Criticality of GDP measurement in energy modelling

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1. Introduction

To generate projections of global energy demand, energy modelling typically leverages main explanatory variables such as national GDP forecasts, income elasticity estimates, and anticipated energy efficiency improvements by end use sector. While extensive research has been done on elasticity estimation and efficiency-improving technologies, relatively less attention has been paid to the most basic input into most models – real GDP – and how its measurement affects the outcome.[2]

Aggregating and comparing economic output among countries requires that GDP data be converted onto a common basis, typically with global GDP expressed in U.S. dollars. The conversions can be based on observed market exchange (MER) rates or purchasing power parity (PPP) rates where, in the latter, corrections are made for relative price levels among countries (IPCC 2007). A central question in electing to use MER or PPP exchange rates is whether the correction for relative price levels helps to lessen distortions internationally and intertemporally when comparing GDP or the standard of living across economies (Lau 2004). Lau (2004) demonstrates that PPP exchange rates typically raise the measured GDP or low-income countries and lower those of high-income countries. Overall, the use of PPP instead of MER exchange rates tends to raise the level of global and regional GDP as well as the growth rates over time (Pant and Fisher 2007). When energy demand is projected using GDP as the main explanatory variable, the GDP conversions in international comparisons therefore can be particularly important due to three energy modelling conventions that are commonly employed in practice, including:

1) **Regional aggregation**, particularly among groups of emerging economies that individually are deemed not to be material (e.g., Other Asia Pacific);

2) **Adoption of cross-country or cross-sector analogues**, where elasticities and/or GDP growth rates may be assumed to be the same or follow similar trends; or,

3) **Simplified analytical approaches**, such as energy intensity ratio-driven modelling, where proper calibration may not be feasible due to sector data limitations among many emerging economies.

This note explores the energy modelling implications of GDP measurement under these three conventions. When used with PPP-based GDP, each convention can lead to biased projections of energy demand. When this occurs, energy modelers may attempt to compensate for the outcome by altering their conclusions about the extent of improvement in energy efficiency or intensity. This is particularly important because efficiency improvements and technology changes are traditionally estimated as a residual. Consequently, the conventions could affect expectations about energy efficiency gains, which in turn could influence energy investments and policies.

The key findings are as follows. MER-based income elasticities should be used when projecting energy demand from MER-based economic projections, and PPP-based income elasticities should be used when projecting energy demand from PPP-based economic projections. The consistency between the bases for the elasticities and the GDP assumptions may be more important than the choice of MER or PPP exchange rates.

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[2] Nordhaus (2007) offers an extensive treatment of alternative output measures in context with computable general equilibrium modeling. Newell et. al. (2018) and Newell (2015) offer thoughtful energy outlook comparisons by industry members. Kravis, Heston and Summers (1982) present a taxonomy of product and income measures.

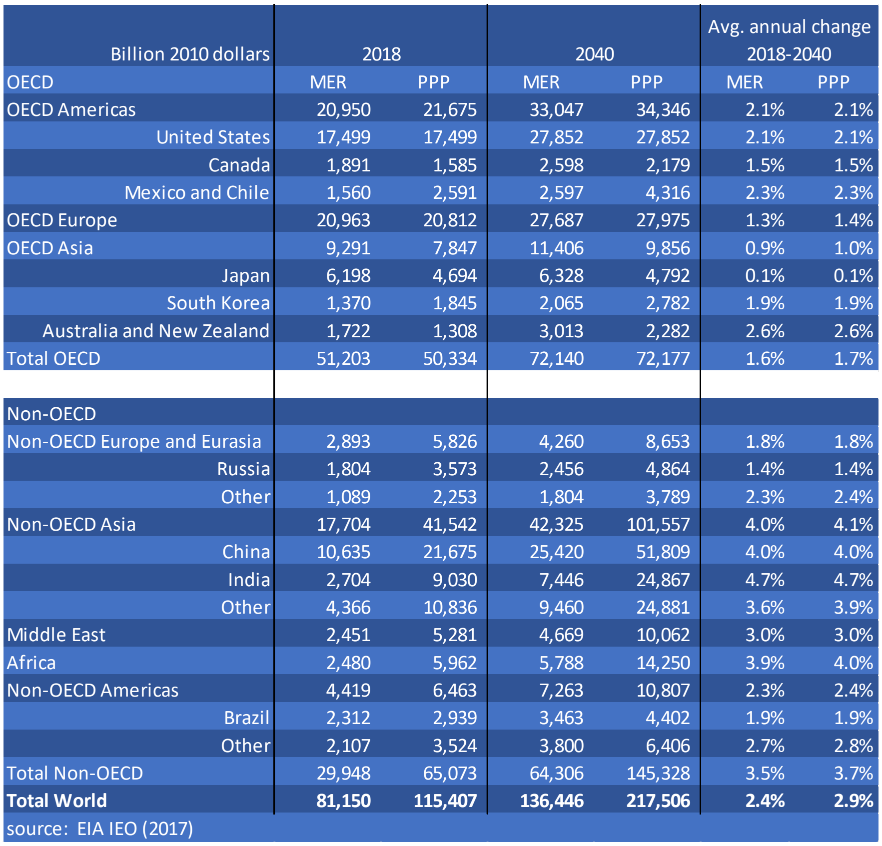
Another key finding is that the income elasticities used in energy modeling should be based upon the region and end use sector being evaluated. If one projects demand for each country and sector before aggregating energy demand to regional or world totals, one should derive income elasticities for each country and sector. However, if one needs to aggregate some countries into a “residual” region, the income elasticities should be measured appropriately for the group of countries and sectors.

