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Energy Productivity, Labor Productivity, and Global Warming

Lance Taylor*

Abstract Growth rates of energy productivity and the energy/labor ratio (which sum to the growth rate of labor productivity) are reviewed for groups of developing and the rich OECD economies. Their ratios of CO_2 emission to energy use are also compared. The CO_2/energy ratios are not substantially higher in poor than rich countries. If they stay relatively stable, then achieving a "flat path" with zero growth of energy use to combat global warming would require changes in growth rates of energy productivity and energy/labor ratios in the range of two percentage points, of the same magnitude as the growth rates of those variables themselves.

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Global warming is the consequence of three very strong and increasingly contradictory trends.

First, emission of carbon dioxide, the main driver (for now) of the greenhouse effect, is a direct consequence of using fossil fuels and biomass as the predominant sources of energy for utilization by humans.

Second, people in developing countries worldwide desperately want to increase their real income levels per capita. That necessarily requires growth in real output per unit of labor, or labor productivity. Population growth also enters the equation for overall income (and output) expansion but if all goes well its energy-use impacts will be less than those of rising per capita incomes.[1]

Third, historically a crucial factor supporting rising labor productivity and per capita income has been increasing use of energy. This is an old idea, widely accepted among ecological economists but never fully taken on board by the professional mainstream. It dates back to the "energetics" movement of the last half of the 19th century (Martinez-Alier with Schlüpmann, 1987; Mirowski, 1989) but not much further.[2]

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[1] Let X be real output, and assume that the both labor force and population are proportional to a variable L (that is, labor force participation rates are stable). Let $\varepsilon_L = X/L$ be output (or income) person and a "hat" over a variable denote its growth rate, e.g. $\hat{X} = (\frac{dX}{dt})/X$. Then $\hat{X} = \hat{\varepsilon}_L + \hat{L}$, or output growth is the sum of growth rates of per capita income and population. If over the next few decades poor countries do have rising per capita income (the historical rate in rich economies is around 2% per year), productivity growth $\hat{\varepsilon}_L$ will dominate population expansion $\hat{L}$.

[2] Leibniz proposed the basic concept of energy around 1680 but it did not take its modern form until the 1840s.

A slightly overstated paraphrase is "The currency of the world is not the dollar, it's the joule." (Lewis, 2007)

One can make the linkage between rising labor productivity and increasing energy use a bit more precise by comparing growth rates of average labor and energy productivities and the energy/labor ratio. It is easy to show that the latter two growth rates must sum to the first as an algebraic identity.[3]

Empirical Results

To concentrate on global warming, it makes sense to focus on fossil fuels and biomass as the principal energy inputs at a national level (so energy production from hydro, solar, wind, nuclear.... is ignored).

Figure 1 presents two scatter diagrams of growth rates of the ratio of annual energy use to employment and labor productivity, for the periods 1970-1990 and 1990-2004 for 12 regional groups of developing economies[4] and the rich countries in the OECD. There appears to be a robust relationship between increasing energy use per worker and labor productivity growth, with a steeper slope and a better fit in the later period. Similar results show up when growth rates are compared at the individual country level. The slope of the relationship in 1990-2004 is around 0.6, suggesting a substantial contribution of more energy use per worker to higher productivity.

Figure 1

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[3] Let average energy productivity be $\varepsilon_E = X/E$, with *E* as energy input. Then $\frac{\varepsilon_L}{\varepsilon_E} = \frac{E}{L} = \lambda$. It follows that $\hat{\varepsilon}_L = \hat{\varepsilon}_E + (\hat{E} - \hat{L}) = \hat{\varepsilon}_E + \hat{\lambda}$. Output is measured in real 1990 dollars at market prices, *not* in terms of purchasing power parity which is macroeconomically meaningless (Rada von Arnim and Taylor, 2008).

[4] These groups are described and analyzed extensively in Rada von Arnim and Taylor (2008).

Table 1 presents the data in numerical form for the regions and selected countries. A unit of time is necessarily involved – so we are really considering power usage. The numbers are in units of terajoules per worker-year.[5] In 2004, there was evidently a wide range of energy/labor ratios per year – from 0.01 (77 gallons of gasoline) in sub-Saharan Africa to 0.74 (5700 gallons) in Saudi Arabia. The ratio is 0.58 in the US and less than 0.3 in Western European countries, the Asian Tigers, and Japan.

