Problems with the "End of Growth" hypothesis and its generalization

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The concept of natural resource based limits to economic growth has received substantial attention since the late 1960s [1–7]. While the underlying concept remains valid in theory, practical predictions based on these concerns remain elusive. On a finite planet, the use of non-renewable natural resources poses a real boundary. However, often overlooked is the capacity for technological innovation and the potential decoupling of non-renewable natural resource use from economic growth. Consequently, while there are theoretical limits to the employment of non-renewable natural resources for economic growth, there is no theoretical limit to economic growth. In recent work, Rubin [8] has described in detail what he sees as potential supporting material for an "end of growth." However, we present herein a range of concerns regarding this hypothesis as outlined in ref. [8]. We find that the following statements (with our approach taking the form of statement from ref. [8] / our evaluation) made in this publication do not appear to be rigorously supported by a breadth and depth of evidence:

p. 17: "Many folks are already questioning whether the boundless pursuit of personal consumption is really the key to a sense of well-being, particularly when we see the toll our ravenous lifestyles take on the planet. Countries that rank the highest on the United Nations' Index of Human Development don't have the largest or fastest-growing economies. Could there be a lesson there?"

Figure 1 shows a plot of the United Nations (UN) Human Development Index (HDI) for 2011 [9] versus the corresponding 2011 gross national income (GNI) per capita in constant 2005 international dollars [10] for the world's nations. It is clear that countries with the population-normalized largest economies have the highest HDIs. Effectively, this single plot undermines much of the premise for Rubin's book. If we assume a causative relationship, it appears that economic growth improves human development, and without economic growth, human development will be stunted or regress.

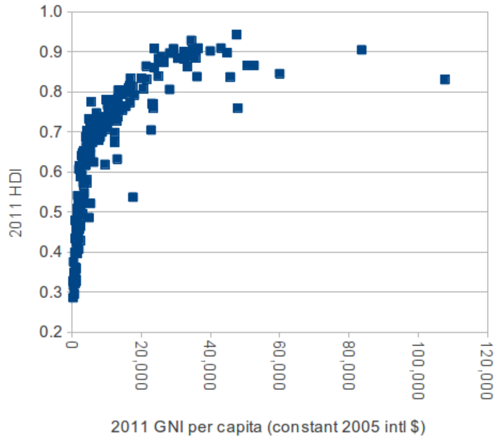

Figure 1: United Nations Human Development Index (HDI) for 2011 versus the corresponding 2011 gross national income (GNI) per capita in constant 2005 international dollars for the world's nations.

Rubin is correct in stating that "[c]ountries that rank the highest on the United Nations' Index of Human Development don't have the ... fastest-growing economies," as can be seen in a plot of average annual per capita gross domestic product (GDP) growth [11] over the period from 2001 through 2010 and the corresponding 2011 HDI (Figure 2). But Rubin has put forward a classic logical fallacy. Generally, less developed nations are growing their economies at a faster rate than the most developed nations. For example, the average annual per capita GDP growth [11] between 2001 and 2010 by region/income class is given in Table 1. We do not see a correlation between per capita GDP growth and the HDI, but we do know that there is a strong positive correlation between the size of an economy and the HDI of its citizens. Consequently, our conclusions are the opposite to what Rubin appears to be advocating. Namely, economic growth appears to improve the HDI; and thus, developed nations need to find effective ways of growing their economies more rapidly. Developing nations appear to understand this relationship, hence why they seek (and are obtaining) rapid rates of per capita

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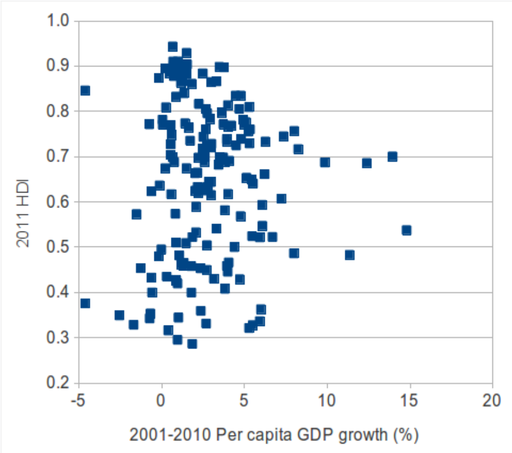

Figure 2: The United Nations Human Development Index (HDI) for 2011 versus average annual per capita gross domestic product (GDP) growth between 2001 through 2010.

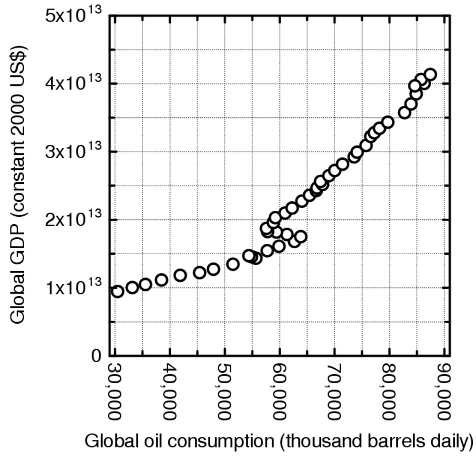

Figure 3: Relationship between global GDP (in constant 2000 US dollars) and global oil consumption between 1965 and 2010.

economic growth.

p. 37: "You can draw a straight line between oil consumption and GDP growth. The more oil we burn, the faster the global economy grows. On average over the last four decades, a 1 percent bump in world oil consumption had led to a 2 percent increase in global GDP. That means if GDP increased by 4 percent a year - as it often did before the 2008 recession - oil consumption was increasing by 2 percent a year."

This analysis is too simplistic to offer significant utility in understanding the global economy and its past, present, and future relationship to oil consumption. Figure 3 shows the annual global GDP (in constant 2000 US dollars) [12] versus the corresponding global oil consumption [13] between 1965 and 2010. There is a strong relationship between global economic growth and oil consumption, but this relationship appears to have changed over time. When we look at annual global GDP on a purchasing power parity (PPP) basis (in constant 2005 international dollars; data only available from 1980 onwards) [14] versus the corresponding global oil consumption [13] between 1980 and 2010, a similar trend emerges (Figure 4). The increases in global GDP can be broken down into temporal slices and compared to the corresponding increases in oil consumption (OC) over each timeframe in both constant 2000 US dollars GDP [1] and constant 2005 international dollars GDP-PPP [2] bases to reveal highly variable GDP:oil consumption ratios over time. Because the developing world has been progressively comprising a greater proportion of the global economy over the past half-century, we find that the GDP:oil ratio in PPP based constant 2005 international dollars exhibits a correspondingly greater positive deviation from the GDP:oil ratio in constant 2000 US dollars.