Finally, assumptions relating to aggregate energy efficiency at the economy level should be based initially upon understanding historical trends within each country or residual region under consideration. These trends can then be adjusted to incorporate new developments if necessary. Examples of new developments might include energy or environmental policies, increased efficiency, or structural market shifts versus past trends. But these additional assumptions need to be discussed and understood by all.

2. Comparing GDP at MER and PPP-based exchange rates

Table 1 compares real GDP at MER and PPP-based exchange rates. The 2018 MER- and PPP-based GDP levels for OECD economies in total are within two percent of one another, but the adjustment for purchasing power among Non-OECD economies more than doubles the region’s GDP to $65 trillion, compared with $30 trillion on a MER basis. The difference arises due to the wide disparity in relative prices among the non-OECD economies. Globally, PPP-based exchange rates yield 2018 GDP of $115.4 trillion, compared with $81.2 trillion at MER-based rates. With an average annual growth rate of 2.9% per annum (p.a.) instead of 2.4% p.a., in 2040 the global GDP estimate of $217.5 trillion becomes 60% larger than MER GDP.

Table 1. Real GDP exchange rate comparison, 2018 – 2040



Billion 2010 dollars	2018		2040		Avg. annual change 2018-2040	
OECD	MER	PPP	MER	PPP	MER	PPP
OECD Americas	20,950	21,675	33,047	34,346	2.1%	2.1%
United States	17,499	17,499	27,852	27,852	2.1%	2.1%
Canada	1,891	1,585	2,598	2,179	1.5%	1.5%
Mexico and Chile	1,560	2,591	2,597	4,316	2.3%	2.3%
OECD Europe	20,963	20,812	27,687	27,975	1.3%	1.4%
OECD Asia	9,291	7,847	11,406	9,856	0.9%	1.0%
Japan	6,198	4,694	6,328	4,792	0.1%	0.1%
South Korea	1,370	1,845	2,065	2,782	1.9%	1.9%
Australia and New Zealand	1,722	1,308	3,013	2,282	2.6%	2.6%
Total OECD	51,203	50,334	72,140	72,177	1.6%	1.7%
Non-OECD						
Non-OECD Europe and Eurasia	2,893	5,826	4,260	8,653	1.8%	1.8%
Russia	1,804	3,573	2,456	4,864	1.4%	1.4%
Other	1,089	2,253	1,804	3,789	2.3%	2.4%
Non-OECD Asia	17,704	41,542	42,325	101,557	4.0%	4.1%
China	10,635	21,675	25,420	51,809	4.0%	4.0%
India	2,704	9,030	7,446	24,867	4.7%	4.7%
Other	4,366	10,836	9,460	24,881	3.6%	3.9%
Middle East	2,451	5,281	4,669	10,062	3.0%	3.0%
Africa	2,480	5,962	5,788	14,250	3.9%	4.0%
Non-OECD Americas	4,419	6,463	7,263	10,807	2.3%	2.4%
Brazil	2,312	2,939	3,463	4,402	1.9%	1.9%
Other	2,107	3,524	3,800	6,406	2.7%	2.8%
Total Non-OECD	29,948	65,073	64,306	145,328	3.5%	3.7%
Total World	**81,150**	**115,407**	**136,446**	**217,506**	**2.4%**	**2.9%**

source: EIA IEO (2017)

Despite the large differences in GDP levels and growth rates, Lau (2004) explains that in theory there should no compelling reason to choose between one set of foreign exchange rate bases over another. Both MER and PPP-based rates can be arbitrary (Lau 2004), and estimation of income elasticities in energy models that are specific to each individual country and end use sector should be indifferent as to which GDP data series is chosen.