Table 1

Global Warming

In the context of global warming, these numbers are not reassuring. For example, if the slope of the relevant future curve as in Figure 1 really is 0.6, then 2% per capita income growth would require the energy/labor ratio to rise at 1.2% per year. Factoring in population growth might raise total energy usage by around 2% annually. In fact, the situation is not quite so dire because the largest non-industrialized groups (notably China, the former USSR, South Asia, and the semi-industrialized economies) report relatively high energy productivity growth. But it still makes sense to ask how

[5] One joule is the energy required to lift a small (100 gram) apple one meter against the earth's gravity. One terajoule is roughly equivalent to 7700 gallons of gasoline or 31 tons of coal. Alternatively, one watt equals one joule of energy use per second. Dividing terajoules per year by the number of seconds in a year shows that an American worker utilizes 19.3 kilowatts of power to produce his or her contribution to real GDP. An African uses 300 watts.

current growth rates of energy consumption may feed into the atmospheric stock of carbon dioxide.

As background, Table 2 presents comparisons of energy consumption per worker and carbon dioxide emission per capita for the world and selected countries in 2004. Emissions per unit of energy are in the range of 65-75 metric tons per terajoule in rich countries and somewhat higher in (some) developing and transition economies. One implication is that lower emission levels in the latter are mostly due to smaller energy/labor ratios. The numbers for China, Kenya, Brazil, etc. suggest that there is room for cutting worldwide emissions simply by increasing poor countries' efficiency of carbon utilization, but that major benefits can only come from cutting back on energy use per capita and per unit of economic output.[6]

Table 2

Rich and Poor Country Trade-offs

Assuming that the CO_2/energy stays constant, Figure 2 illustrates the potential trade-offs. In the period 1990-2004, energy productivity rose at 1.9% per year in the "rich OECD" economies and at 2.8% in the rest of the world because of high productivity growth rates (noted above) in some of the larger economies. The solid line is an isocline showing combinations of energy productivity growth rates that would have been needed to hold the growth rate of total energy use to zero. This scenario represents the initial

[6] In any case, switching from the current worldwide mix of fossil fuel energy sources to using natural gas (the least carbon-intensive source) exclusively would reduce carbon emissions by only about 15% (see Lewis, 2007).

stages of the "flat path" of energy use that Socolow and Pacala, 2006) propose to hold atmospheric CO_2 to less than twice its pre-industrial level.

Figure 2

The prospects are not favorable. Had the energy productivity growth rate in poor countries remained stable, a rate of almost 4.5% per year would have been required in the developed world to hold energy growth to zero. By way of contrast, the Kyoto targets call for (roughly) an annual 1% reduction in energy use for the rich countries, implying that their energy productivity growth rate would have to be about 4%. The growth of worldwide energy consumption would fall from 1.1% to 0.65% per year, well above the flat path.[7] With a constant rate in the rich countries, energy productivity growth of almost 5% per year would have been needed in the poor ones.

The growth rates of the energy/labor ratio corresponding to these cases for rich and poor countries are -2.5% and -2.3% respectively. Compared to the historical data summarized in Table 1, these numbers look extremely optimistic. The changes are of the same absolute magnitude as the historical growth rates themselves! The only countries that are now in the required range of energy/labor growth rates are stagnant with negligible or negative labor productivity growth. And in the recent period, there has been no significant downward trend in energy/labor ratios in rich economies.

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[7] The calculations are based on an equation for the worldwide growth rate of energy consumption, $\hat{E} = \theta(\hat{L}_R + \hat{\varepsilon}_{LR} - \hat{\varepsilon}_{ER}) + (1-\theta)(\hat{L}_P + \hat{\varepsilon}_{LP} - \hat{\varepsilon}_{EP})$, where the subscripts *R* and *P* stand for rich and poor countries respectively, and θ is the share of the rich in world energy use (about 45% in 2004).

On the whole, poor countries import “modern” technologies previously created in advanced economies. The key policy question is whether in the near future rich country energy/labor ratios can be reduced (or energy productivity increased relative to labor productivity) substantially by technological innovation and social rearrangements.[8] If such innovations work out, then perhaps they can be passed to developing economies soon enough to enable them to maintain positive per capita output growth with only slowly increasing or (better) decreasing energy/labor ratios.

