pattern for non-OECD countries. Annual rates for each are relatively close between 2006 and 2011 [with PPP slightly higher than the other two], but there are clear differences in other years [Figure 5]. The differences at the end of the period are primarily due to the slowing of Chinese and Indian GDP growth, which have a substantial impact on the oil-weighted series because of their importance as oil consumers.

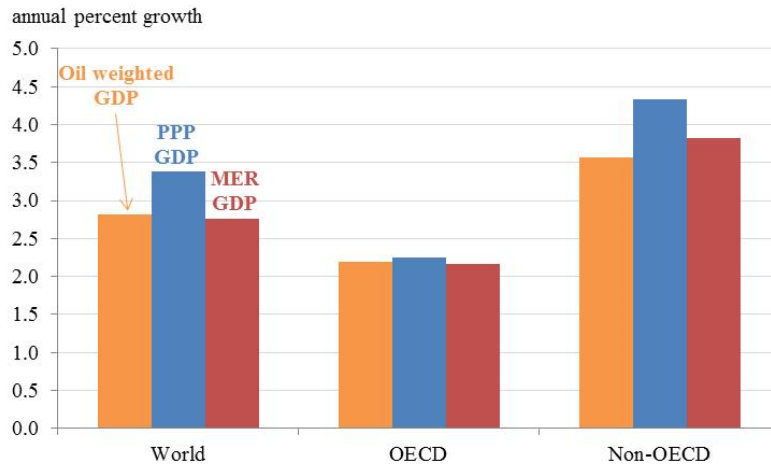
Figure 5: Comparison of annual growth in non-OECD real GDP



Source: EIA, Oxford Economics

PPP-based GDP growth rates also are higher than the other two when comparing forecasts for 2016 [Figure 6].<sup>4</sup> This difference is most pronounced for non-OECD countries, less so for the world, and barely discernable in the OECD. Forecast growth in the oil-weighted GDP index is closest to that of MER-based GDP for the world and non-OECD in 2016.

**Figure 6: Forecast annual growth in 2016**



Source: EIA, IHS Global Insight

We show below that some of these differences depend on the base year selected for the calculation of the MER and oil-weighted GDP measures. A change in the base year alters each country's MER and their share of world oil consumption.<sup>5</sup>

What else explains these trends? Much of it likely has to do with how the GDP measure is weighted. PPP exchange rates allow volume comparisons across countries by accounting as much as possible for price differences. The oil-weighted index in effect does something similar by weighting each country's GDP by its volumetric share in total oil consumption. Instead of increasing the value of GDP in countries where prices for non-traded goods are especially low, as happens with PPP conversions, the index increases the value of GDP in countries where oil consumption is relatively high.

So oil-weighted GDP grows robustly in the early 2000s because large oil consumers were also growing robustly, particularly the OECD countries and China. However, index growth slowed as some bigger consumers experienced a major recession and relatively tepid recoveries, and the Chinese economy began to transition away from energy-intensive industries. In terms of forecasts, index growth is lower than that of PPP GDP because bigger oil consumers such as China and Europe are expected to grow

<sup>4</sup> The MER and PPP data are from IHS Global Insight, the oil consumption weighted GDP values are from EIA calculations based on EIA and IHS Global Insight data.

<sup>5</sup> PPPs are published by the [International Comparison Program \(ICP\)](#) only for a single benchmark year (PPP conversion factors are based on the 2011 ICP round), although the OECD and Eurostat publish estimates for 47 countries on an annual basis. Because PPPs for other years are [extrapolated according to country GDP deflators](#), the selection of a different year as the base year does not change the calculated world GDP growth rates.



slower than countries such as India, where GDP is substantially underestimated because of price differences.

## Calculation of Oil Consumption-Weighted GDP

Oil-weighted GDP is calculated in several steps. First, we gather historical and forecast levels of real GDP for as many countries as possible from around the world. These data series are measured in local currencies and may have different base years. To make them consistent, we then create a GDP index for each country, where the base year/quarter value is set to 100.<sup>6</sup> EIA's base year/quarter is currently 2010Q1.