In practice, the majority of energy industry outlooks employ PPP-based exchange rates because, as Nordhaus (2007) emphasizes, PPP measures are intended to represent incomes and outputs more accurately than MER measures and thereby could better reflect the purchasing power for energy goods and the inflection point for the affordability of vehicles and energy-consuming appliances.[3] However, this could be a questionable assumption, since: 1) many commodities – including oil, refined products, coal, and natural gas – are internationally tradeable goods that typically are priced in U.S. dollars; and, 2) globally fuels have increasingly converged towards international prices with the elimination of price controls or subsidies that historically distorted domestic demand (Russell 2018). Subsides remain persistent in a handful economies, such as Saudi Arabia and Venezuela, and the question remains whether a global PPP-based adjustment of GDP is an appropriate remedy.

Lau (2004) highlights that the use of market prices prevailing in the developed economies could be reasonable since: (1) these prices are more likely to reflect the underlying scarcities than prices prevailing in the developing economies; and, (2) the consumption patterns among developed economies generally are more stable than those in the developing economies. Historically, however, there have been prominent examples where the use of MER-based GDP yielded outcomes that failed to conform with conventional wisdom, and these were rationales for using PPP-GDP. For example, Lau (2004) noted that for many years Japanese GDP per capita was much higher than that of the U.S., but almost no economist in either Japan or the U.S. believed that was actually the case. As another example, Lau (2004) highlighted that Chinese GDP per capita was only three percent that of the United States, which directionally seemed correct but was low in magnitude. With the passage of time, these particular issues no longer persist with comparative MER-based GDP comparisons among the United States, Japan or China.[4] Although there may well be other issues, the resolution of major past ones has weakened the obvious arguments in favor of PPP adjustments. PPP-based estimation is nevertheless the most commonly employed basis, and with the conventions that much of the industry and consultant community tends to follow it can make a substantive difference to energy forecasts, as the next section details.

3. Analytical framework demonstrating why the exchange rate basis matters to energy modelling

This section presents an analytical framework to demonstrate the potential impact of the exchange rate basis selection, with or without use of any of the three modelling conventions – regional aggregation, analog selection, and analytical simplification.

Consider a single-factor model where energy demand at period $t=1,\ldots,T$ is a function of income measured on foreign exchange rate basis $fx = MER$ or PPP, such that energy demand $D_t = f(GDP^{fx})$. A projection of demand at period $t+1$ could be derived based on our estimates of the income elasticity of demand (ε_y^{fx}) and expectation for GDP growth between periods t and $t+1$ as follows:

$$D_{t+1} = D_t + \varepsilon_y^{fx} * \%\Delta GDP^{fx} \qquad (1)$$

From the foregoing section, it generally is the case among emerging economies and globally that

$GDP^{PPP} > GDP^{MER}$ and $\%\Delta GDP^{PPP} > \%\Delta GDP^{MER}$ – and vice versa for many developed economies.

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[3] The IEA and many major oil companies including BP and Shell employ PPP-based GDP; see IEA (2017), Shell (2018) and Dale (2018). By contrast, ExxonMobil bases its energy outlook on MER-based GDP, global $72 trillion in 2010 constant dollars (Gardner 2016). Nordhaus (2007) proposes a hybrid approach, but in practice most organizations have calibrated their models to one basis or the other.

[4] Japan's GDP per capita has been below that of the U.S. since 2001. China's 2018 GDP per capita is 14.4% that of the U.S. on a MER basis and 29.4% that of the U.S. on a PPP basis. By 2040, these percentages rise to 24.9% (MER) and 50.7% (PPP).

If energy demand is forecasted individually for each country and end use sector, the choice between MER or PPP-based GDP should make no substantive difference to energy demand projections, so long as an energy model is properly calibrated to the data. This should be the goal.

Intuitively, the historical amount of energy demand is given, so if GDP on a PPP basis is higher than that on a MER basis then it also must be the case that the measured income elasticity, obtained by regressing energy demand on real GDP, must be smaller to an offsetting degree, i.e., $\varepsilon^{PPP} < \varepsilon^{MER}$. For example, suppose oil demand in the road transportation sector of an emerging economy increased to 10.6 million barrels per day (mb/d) from 10.0 mb/d in a given year, and GDP growth rates on PPP and MER bases were 3.5% and 3.0%, respectively. If this were the only measured factor, one could calculate the income elasticity of demand to be 2.0 on a MER basis (= 6% / 3%) but 1.7 on a PPP basis (= 6% / 3.5%). Conducting the analysis at a disaggregated country level and properly calibrating income elasticities to the observed data therefore are grounding principles to derive forecasts that are not *a priori* biased.