When just the Organisation for Economic Co-operation and Development (OECD) countries are considered, the situation gets more complex. Figures 5 and 6 show OECD annual GDP in constant 2000 US dollars [12] and constant 2005 international dollars [14] since 1965 and 1980, respectively, versus the corresponding OECD annual oil consumption [13]. Once again, the increases in OECD GDP can be broken down into temporal slices and compared to the corresponding increases in oil consumption over each timeframe on both constant 2000 US dollars GDP [3] and

[1]1965-1969: global GDP increased 25.1%, OC increased 37.4%, GDP:oil ratio=0.7; 1970-1974: global GDP increased 19.1%, OC increased 20.8%, GDP:oil ratio=0.9; 1975-1979: global GDP increased 19.0%, OC increased 17.4%, GDP:oil ratio=1.1; 1980-1984: global GDP increased 9.8%, OC decreased 4.0%, GDP:oil ratio=-2.4; 1985-1989: global GDP increased 16.2%, OC increased 10.5%, GDP:oil ratio=1.5; 1990-1994: global GDP increased 9.0%, OC increased 3.5%, GDP:oil ratio=2.6; 1995-1999: global GDP increased 13.5%, OC increased 8.1%, GDP:oil ratio=1.7; 2000-2004: global GDP increased 10.8%, OC increased 8.0%, GDP:oil ratio=1.3; 2005-2009: global GDP increased 7.2%, OC increased 0.8%, GDP:oil ratio=8.6; 2000-2010: global GDP increased 28.2%, OC increased 14.2%, GDP:oil ratio=2.0; 2005-2010: global GDP increased 11.7%, OC increased 4.2%, GDP:oil ratio=2.8; 1970-2010: global GDP increased 238%, OC increased 93%, GDP:oil ratio=2.6; and 1980-2010: global GDP increased 132%, OC increased 43%, GDP:oil ratio=3.1

[2]1980-1984: global GDP increased 10.0%, OC decreased 4.0%, GDP:oil ratio=-2.5; 1985-1989: global GDP increased 16.2%, OC increased 10.5%, GDP:oil ratio=1.5; 1990-1994: global GDP increased 8.1%, OC increased 3.5%, GDP:oil ratio=2.3; 1995-1999: global GDP increased 14.5%, OC increased 8.1%, GDP:oil ratio=1.8; 2000-2004: global GDP increased 14.1%, OC increased 8.0%, GDP:oil ratio=1.8; 2005-2009: global GDP increased 12.7%, OC increased 0.8%, GDP:oil ratio=15.1; 2000-2010: global GDP increased 41.0%, OC increased 14.2%, GDP:oil ratio=2.9; 2005-2010: global GDP increased 18.3%, OC increased 4.2%, GDP:oil ratio=4.4; and 1980-2010: global GDP increased 157%, OC increased 43%, GDP:oil ratio=3.7

[3]1965-1969: OECD GDP increased 25.3%, OC increased 38.5%, GDP:oil ratio=0.7; 1970-1974: OECD GDP increased 17.7%, OC increased 15.8%, GDP:oil ratio=1.1; 1975-1979: OECD GDP increased 18.3%, OC increased 14.2%, GDP:oil ratio=1.3; 1980-1984:

Table 1: Average annual per capita GDP growth between 2001 and 2010 by geographic region/income class.

Region/income class	2001-2010 average annual per capita GDP growth
World	1.32%
OECD members	0.81%
Heavily indebted poor countries	2.32%
Least developed countries (UN classification)	3.82%
Low income countries	3.12%
Middle income countries	4.80%
High income countries	0.88%
North America	0.69%
European Union	1.01%
Latin America and Caribbean (developing countries only)	2.08%
Sub-Saharan Africa (developing countries only)	2.18%
Middle East and North Africa (developing countries only)	2.59%
Europe and Central Asia (developing countries only)	4.66%
East Asia and Pacific (developing countries only)	8.25%

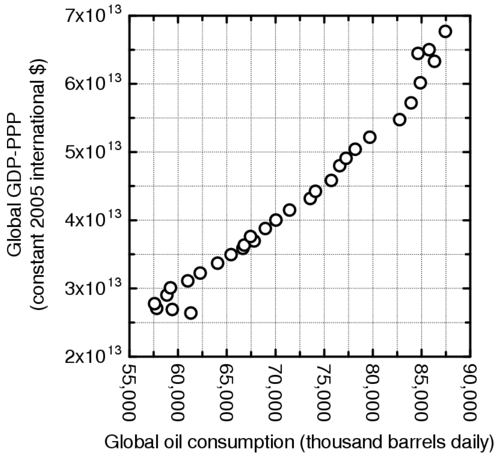

Figure 4: Relationship between global GDP-PPP (in constant 2005 international dollars) and global oil consumption between 1980 and 2010.

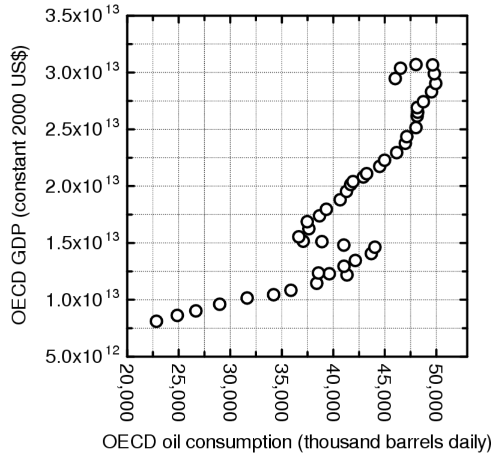

Figure 5: Relationship between OECD GDP (in constant 2000 US dollars) and OECD oil consumption between 1965 and 2010.

constant 2005 international dollars GDP-PPP [4] bases. In this case, as we would expect, GDP:oil ratios based on constant 2000 US dollars and constant 2005 international dollars are very similar. But the points to note are that the long-term GDP:oil ratio for OECD members is much higher than for the global economy, and that over the past decade the GDP:oil ratio for OECD members has been negative.

Similar figures can be constructed for the United States (the constant 2000 US dollars and constant 2005 international dollars trends are equivalent for this nation, so only the former set of data and trends will be presented; Figure 7), as well as a temporal slice GDP:oil ratio analysis over time.[5] The long-term GDP:oil ratio for the US is much higher than for the global economy (and higher than the

OECD GDP increased 9.7%, OC decreased 8.3%, GDP:oil ratio=-1.2; 1985-1989: OECD GDP increased 15.8%, OC increased 10.2%, GDP:oil ratio=1.6; 1990-1994: OECD GDP increased 7.9%, OC increased 6.8%, GDP:oil ratio=1.2; 1995-1999: OECD GDP increased 12.9%, OC increased 6.8%, GDP:oil ratio=1.9; 2000-2004: OECD GDP increased 8.2%, OC increased 2.9%, GDP:oil ratio=2.8; 2005-2009: OECD GDP increased 1.5%, OC decreased 7.9%, GDP:oil ratio=-0.2; 2000-2010: OECD GDP increased 16.1%, OC decreased 3.4%, GDP:oil ratio=-4.8; 2005-2010: OECD GDP increased 4.6%, OC decreased 6.9%, GDP:oil ratio=-0.7; 1970-2010: OECD GDP increased 191%, OC increased 36%, GDP:oil ratio=5.3; and 1980-2010: OECD GDP increased 105%, OC increased 13.4%, GDP:oil ratio=7.8