The next step is to gather historical oil consumption volumes for each of those countries for which we have GDP estimates.<sup>7</sup> Oil consumption data can change significantly from year to year in some countries, and in order to minimize the effect of this volatility on the weighted index, we also choose a base year and calculate each country's shares of total consumption for that specific year [currently 2010]. For a world GDP growth rate, each country's oil consumption is calculated as a share of the total for all of the countries. Similarly, we can calculate an OECD or non-OECD GDP growth rate using each OECD or non-OECD country's consumption as a share of OECD or non-OECD total consumption, respectively.

The final step is to combine all the information [oil-consumption shares and GDP indices] in order to calculate an overall GDP index for the world, OECD countries, and non-OECD countries. We do this using a weighted geometric mean, where the final value of the weighted index for a given year is proportional to the product of each country's GDP index raised to the power of its share. Specifically:

$$GM_t = \left( \prod_{i=1}^N gdp_{i,b,t}^{sh_i} \right)^{1/\sum_{i=1}^N sh_i} \quad [1]$$

where  $GM_t$  is the geometric mean at time  $t$ ;  $gdp_{i,b,t}$  is the GDP index for country  $i$ , with base year  $b$ , at time  $t$ ; and  $sh_i$  is the share of country  $i$ 's oil consumption relative to either the world, OECD, or non-OECD total in a pre-specified base year.

For example, to get a value for the world index in 2015, we take the calculated GDP index value of each country in 2015 and raise it to a power that is equal to its respective share of world oil consumption in 2010. We then multiply all of these weighted indices together to get a value for world oil consumption weighted GDP in 2015.

Why use a geometric mean instead of a standard arithmetic one? Primarily because such averages are less sensitive to outliers, and GDP data at the country level are notoriously volatile on a year-to-year basis.<sup>8</sup> The geometric mean in effect "normalizes" the various indices so that the values for a larger

<sup>6</sup> The source for the GDP data is IHS Global Insight; the historical values come from various national statistical agencies, and in some cases IHS themselves, while the forecasts are from IHS.

<sup>7</sup> These are based on petroleum consumption data from EIA's international energy statistics, see: <http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm>.

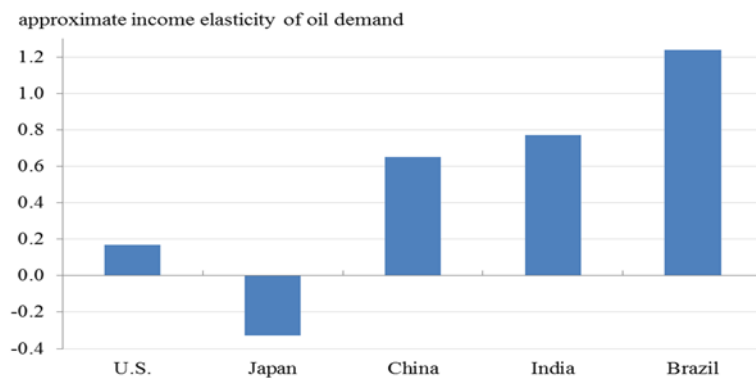
<sup>8</sup> See Lawrence Spizman and Marc A. Weinstein (2008). A Note on Utilizing the Geometric Mean: When, Why and How the Forensic Economist Should Employ the Geometric Mean. *Journal of Legal Economics* 15(1): p. 43-55.

country do not dominate the weighting over smaller ones, or so that outliers have less of an impact on the final values.

## GDP Elasticity of Consumption

A significant shortcoming of using an aggregated regional or world oil-consumption-weighted GDP growth rate [as well as the MER- and PPP-weighted rates] as an indicator of world oil consumption growth is that it does not account for differences in the elasticity of oil consumption with respect to changes in GDP [and income] across countries. Generally, the percentage change in oil consumption for a 1% change in real GDP is larger for the emerging economies [e.g., non-OECD countries] than in the advanced economies [e.g., those in the OECD] [Figure 7]. For example, increasing incomes have a greater effect on transportation use in the emerging economies because of the increasing proportion of households that own and drive vehicles.