In practice, however, one or more of the foregoing three conventions – regional aggregation, analog adoption, or analytical simplification – often is employed to make the data requirements and analysis manageable for a small department.

3.1. Regional aggregation

A common shortcut employed in practice is an "80/20" rule to focus on the largest and most prominent economies. For example, residual regional aggregates may be developed for Other Asia, Other Africa, Other Europe, and the Western Hemisphere. In Table 1, the "other" residual regional categories make up about one-quarter of the Non-OECD total, regardless of which foreign exchange rate basis is selected. If energy demand is modeled collectively by residual region, the first challenge in the single-factor model is to derive an income elasticity that is appropriate to each, given the country, sector and energy mix will have shifted historically as energy in some countries and sectors grew more than others (and may differ in the future). This is non-trivial, but an additional challenge is to identify any bias to GDP growth that may result from the GDP exchange rate basis. In Table 1, real GDP for the residual regional aggregates collectively grow by 12% more between 2018 and 2040 on a PPP basis than they do on a MER basis. It may appear to be obvious, but if the income elasticity used in practice does not appropriately reflect the historical differences between MER and PPP-based GDP growth rates, then the relatively higher GDP growth rate will, per formula (1), be amplified in the energy demand forecast. This is a source of potential bias and interacts with the second common convention, analog adoption.

3.2. Analog adoption

Another convention that commonly is employed is to set elasticities based on logical analogs. Ideally, elasticities should be measured based on careful econometric analysis for each economy and sector. Even with econometric analysis, however, there will invariably be examples where the elasticities are statistically indeterminate and therefore require assumptions. For example, Japan's income has continued to grow, but its energy demand has fallen in recent years, so one is unlikely to measure a positive income elasticity even in a properly specified model. In this case, a small positive income elasticity might be assumed but more than offset by those for prices and other factors, which will be discussed in Section 4. Moreover, other economies in Asia Pacific might be assumed to mature along the same lines as Japan, with elasticities that evolve in tandem with greying demographics or stringent energy policies with a combination of high population density and income.

An approach such as this is common in practice and has some intuitive appeal in that it provides the analyst a rationale that can readily be understood and explained. However, good elasticity estimates come from sound data – data that measure what they are supposed to measure and are not artifacts of other data. When and if elasticities are measured improperly, the direction of any bias is not *a priori* clear, but this convention is potentially fraught with measurement error.

With the first convention, there is at least the potential that accurate measurement of a relatively smaller income elasticity may help to offset the upward bias to energy that occurs when modelling regional energy based on PPP-

GDP. If the first and second conventions are employed in combination, however, the relatively higher growth rate under PPP-GDP can magnify the energy demand forecast based on differences between the MER and PPP GDP bases.

3.3. Analytical simplification

A third convention is analytical simplification through the use of energy intensity calculations and assumed improvements. This type of model tends to be a fallback in practice whenever sector-specific specifications are not easily obtained. In this case, energy demand in period $t+1$ equals:

$$D_{t+1} = (GDP_{t+1}{}^{fx})*(D_t / GDP_t{}^{fx})*(1- e_t), \tag{2}$$

where e_t is the percentage change in energy intensity and could be positive or negative, depending on the economy, sector and period in question. This simplified approach implicitly assumes that historical improvements in energy intensity may be representative of prospective improvements, which could be a reasonable approximation if there were no concerns with structural changes in the economy, energy/environmental policy, or technology. Similar to the regional aggregation convention, however, any bias due to the use of PPP GDP instead of MER GDP would depend on whether the pace of improvement e_t is properly calibrated with historical energy intensity under the alternative GDP bases.

As regional/global PPP GDP begins at a higher level and grows relatively more rapidly than MER-based GDP, a tendency can arise under PPP-based GDP for this convention directly to suggest more rapid energy intensity improvement for Non-OECD economies.