[4] 1980-1984: OECD GDP increased 9.5%, OC decreased 8.3%, GDP:oil ratio=-1.1; 1985-1989: OECD GDP increased 15.4%, OC increased 10.2%, GDP:oil ratio=1.5; 1990-1994: OECD GDP increased 8.1%, OC increased 6.8%, GDP:oil ratio=1.2; 1995-1999: OECD GDP increased 13.7%, OC increased 6.8%, GDP:oil ratio=2.0; 2000-2004: OECD GDP increased 8.6%, OC increased 2.9%, GDP:oil ratio=3.0; 2005-2009: OECD GDP increased 2.2%, OC decreased 7.9%, GDP:oil ratio=-0.3; 2000-2010: OECD GDP increased 17.6%, OC decreased 3.4%, GDP:oil ratio=-5.2; 2005-2010: OECD GDP increased 5.4%, OC decreased 6.9%, GDP:oil ratio=-0.8; and 1980-2010: OECD GDP increased 109%, OC increased 13.4%, GDP:oil ratio=8.1

[5] 1965-1969: USA GDP increased 17.9%, OC increased 22.8%, GDP:oil ratio=0.8; 1970-1974: USA GDP increased 15.0%, OC increased 13.1%, GDP:oil ratio=1.2; 1975-1979: USA GDP increased 20.2%, OC increased 12.9%, GDP:oil ratio=1.6; 1980-1984: USA GDP increased 12.6%, OC decreased 7.8%, GDP:oil ratio=-1.6; 1985-1989: USA GDP increased 15.0%, OC increased 10.2%, GDP:oil ratio=1.5; 1990-1994: USA GDP increased 10.5%, OC increased 4.3%, GDP:oil ratio=2.4; 1995-1999: USA GDP increased

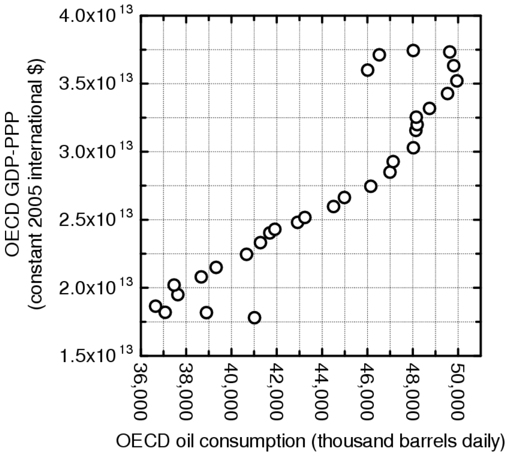

Figure 6: Relationship between OECD GDP-PPP (in constant 2005 international dollars) and OECD oil consumption between 1980 and 2010.

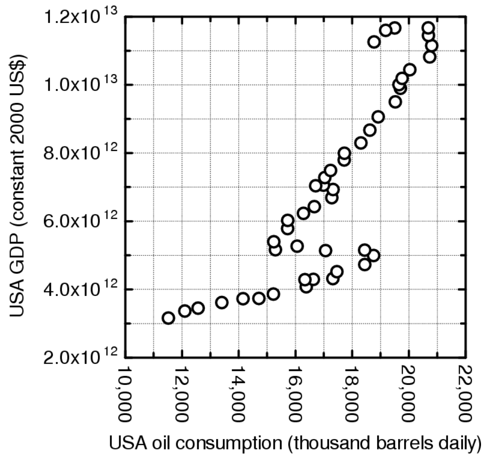

Figure 7: Relationship between US GDP (in constant 2000 US dollars) and US oil consumption between 1965 and 2010.

OECD average). Over the past decade, the GDP:oil ratio for the US has been negative.

In general, the world's economy is becoming less carbon and energy intensive over time, as seen in temporal trends for carbon dioxide emissions normalized to GDP (in constant 2000 US dollars [Figure 8] [15] and constant PPP 2005 international dollars [Figure 9] [16]) and per capita (Figure 10) [17], as well as energy use per unit GDP in constant PPP 2005 international dollars (Figure 11) [18], in the following regions: global, OECD, United States, Canada, and China. Consequently, Rubin's statements

18.9%, OC increased 10.1%, GDP:oil ratio=1.9; 2000-2004: USA GDP increased 9.3%, OC increased 5.2%, GDP:oil ratio=1.8; 2005-2009: USA GDP increased 1.0%, OC decreased 9.8%, GDP:oil ratio=-0.1; 2000-2010: USA GDP increased 17.2%, OC decreased 2.6%, GDP:oil ratio=-6.5; 2005-2010: USA GDP increased 4.0%, OC decreased 7.8%, GDP:oil ratio=-0.5; 1970-2010: USA GDP increased 211%, OC increased 30%, GDP:oil ratio=6.9; and 1980-2010: USA GDP increased 126%, OC increased 12.4%, GDP:oil ratio=10.1

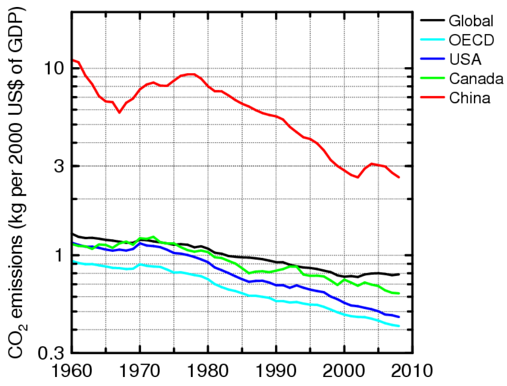

Figure 8: Historical trends in carbon dioxide emissions normalized to GDP (in constant 2000 US dollars) between 1960 and 2008.

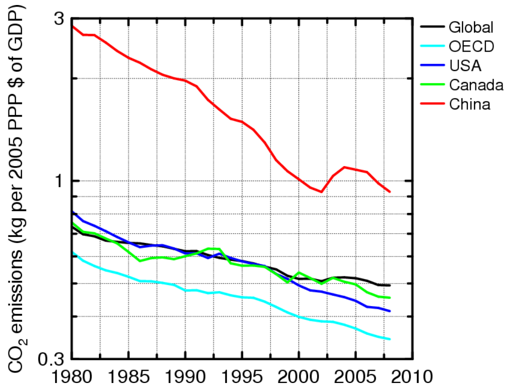

Figure 9: Historical trends in carbon dioxide emissions normalized to GDP (in constant PPP 2005 international dollars) between 1980 and 2008.

grossly oversimplify the heterogeneity in both space and time for the relationship between oil consumption and economic growth. As carbon and energy efficiencies increasingly manifest themselves within larger segments of the global economy, resilience to periods of higher oil prices is expected to increase.

pp. 37-38: "Consider the first oil shock, created by the Organization of Petroleum Exporting Countries (OPEC) following the Yom Kippur war in 1973. Set off by this Arab-Israeli conflict, OPEC's Arab members turned off the taps on roughly 8 percent of the world's oil supply by cutting shipments to the United States and other Israeli allies. Crude prices spiked, and by 1974 real GDP in the United States had shrunk by 2.5 percent."