**Figure 7: Average GDP elasticities of oil consumption for select countries, 1992-2013**



Source: EIA, Oxford Economics

First, consider the two largest oil-consuming countries that are members of the OECD: the United States and Japan. From 1992 through 2013, oil consumption grew by 0.6% per year in the United States, while real GDP grew by an average of 2.6%. These growth rates imply a simple average elasticity of oil consumption with respect to GDP over this time of +0.17 ( $= 0.6\%/2.6\%$ ). In Japan, which was the world's second largest economy over much of this period, oil consumption fell by an average of 0.7% per year while real GDP increased by an average of 0.85%, yielding an average elasticity of -0.33 ( $= -0.7\%/0.85\%$ ). The world's two largest economies for much of the period had either slow or negative oil consumption growth relative to GDP.

Contrast this with China, where the average GDP elasticity of consumption averaged 0.65 from 1992 to 2013, or India where the average elasticity was 0.77. Consumption in Brazil was even more responsive than these two, with oil consumption growth outpacing real GDP growth, yielding an average elasticity of 1.24.

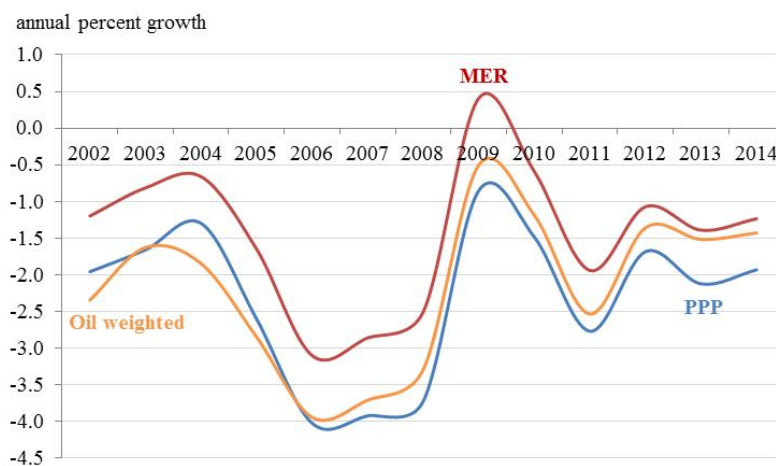
Consequently, when using any aggregated regional or world GDP growth rate as an indicator of oil consumption growth, it is important to differentiate which economies are growing the strongest, and a distinction between OECD from non-OECD countries, at a minimum, would improve the analysis.

## Oil Intensity

Even after separating OECD from non-OECD countries, forecasting oil consumption based on regional GDP growth rates is still problematic because GDP elasticities of consumption are different across countries and are not constant over time. An indicator of different and changing elasticities is the change in oil intensity (oil consumption as a share of GDP), particularly when examined in context over the business cycle.

**Figure 8**, **Figure 10**, and **Figure 12** show the annual change in oil intensity over the 2002-2013 period for the world, OECD, and non-OECD.<sup>9</sup> **Figure 9**, **Figure 11**, and **Figure 13** show average annual growth rates of real GDP and oil consumption over different ranges of time for the same three regions.

**Figure 8: Comparison of annual growth in world oil intensity using different GDP series**

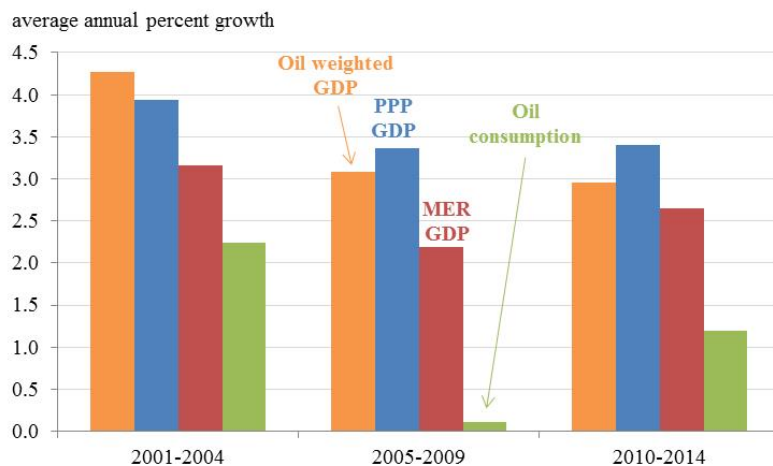


Source: EIA, Oxford Economics

World oil intensity is generally declining for all of the GDP series over this time period [**Figure 8**]. Oil-weighted GDP falls the fastest until around 2005, and PPP-based oil intensity falls fastest thereafter. MER-based oil intensity shows the slowest rate of decline of the three series. What is driving the differences in decline rates?