In general, each of the three conventions under PPP GDP can produce a material upward bias for energy demand among aggregates of Non-OECD economies. When this occurs, however, the result does not necessarily translate into the analyst's final projections. In practice, it may lead to additional iterations of the forecast with alternative assumptions about energy efficiency, policy, or technology. In this sense, employing PPP-based GDP could provide greater headroom for an analyst or organization to be "bullish" on technology or energy intensity improvements, but the gains would be illusory. This is a pragmatic view of how energy outlook processes work within many organizations, so striving to make assumptions that are consistent and transparent can improve both the quality and comparability of the outcomes.

4. A positive framework for global energy modelling

To this point, the consideration has been a single-factor model focused on income. Prices and other factors in general also are important. Some institutions estimate retail prices and price elasticities by end use sector, but many do not as the data requirements are high and in many cases price elasticities empirically may not identify with the proper sign.[5] Some institutions bypass price effects and instead focus collectively on everything left over after accounting for income effects. Regardless of the specification, most institutions also employ deterministic modelling. By contrast, the following energy model structure allows for dynamic probabilistic analysis:

$$D_{t+1} = D_t + \varepsilon_y{}^{fx} * \%\Delta GDP^{fx} + \varepsilon_p * \%\Delta p + \varepsilon_o * \%\Delta\Omega, \tag{3}$$

where ε_p is the price elasticity of demand at domestic prices, $\%\Delta p$ is the change in price to the end use sector being modeled, ε_o is the residual demand elasticity with respect to all other factors (e.g., annual calendar, seasonal and event-based differences as well as potential measurement issues), and $\%\Delta\Omega$ is what is left over, which can be quantified. Since this can be implemented on a MER basis and automated by end use sector for every economy in the IEA's extensive database, it directly avoids problems with regional aggregation and analog adoption. Additionally, since variation due to changes in the energy and economic mix and intensity also are quantified and

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[5] For many emerging economies, energy prices and demand have risen in tandem, so to simulate the effects of price changes one must employ a representative price elasticity and have responses to income and collectively all other factors that on average account for changes in energy demand. Some organizations do not attempt to capture price elasticities directly since they are relatively small compared with income effects in the long run.

represented as probability distributions, the framework avoids broad-brush analytical simplification to the point of only leveraging the energy intensity. The elasticities' probability distributions could be assumed to be static in fully deterministic model. Alternatively, if there are strong prior expectations about how the distributions might evolve, a dynamic assumption can be applied.

As with any energy model, the challenge remains of how to overlay assumptions about structural changes in technology and inter-fuel competition. In this framework, overlays must be applied explicitly, rather than implicitly through other parameters. This framework was effective for corporate planning at Talisman Energy and was programmed in Wolfram Mathematica as a simulation, with estimation of residual terms to specify a probability distribution by country and sector for energy demand unaccounted for by income and price elasticities and their changes (Foreman 2010).

5. Conclusions

The fundamental suggestion is to analyze and project energy by individual economy and end use sector, to the maximum extent that is tractable for an analytical department. When there is minimal regional aggregation involved, accurate estimation of income elasticities of demand can largely neutralize concerns about potential modelling biases. As discussed, however, most organizations necessarily take short cuts by modelling regional aggregates of energy in emerging economies, adopting analogs for elasticities, or simplifying analytical approaches.

Regardless of whether energy modeling is based on MER or PPP exchange rates, the consistency between the exchange rate basis used to develop the income elasticities and GDP assumptions is paramount to minimize modeling bias. Specifically, MER-based income elasticities should be used when projecting energy demand from MER-based economic projections, and PPP-based income elasticities should be used when projecting energy demand from PPP-based economic projections.

Another key finding is that the income elasticities used in energy modeling should be based upon the region and end use sector being evaluated. If one projects demand for each country and sector before aggregating energy demand to regional or world totals, one should derive income elasticities for each country and sector. However, if one needs to aggregate some countries into a "residual" region, the income elasticities should be measured appropriately for the group of countries and sectors. In these cases, employing MER-GDP generally can minimize the potential for modelling bias, which in turn can underpin a well-informed and consistent discussion about the states of energy intensity, technology and efficiency improvements.

This paper also has proposed a positive energy modelling framework that focuses on measuring the impact of income, prices and an explicit residual that may be persistent. This approach is conductive to probabilistic and dynamic implementation and requires explicit overlays for assumptions about structural changes in technology and inter-fuel competition, which leads to the final point.

Assumptions related to energy efficiency at the economy level should be based initially upon understanding historical trends within each country or residual region under consideration. These trends can then be adjusted to incorporate new developments if necessary. Examples of new developments might include energy or environmental policies, increased efficiency, or structural market shifts versus past trends. But these additional assumptions need to be transparent, discussed, and understood by all.

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