In contrast, the United States' real GDP [12] only declined by 0.5% between 1973 and 1974. It is also of note that in 1973, OPEC's oil production was 29.9 million barrels per day, and in 1974, OPEC's oil production was 29.7 million barrels per day [13]. The substantial decline in OPEC's oil production didn't come until 1975, when production dropped to 26.2 million barrels per day, and then rebounded to a 1976 production level of 29.6 million bar-

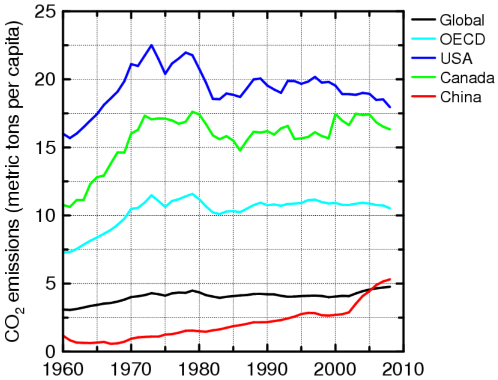

Figure 10: Historical trends in per capita carbon dioxide emissions between 1960 and 2008.

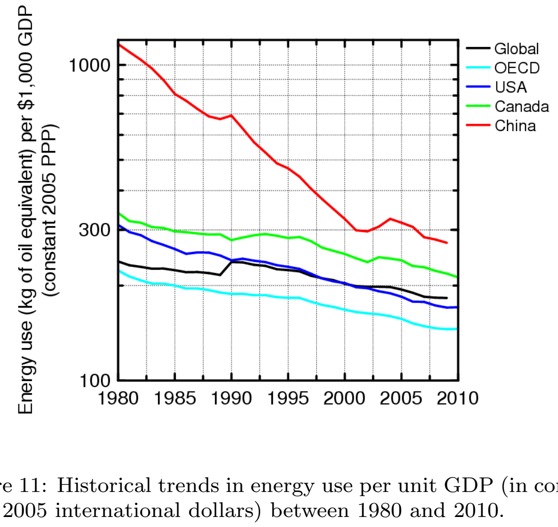

Figure 11: Historical trends in energy use per unit GDP (in constant PPP 2005 international dollars) between 1980 and 2010.

Table 2: Public social expenditure-to-GDP ratios for the EU member states, as well as the United States and Canada, in 1980, 2007, and 2011 [19].

Country	1980	2007	2011
Austria	22.4%	16.0%	16.4%
Belgium	23.5%	26.3%	28.9%
Czech Republic	n/a	18.8%	20.6%
Denmark	24.8%	26.0%	29.9%
Estonia	n/a	13.0%	18.3%
Finland	18.1%	24.9%	28.4%
France	20.8%	28.4%	30.4%
Germany	22.1%	25.2%	26.4%
Greece	10.2%	21.3%	23.4%
Hungary	n/a	22.9%	23.1%
Ireland	16.7%	16.3%	21.4%
Italy	18.0%	24.9%	27.0%
Luxembourg	20.6%	20.6%	23.4%
Netherlands	24.8%	20.1%	22.2%
Poland	n/a	19.8%	21.4%
Portugal	9.9%	22.5%	25.3%
Slovakia	n/a	15.7%	17.6%
Slovenia	n/a	20.3%	24.0%
Spain	15.5%	21.6%	25.9%
Sweden	27.2%	27.3%	27.2%
United Kingdom	16.5%	20.5%	23.7%
United States	13.2%	16.2%	20.3%
Canada	13.7%	16.9%	19.3%

rels per day. Interestingly, the US real GDP only declined 0.2% between 1974 and 1975, and then increased by 5.4% between 1975 and 1976.

p. 50: "Europe is stuck in a quagmire of austerity measures, budget deficits and financial bailouts. As its political leaders are finding out, it's a situation fraught with the likelihood of debt default, social upheaval and political change. The economic hopes of an entire continent are wrapped up in a single magic bullet: growth. Were a strong-enough economic rebound to take hold, it could slay the deficit and spare the EU [European Union]. A sharp rebound in economic growth would fill government coffers with tax revenues that could be used to pay back the huge amounts owed to creditors. At the same time, a turnaround in the EU's financial fortunes would spare citizens from suffering through more income-sucking tax increases and bone-deep cuts to social spending."

As recently noted by the OECD, "[p]ublic social expenditure-to-GDP ratios increased in all OECD countries during the recent economic downturn. The largest increases took place in Estonia, Ireland and Spain" [19]. Table 2 provides public social expenditure-to-GDP ratios for the EU member states, as well as the United States and Canada, in 1980, 2007, and 2011. OECD members states have generally seen significant increases in social spending since the 1980s, both in percentage of GDP and in real dollar spending terms (with the exception of Greece, whose real public social spending in 2011 was equivalent to that in 2007).

pp. 78-79: "Before the Iranian revolution of the late 1970s, the country was pumping almost 6 million barrels a day. Some forty years later, Iran's production is still below 4 million barrels a day ... When Iraqi dictator Saddam Hussein ran the show in Baghdad, during its peak

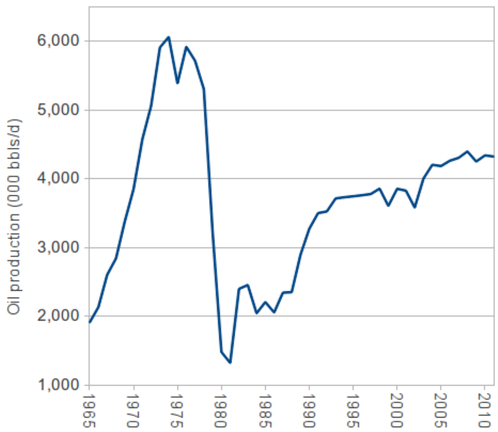

Figure 12: Historical oil production in Iran between 1965 and 2011.

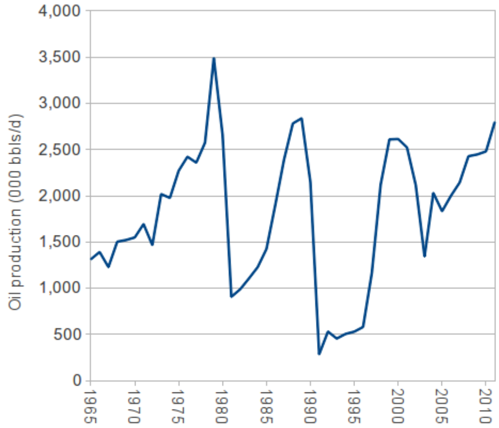

Figure 13: Historical oil production in Iraq between 1965 and 2011.

years in the 1980s the state-owned Iraq Petroleum Company cranked out more than 3.5 million barrels a day. Almost a decade after the United States invaded the country and toppled the Hussein's regime, Iraq's production is still less than it was twenty-five years ago by roughly 500,000 barrels a day."