<sup>9</sup> We use the growth rates of oil intensity because level values are very different due to the conversion methods.

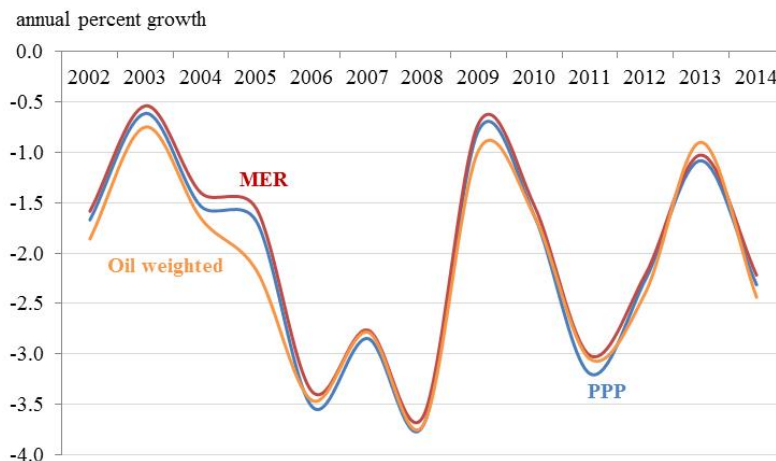
**Figure 9: Comparison of average annual growth in real world GDP**



Source: EIA, Oxford Economics

Over this entire time period real GDP grows faster than oil consumption, although oil consumption growth shows larger variation [Figure 9]. As a result, it appears that the changes in world oil intensity growth follow periods of higher and lower oil consumption growth: oil consumption grew robustly from 2001-04, and oil intensity declined at a lower rate; oil consumption growth slowed dramatically over the 2005-09 period and oil intensity growth increased for most of those years; and oil consumption grew moderately from 2010-14, similar to oil intensity.

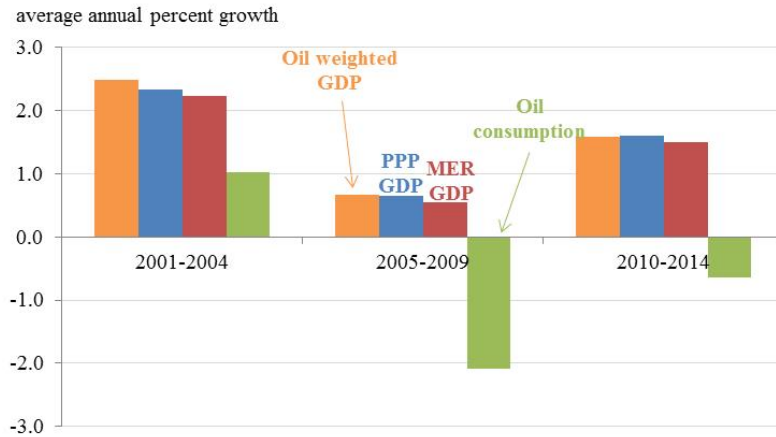
**Figure 10: Comparison of annual growth in OECD oil intensity using different GDP series**



Source: EIA, Oxford Economics

Year-over-year declines in energy intensity for the OECD are similar across the three series, with the exception of 2002-05 [Figure 10]. This is consistent with the similar rates of GDP growth after 2005 across the series highlighted in Figure 11.

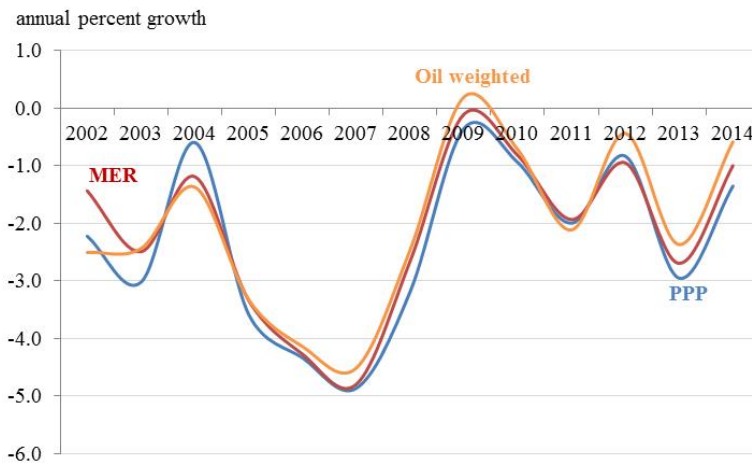
**Figure 11: Comparison of average annual growth in real OECD GDP**