If such a growth pattern does not prove to be possible, then the three contradictory trends mentioned at the outset will inevitably collide. Only 16% of the world’s population now lives in the rich countries which account for 45% of world energy use. Both shares are declining. Unless the advanced economies find the means to reduce their own energy-labor ratios substantially (and unhistorically!) and pass the techniques along to the rest of the world, the consequences of colliding income growth, energy use per capita, and global warming trends are unforeseeable but may well be catastrophic indeed.

References

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[8] The same observation applies to CO_2/energy ratios as well.

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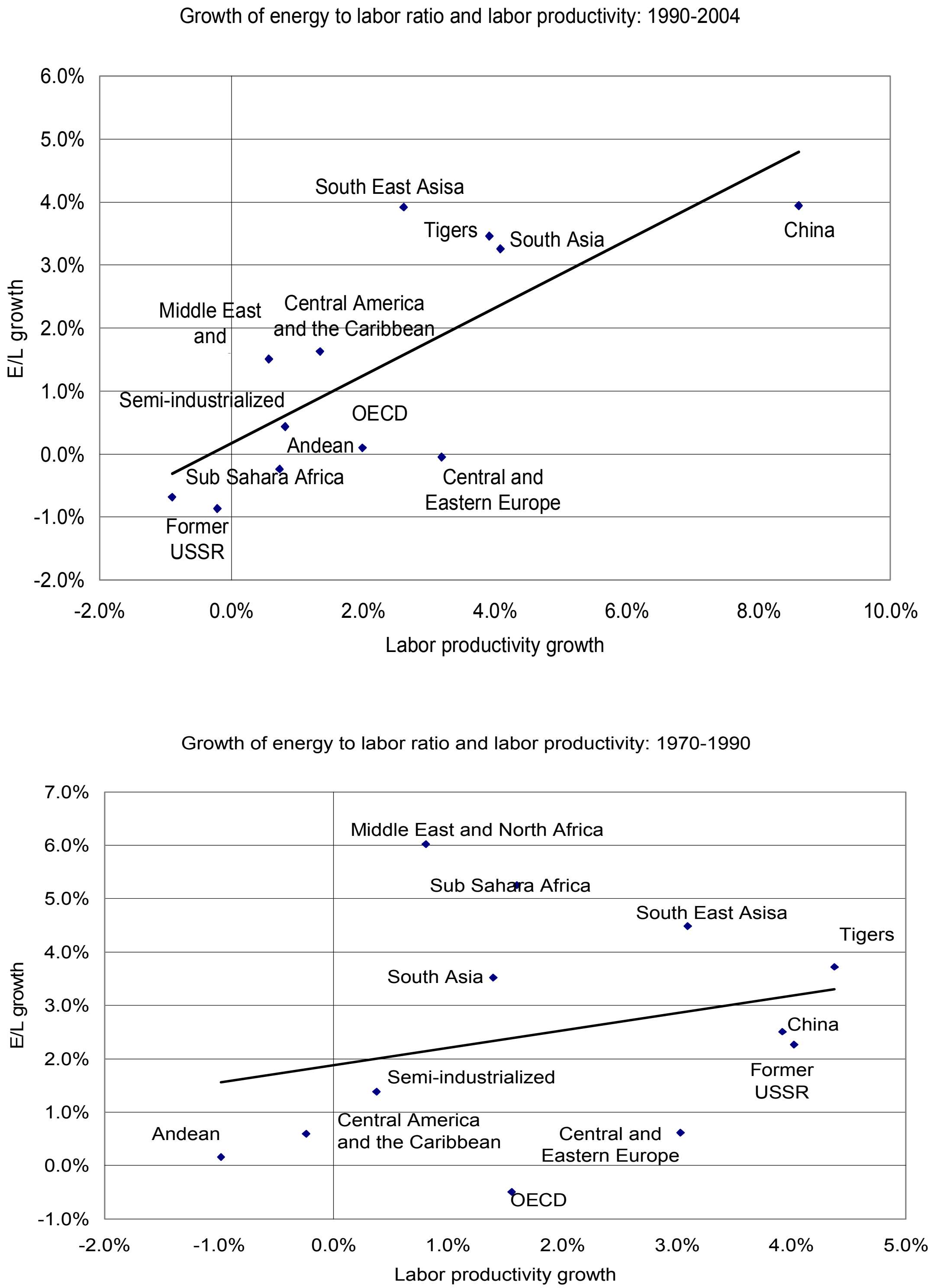

Figure 1: Growth rates of labor productivity and the energy/labor ratio.