Figure 12 shows Iran's oil production between 1965 and 2011. It is clear that - in contrast to Rubin's claims - Iran's oil production has been above 4 million barrels per day for some time (since 2003). Figure 13 shows Iraq's oil production between 1965 and 2011. In contrast to what Rubin claims, Iraq did not produce "more than 3.5 million barrels a day ... during its peak years in the 1980s." Rather, Iraq only produced 3.5 million barrels per day for a single year (1979). The previous (1978) and following (1980) years had much lower oil production rates of 2.6 and 2.7 million barrels per day, respectively. During the peak years of the late 1980s (i.e., about "twenty-five years ago"), Iraq only reached a production maximum of 2.8 million barrels per day. Furthermore, in 2011, Iraq's oil production reached 2.8 million barrels per day - equal to the late 1980s production peak and larger than the pre-2003 Iraq-US War peak of 2.6 million barrels per day.

p. 111: "Because Australia's domestic power market is relatively small, only needing to serve 20 million people spread across a coal-rich continent, Australia can ship most of its coal to China and Japan, and on its own accounts for about 40 percent of global exports."

In contrast, Australia only accounts for about one-quarter (27%) of global coal exports [20].

p. 131-132: "The proposed Keystone line would facilitate an ideal marriage between Texas refineries hungry for more supply and new Canadian oil in need of a home. A surplus of oil backing up at Cushing [Oklahoma] has turned into a sweet deal for Midwest refineries, and it's why West Texas Intermediate crude (WTI) traded for more than $20 a barrel lower than benchmark world oil prices for most of 2011. Without a new pipeline, Midwest refiners will get to keep paying a discounted price for Canadian oil. What exactly happens to that missing $20 a barrel? US motorists certainly don't get a break at the pumps. By and large, American drivers pay the same price no matter where in the country they live. No, the big winners are the oil companies that own the Midwest refineries; they've been pocketing huge profits on the back of abundant supplies from Canada."

This interpretation is not accurate. As seen by snapshots taken on May 21, 2008,[6] July 7, 2008,[7] March 14, 2010,[8] February 13, 2012,[9] and June 19, 2012,[10] gasoline prices vary substantially around the United States (Figure 14). On June 19, 2012, we see a 33% difference in average gasoline prices between the least and most expensive counties.

As for the relationship between gas prices and the so-called Canadian discount, the United States Energy Information Administration (US-EIA) appears to disagree with Rubin's view that the discount is never passed along to the consumer in any form. In analyzing the February 13, 2012 gas price map shown in Figure 14 and the corresponding average gasoline prices in the Rocky Mountain region versus the American average between early 2010 and early 2012 (Figure 15), the US-EIA made the following statements: "In contrast to the eastern half of the United States, the gasoline market in the Rocky Mountain region is fairly self-sufficient. Refineries within the Rockies use crude oil produced within the region, the neighboring Midwest region, or imported from Canada. Over the

[6] http://www.thebuzzmedia.com/us-gas-price-heat-map/

[7] http://blogs.internetautoguide.com/6259270/gas-prices/usa-national-gas-temperature-map-cheap-gas-in-mid-west/index.html

[8] http://www.visualinformation.info/wp-content/uploads/2010/03/gas-price-us.jpg

[9] http://www.eia.gov/todayinenergy/detail.cfm?id=4990

[10] http://www.gasbuddy.com/

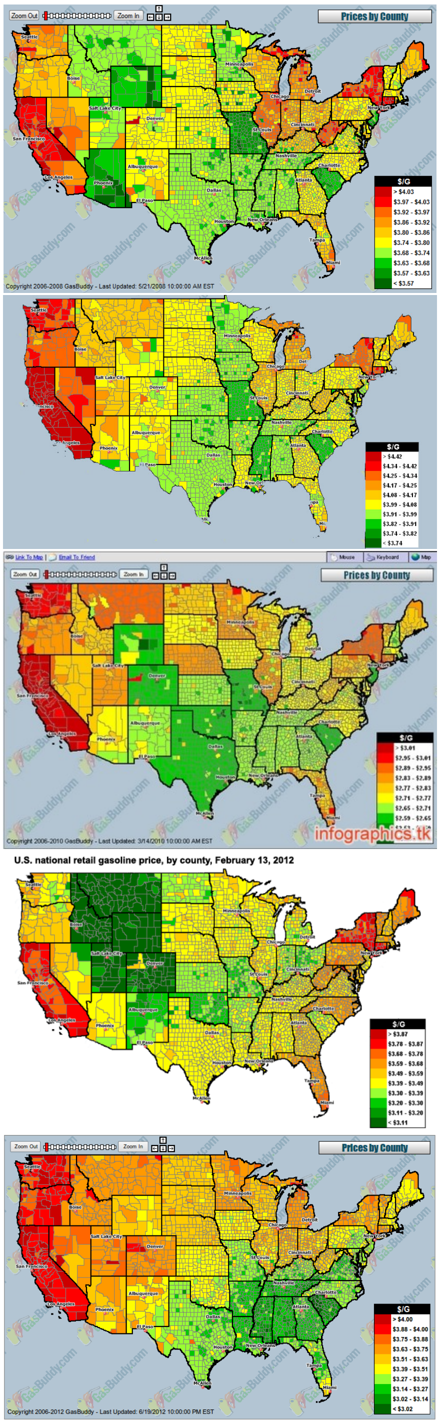

Figure 14: Gasoline prices in the lower 48 states of the continental US on May 21, 2008, July 7, 2008, March 14, 2010, February 13, 2012, and June 19, 2012.

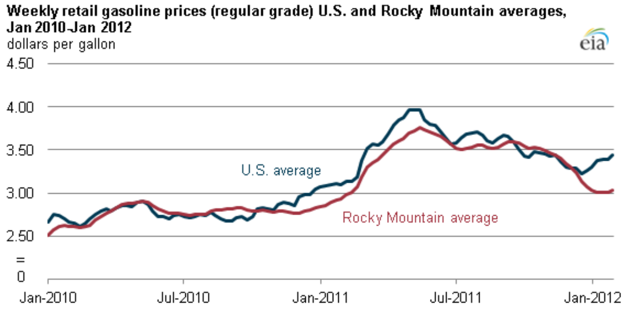

Figure 15: Nationwide and Rocky Mountain region weekly retail regular grade gasoline prices between January 2010 and January 2012 in the United States. Taken from http://www.eia.gov/todayinenergy/detail.cfm?id=4990.

past year, due to transportation constraints and increasing production, these crude oils have tended to sell at a discount to many other crude oils. Prior to 2011, refineries in the Rockies generally paid about $3 less per barrel for their crude oil than the average U.S. refinery. However, through the first 11 months of 2011 this difference grew to an average discount of $14 per barrel. In November 2011, the most recent month for which EIA has data, the gap was $16 per barrel. These lower crude oil costs have created generally lower-than-average retail gasoline prices in the Rockies for most of 2011.

While EIA does not have data beyond November, it is likely that crude oil in the Rockies compared to the rest of the country became even cheaper in January as spot prices for some Canadian crude oils and Bakken crude oil became more steeply discounted compared to many crudes used by U.S. refiners in other parts of the country. Canadian and Bakken crude oils are more indicative of crude oil input costs in the Rockies than crudes such as West Texas Intermediate (WTI) and Louisiana Light Sweet (LLS), which are more widely used in the Midwest and Gulf Coast, respectively. These recent price declines may have provided additional impetus for the sharp decline in Rocky Mountain gasoline prices."