Source: EIA, Oxford Economics

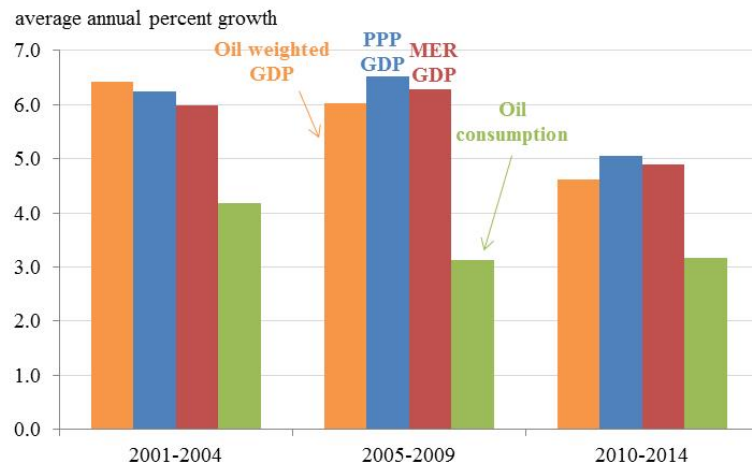
As with the world, the variations in OECD oil intensity mainly follow those in oil consumption growth. However, changes in GDP growth do appear to play a more important role here, particularly over the 2010-14 period.

**Figure 12: Comparison of annual growth in non-OECD oil intensity using different GDP series**



Source: EIA, Oxford Economics

The Non-OECD shows more divergence in oil intensity than the OECD over time [Figure 12]. After 2005, the PPP-based series shows the fastest decline, but oil-weighted shows the slowest. The MER growth rate generally stays between the other two for most of the period.

**Figure 13: Comparison of average annual growth in real non-OECD**

Source: EIA, Oxford Economics

Oil intensity changes appear to follow both GDP and oil consumption growth for the non-OECD [Figure 13]. Although GDP growth does not change much through 2009, the declines in oil intensity accelerate with the decrease in oil consumption growth. After 2009, real GDP growth falls and oil consumption growth remains steady, but oil intensity declines slow in conjunction with GDP.

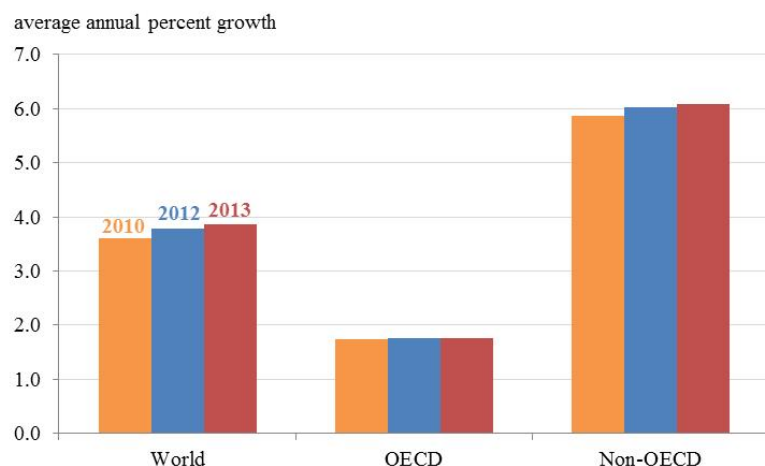
In general, world oil intensity falls at a slower rate for MER-based series than the other two, and it falls fastest for the PPP-based intensity. The PPP-based series also declines at the fastest rate for the non-OECD, but oil-weighted intensity declines slowest. The changes in oil intensity are similar for the OECD across the series. The trends in oil intensity mirror those in the GDP growth rates over time

### Changes in Base Year Weights

As described above, oil-weighted world, OECD, and non-OECD GDP growth rates use consumption shares in a base year [currently 2010] as weights when aggregating country-level GDP growth rates. Figure 14 shows how average annual growth rates over the 2002-14 period vary for these regions when the base year is changed from 2010 to 2012 or 2013.<sup>10</sup>

<sup>10</sup> Oil consumption shares for 2014 are currently unavailable.