The US-EIA analysis of these PAD District 4 (Rocky Mountain: Colorado, Idaho, Montana, Utah, Wyoming) Canadian oil discounts potentially being passed on to consumers is consistent with the comparison of the 96 month average gasoline prices for the US, Wyoming (in PADD 4), and neighboring South Dakota (in PADD 2 [Midwest: Illinois, Indiana, Iowa, Kansas, Kentucky, Michigan, Minnesota, Missouri, Nebraska, North Dakota, South Dakota, Ohio, Oklahoma, Tennessee, Wisconsin]) (Figure 16). Up until late 2008, we see very little differerence in average gasoline prices among the three regions. Starting in late 2008/early 2009, periods of substantially lower average gasoline prices are evident in Wyoming, whereas immediately next door in South Dakota the average gasoline prices have trended with the US average up to the present. These trends are consistent with the emergence of a sus-

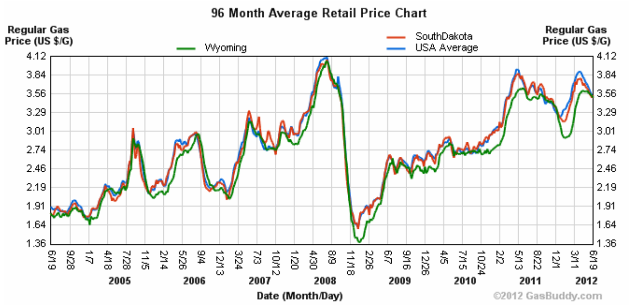

Figure 16: Comparison of the average gasoline prices in the United States with those in Wyoming (PADD 4) and neighboring South Dakota (PADD 2) between June 2004 and June 2012. Taken from http://gasbuddy.com/.

tained price gap between Western Canada Select (WCS) and West Texas Intermediate (WTI)/Brent crude oils over this period.[11] The full WCS discount relative to WTI/Brent may not be always passed along to US gasoline purchasers in its entirety, but - consistent with the US-EIA analysis (and in apparent contrast to Rubin's claims) - there is strong evidence of at least some periodic regional gas price savings in the US due to the WCS discount over the past few years.

p. 161: "The use of oil-fired power generation also separates emerging economies from most developed nations. With the notable exception of post-Fukushima Japan, few OECD countries generate a significant amount of electricity using oil. In North America, coal, natural gas and hydroelectric do the heavy lifting for the electrical grid. In China and India, power generation can still consume a significant amount of oil."

Table 3 shows the percent contributions to total electricity production in China, India, the United States, Canada, and Mexico during 2009 by coal [21], hydroelectric [22], natural gas [23], nuclear [24], and oil [25]. In apparent contrast to what Rubin claims, China and India do not generate substantial portions of their electricity from oil. Indeed, China has a significantly lower percentage of electricity generated from oil than Canada, the United States, and Mexico. In absolute terms, China and India produced 13,255,000,000 kWh and 26,441,000,000 kWh of electricity from oil in 2010 [26], respectively, as compared to the larger quantities of 48,086,000,000 kWh and 43,879,000,000 kWh for the United States and Mexico, respectively, over the same period. As well, in contrast to what Rubin claims, "coal, natural gas and hydroelectric" appear to do substantially more of "the heavy lifting for the electrical grid" in China and India than they do in Canada, the United States, and Mexico: China, 96.9%; India, 92.9%; United States, 74.8%; Canada, 81.7%; and Mexico, 74.6%.

[11] http://www.cbc.ca/news/business/story/2012/04/20/oil-refining-canada.html

Table 3: Percent contributions to total electricity production in China, India, the United States (USA), Canada, and Mexico during 2009 by coal, hydroelectric, natural gas, nuclear, and oil.

Country	Coal	Hydroelectric	Natural gas	Nuclear	Oil
China	78.8%	16.7%	1.4%	1.9%	0.4%
India	68.6%	11.9%	12.4%	2.1%	2.9%
USA	45.4%	6.6%	22.8%	19.9%	1.2%
Canada	15.2%	60.3%	6.2%	15.0%	1.4%
Mexico	11.3%	10.2%	53.1%	4.0%	17.5%

p. 214: "Energy has never been in higher demand than it is in today's world of commercial farming. The quantum leaps made in agricultural productivity in the postwar era were achieved by channeling greater amounts of energy into food production. Farming is now extremely energy intensive, whether the power is diesel for tractors, fertilizer for crops or electricity to run irrigation systems."

In contrast, total energy use on American farms has declined substantially since its peak in the late-1970s [27]. Furthermore, ratios of direct and indirect energy use to output between 1965 and 1999 in the American farm sector indicate clearly that agriculture is becoming substantially less energy intensive in the United States over time. Similarly, the United States Department of Agriculture (USDA) found the following [28]: "[s]ince 1978, the total energy use by the agricultural sector has fallen. Even though energy use has decreased, agricultural output has increased since the late 1970s. One measure of energy efficiency, the ratio of energy use to agricultural output, has fallen by about 50 percent since 1978." In 2010, the USDA food dollar analysis indicated that the energy cost contribution is only 4.8 cents (i.e., 4.8%), and that the current energy contribution towards the food dollar is equivalent to what it was in 1993 (whereas contributions from legal and accounting, finance and insurance, and foodservices have increased consistently since the early 1990s) [29]. In Canada, total energy use for agriculture in 2009 was lower than at any previous point since 1990, and a clear decline in energy use since 2000 is evident [30]. The energy intensity of Canadian agriculture (measured in MJ energy per 2002 constant dollar of GDP contribution) has also declined substantially since 2004. More food is being produced with less energy over time in both Canada and the United States.

Exerpts from "The End of Growth" have also appeared in major newspapers. For example, in the May 5, 2012 edition of the *Globe and Mail* newspaper, an article entitled "The economics of energy conservation" [31] prints an excerpt from ref [8]. A number of issues exist with the information that Rubin presents. Rubin makes the following statement: "Denmark clearly has plenty of good reasons to be proud of its environmental track record. From the moment I glimpsed the wind turbines from my plane seat, though, I couldn't get away from a niggling curiosity about how the country generates the rest of its power.

At the conference I was attending, a speaker from a local power company presented on Denmark's world-leading green technology. I tracked him down after my own talk, figuring he was just the person to ask. He hemmed and hawed, but when I pressed him, he reluctantly told me how his country generates the other 80 per cent of its power. Coal. I was floored. The first thought that crossed my mind was, 'Something is rotten in the state of Denmark!' For a country striving to be completely independent of fossil fuels, Denmark couldn't have picked a worse way to generate electricity. Coal is 20 per cent dirtier than oil and twice as dirty as natural gas. With big dollars at stake selling green energy technology around the world, I can understand why Denmark wants to showcase its offshore wind farms instead of its coal-fired power plants. But the cold hard truth is that it is smokestacks, not wind turbines, that allow most Danes to turn on the lights. Coal's share of power generation, I found out, is the same in Denmark as it is in China. Where China's carbon footprint now dwarfs every other country in the world, though, Denmark's is actually shrinking. How can this be?"

These statements do not appear to be accurate. China does generate about 80% of its electricity from coal [21]. However, Denmark only generates 44% of its electricity from coal, not 80% as Rubin states. This apparent error then undermines some of Rubin's subsequent arguments from his excerpt. Rubin also makes the following statement: "In Denmark, government-regulated power prices are laden with carbon taxes, which means electricity isn't cheap, whether it's wind powered or coal fired. Not surprisingly, Danes use a fraction of the power that North Americans consume." Figure 17 shows annual per capita energy use [32], electric power consumption [33], and carbon dioxide emissions [17] for Denmark, Canada, and the United States between 1960 and 2010. There appears to be no evidence of a shift in Denmark's per capita energy use or carbon dioxide emission patterns that can be linked to the introduction of a carbon tax in 1992. Denmark's per capita energy use has been approximately constant since 1970, its per capita carbon dioxide emissions have been declining at about the same rate since 1970, and the per capita electric power consumption has been stable since the early 1990s (one notes that per capita electric power consumption in the USA has decreased 3.8% since 1992, whereas Denmark's corresponding value has increased 0.2%). Examining the ratio of per capita energy [32] and electric power use [33] and carbon dioxide emissions [17] between Canada and Denmark over the past half-century reveals a similar story (Figure 18): no evidence for any post-1992 carbon tax induced change in Denmark's energy use patterns relative to Canada.

Other other media discussions, Rubin has made the following statements [34]: "In a world of triple-digit oil prices, the global economy will be very different from the one we've known ... [t]he relationship is straightforward: economic growth is a function of energy consumption ... [w]hen the price of oil goes up, something has to give.

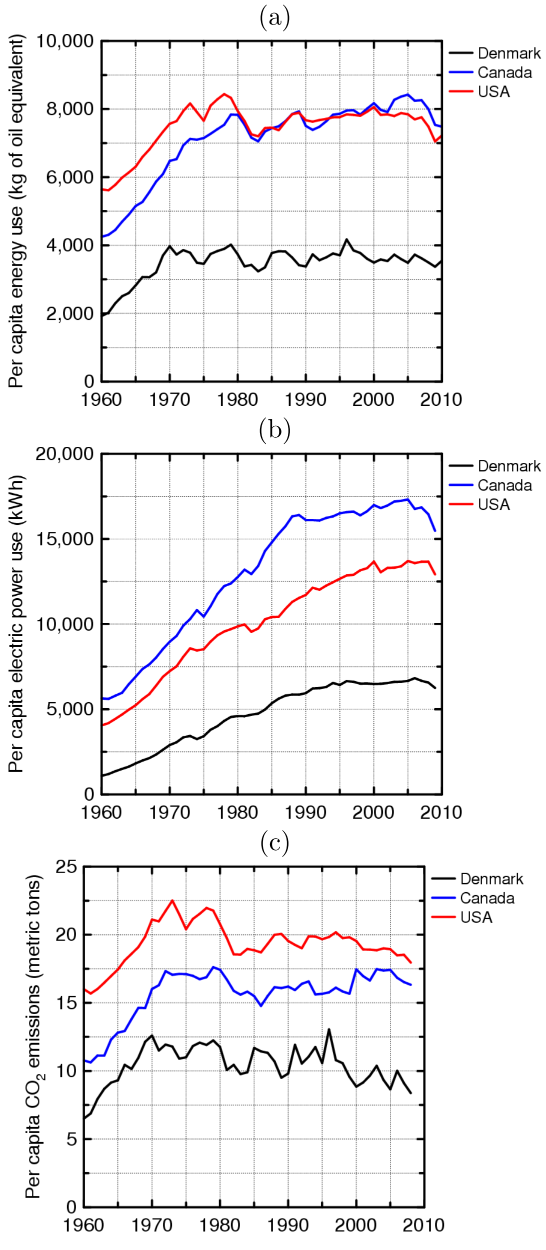

Figure 17: Annual per capita (a) energy use, (b) electric power consumption, and (c) carbon dioxide emissions for Denmark, Canada, and the United States between 1960 and 2010 (2010 data not available for annual per capita electric power consumption; 2009 and 2010 data not available for annual per capita carbon dioxide emissions).

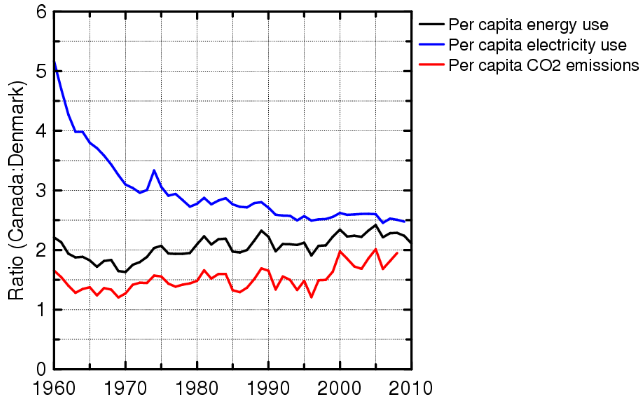

Figure 18: Ratios of per capita energy and electric power use and carbon dioxide emissions between Canada and Denmark from 1960 to 2010 (2010 data not available for annual per capita electric power consumption; 2009 and 2010 data not available for annual per capita carbon dioxide emissions).

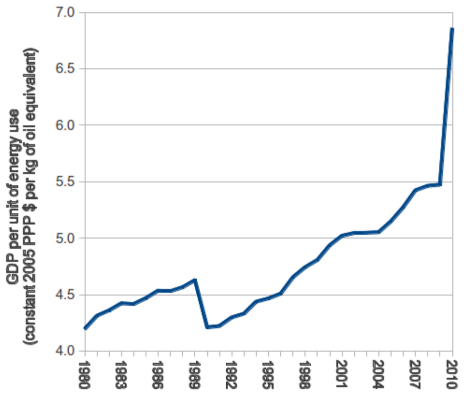

Figure 19: Historical temporal trend in global GDP (in constant PPP 2005 international dollars) per unit of energy use (kg of oil equivalent) between 1980 and 2010.