**Figure 14: Comparison of average annual growth from 2002-2014 with different base years for oil consumption weights**



Source: EIA, Oxford Economics

It appears that there are differences for both the non-OECD and world with changes in base years, and that growth is slightly higher. For the world, this is because the non-OECD share of world consumption is increasing, and the corresponding non-OECD rate of GDP growth rate is higher than the OECD.

This shift occurs within the non-OECD as well: China and India comprise a greater share of oil consumption in 2012 and 2013 than in 2010, and each grows faster than the non-OECD average during the 2002-14 period. Therefore, changes in the base year for oil consumption can affect GDP growth rates, but the differences are not huge.

## Conclusion

The oil consumption weighted GDP index we outline in this paper has several strengths. Most important is that—unlike standard measures of GDP—it takes the distribution of oil consumption across countries into consideration. As a weighted index, the measure is also conceptually straightforward, and it can be calculated using a simple geometric mean.

However, its use comes with strong caveats. The biggest is that the relationships between changes in oil consumption and economic growth are significantly different across countries, and the oil-weighted index may not account for these variations. Evaluating the possible effect of different oil consumption elasticities across countries on the ability to forecast oil consumption based on regional or world GDP growth is a primary subject for future research. In addition, selecting an appropriate base year [as with MER and PPP exchange rates] can be important. Determining the best way to choose such base years is another potential research topic as well.

This brings us back to the main point of the index. Just as preseason rankings of football teams are no substitute for the actual results of games, our oil-consumption-weighted index is not a measure of general economic activity. Rather, it gives a different way to look at world GDP growth that is more directly tied to oil consumption.

## Appendix 1: World GDP Growth Calculations in a Two-Country World

	2010	2011	Growth Rate	Notes
<b>Nominal GDP (local currency) (1)</b>				
China (billion yuan)	53,412	58,802	10.1%	
United States (billion dollars)	14,964	15,518	3.7%	
<b>Real GDP (local currency) (1)</b>				
China (billion yuan)	40,900	44,800	9.5%	
United States (billion dollars)	14,784	15,021	1.6%	
<b>2010 Exchange Rates (yuan per dollar) (1)</b>				
MER - market exchange rate	6.770	6.770		
PPP - purchasing power parity	3.309	3.309		
<b>Real GDP based on MER exchange rate (billion dollars)</b> = real GDP (local currency) / MER exchange rate				
China	5,648	6,184	9.5%	
United States	<u>14,784</u>	<u>15,021</u>	<u>1.6%</u>	
World	20,432	21,204	3.8%	
<b>Real GDP based on PPP exchange rate (billion dollars)</b> = real GDP (local currency) / PPP exchange rate				
China	11,557	12,653	9.5%	
United States	<u>14,784</u>	<u>15,021</u>	<u>1.6%</u>	
World	26,341	37,674	5.1%	
<b>Oil consumption (million barrels per day) (2)</b>				
China	8,938	9,504	6.3%	
United States	<u>19,180</u>	<u>18,882</u>	<u>-1.6%</u>	
World	28,118	28,386	1.0%	
<b>Real GDP - oil-consumption weighted</b>				
China	100	109.483	9.5%	= real GDP (local currency) converted to an index (base year 2010 = 100)
United States	<u>100</u>	<u>101.602</u>	<u>1.6%</u>	= real GDP (local currency) converted to an index (base year 2010 = 100)
World	100	104.2	4.2%	= (U.S. GDP index)^(U.S. consumption share) x (China GDP index)^(China consumption share)

Sources:

(1) World Bank Data (<http://data.worldbank.org/country>), data extracted Feb. 2, 2016.

(2) Energy Information Administration, International Energy Statistics (<http://www.eia.gov/beta/international/data/browser/>), data extracted Feb 2, 2016.