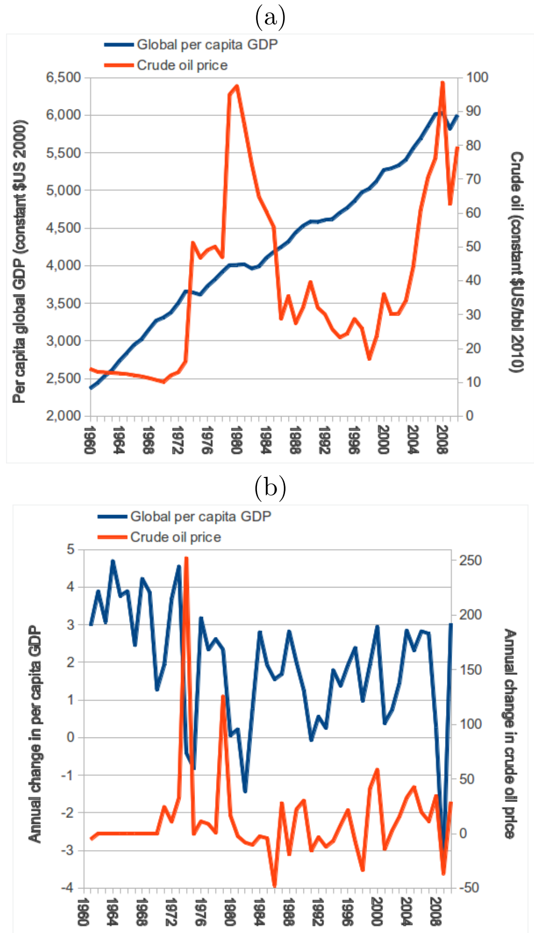

Figure 20: Historical temporal trends in (a) per capita global GDP (in constant PPP 2005 international dollars) and crude oil prices (in constant 2000 US dollars) and (b) the corresponding annual percentage rates of change in per capita global GDP and crude oil prices between 1960 and 2010.

Right now, the European Monetary Union [EMU] looks to be the most imminent casualty. How much longer will Greece slavishly heed the demands of its creditors and impose punishing austerity measures with the only result being the continuing implosion of its economy? Will Spain be able to tighten its belt any further when a quarter of its labour force is already unemployed?" Linking high oil prices in a causal relationship to the EMU financial crisis in problematic. Rising government debt levels, trade imbalances, poor monetary policies, collapse of housing markets, and a general loss of confidence all seem far more likely causes of the EMU's crises than high oil prices. Furthermore, global GDP per unit of energy use [35] has increased substantially since 1980 (Figure 19), and there is no clear relationship between per capita global GDP [36] and crude oil prices [13] over time (both in constant dollar terms) or between the rates of change in per capita global GDP [11] and crude oil prices [13] (Figure 20).

The linkages between sustained high oil prices and a static global economy are not strong. Many more factors determine the past, present, and future trajectories of the global economy beyond just energy prices. Wealth will shift around the globe in the future, as it has in the past. North America and the EU may see a prolonged downward curvature from their historic economic growth patterns, but that is due to much more than just recently high energy prices. The flattening of the North American GDP curve has been occurring for several decades, dating back far before the high oil prices of the mid- to late-2000s.

In 2008, Rubin forecast US$200/bbl oil prices by 2012. When such prices did not materialize, Rubin's explanation was as follows [37]: "What happened to my forecast for $200 oil? Quite simply, the end of growth." Whose growth has ended? Since oil is priced on the world market based on global supply and demand, Rubin must mean the "end of [global] growth." The 2010 GDP-PPP in constant 2005 international dollars [14] was $67.7 trillion, a 5.0% increase over the 2009 global GDP-PPP, and the highest ever global GDP-PPP (2008 was the previous high at $65.0 trillion). Global GDP in constant 2000 US dollars [12] was $41.4 trillion in 2010, a 4.2% increase over 2009 and another new all-time high (the previous record was in 2008 at $40.6 trillion). Figure 21 shows plots of global GDP on a PPP basis in constant 2005 international dollars [14] and in constant 2000 US dollars [12]. In neither case does the "end of growth" appear to have occurred. Similar trends are evident on a per capita basis [36, 38] (Figure 22). As with the early 1970s, late 1970s/early 1980s, early 1990s, and the early 2000s, there are periodic short-term flatlines in the longer-term per capita global GDP growth trend. Have we entered a high-oil price induced permanent end of growth period? This seems unlikely within the context of the data presented above and the historical record.

Overall, we find no significant evidence to support a hypothesis that the global economy has reached the "end of growth" from an economic perspective, or that such economic limits are about to be reached in the near-term. Our conclusions in no way diminish concerns over current and proposed rates of non-renewable resource extraction and the negative impacts of continuing human population growth and industrial expansion on the biosphere. However, any natural system limits that have been reached or exceeded (or are about to be) do not appear to be causing sufficiently large negative feedbacks on global economic growth within the scope of the most commonly employed socio-economic indicators in order to warrant claims that future economic growth will halt or regress.

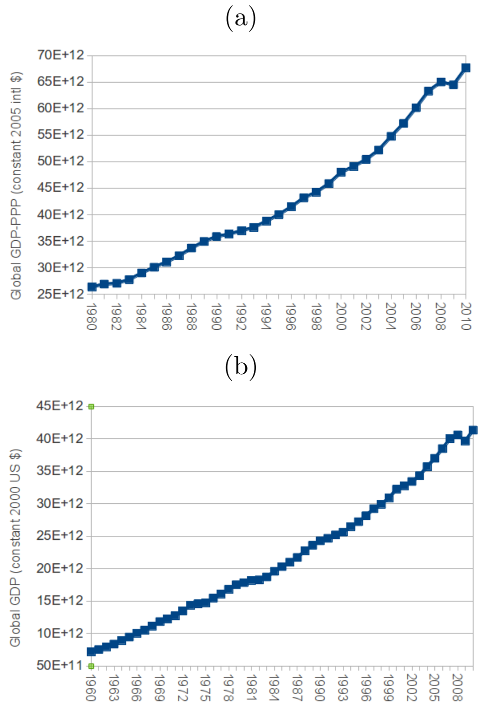

Figure 21: Historical temporal trends in (a) global GDP on a PPP basis (in constant 2005 international dollars) since 1980 and (b) global GDP (in constant 2000 US dollars) since 1960.

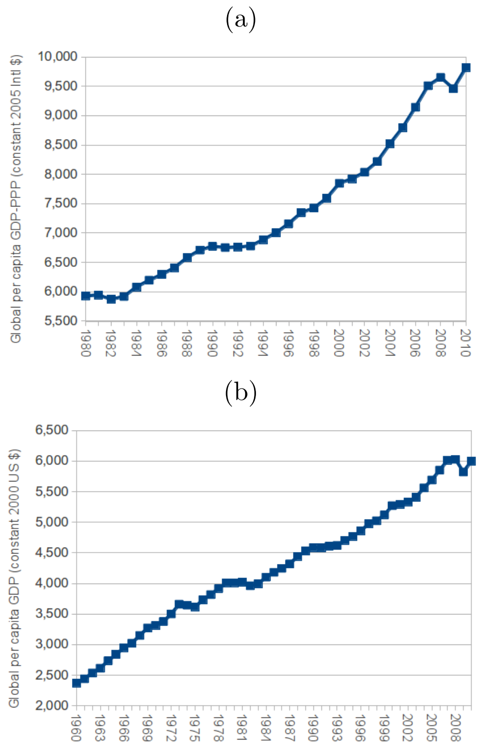

Figure 22: Historical temporal trends in (a) per capita global GDP on a PPP basis (in constant 2005 international dollars) since 1980 and (b) per capita global GDP (in constant 2000 US dollars) since 1960.

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