1970-1990	Selected OECD	Central and Eastern Europe	USSR* (1989 end year)	Tigers	South East Asia	China	South Asia	Semi-Industrialized countries	Central America and the Caribbean	Andean	Middle East	SubSahara Africa
Growth Rates Energy Productivity	2.1%	2.4%	1.6%	0.6%	-1.3%	1.4%	-2.1%	-1.0%	-0.8%	-1.1%	-4.9%	-3.5%
Growth Rates Labour Productivity	1.6%	3.0%	4.0%	4.4%	3.1%	3.9%	1.4%	0.4%	-0.2%	-1.0%	0.8%	1.6%
Growth Rates E/L	-0.5%	0.6%	2.3%	3.7%	4.5%	2.5%	3.5%	1.4%	0.6%	0.2%	6.0%	5.3%
E/L beginning year (1970)	0.49	0.21	0.26	0.08	0.01	0.02	0.01	0.09	0.04	0.04	0.05	0.0048
E/L end year (1990)	0.45	0.24	0.40	0.17	0.03	0.04	0.02	0.12	0.05	0.04	0.16	0.0133

1990-2004	Selected OECD	Central and Eastern Europe	USSR* (beginning year)	Tigers	South East Asia	China	South Asia	Semi-Industrialized countries	Central America and the Caribbean	Andean	Middle East	SubSahara Africa
Growth Rates Energy Productivity	1.9%	3.2%	2.1%	0.4%	-1.3%	4.5%	0.8%	0.4%	-0.3%	1.0%	-0.9%	-0.2%
Growth Rates Labour Productivity	2.0%	3.2%	-0.2%	3.9%	2.6%	8.6%	4.1%	0.8%	1.3%	0.7%	0.6%	-0.9%
Growth Rates E/L	0.1%	0.0%	-0.9%	3.5%	3.9%	3.9%	3.3%	0.4%	1.6%	-0.2%	1.5%	-0.7%
E/L beginning year (1990)	0.45	0.24	0.41	0.17	0.03	0.04	0.02	0.12	0.05	0.04	0.16	0.01
E/L end year (2004)	0.45	0.24	0.37	0.27	0.05	0.07	0.04	0.12	0.06	0.04	0.19	0.01

Table 1: Growth of energy productivity, labor productivity, and the energy/labor ratio.

Data Sources: World Bank Development Indicators 2005 database; Gronningen Center for Growth and Development

2004	World	US	UK	Sweden	France	Japan
Total CO_2 Emission						
(thousands of metric tons)	27,245,758	6,049,435	587,261	53,033	373,693	1,257,963
Total Energy Consumption						
(thousands of terajoules)	361,849.00	81,762.00	8,926.00	671.00	5,667.00	17,094.00
Employment	2,836,437	140,702	28,008	4,311	24,963	63,290
Population	6,411,145	293,028	60,271	8,986	60,991	127,480
Energy Consumption/Labor	0.13	0.58	0.32	0.16	0.23	0.27
CO_2 Emission/Energy						
Consumption	75.3	74.0	65.8	79.0	65.94	74
CO_2 Emissions/Population	4.25	20.6	9.7	5.9	6.1	9.9

2004	China	India	Argentina	Brazil	Venezuela	South Africa	Kenya	Saudi Arabia	Poland	Russia
Total Carbon Emission (thousands of metric tons)	5,012,377	1,342,962	141,786	331,795	172,623	437,032	10,588	308,393	307,238	1,524,993
Total Energy Consumption (thousands of terajoules)	51,339	14,890	2,358	4,880	2,295	4,939	119	5,715	3,745	24,355
Employment	752,000	394,612	14,329	71,058	8,855	19,092	15,110	7,675	13,855	66,407
Population	1,295,734	1,065,071	38,984	183,169	24,765	44,448	33,973	25,796	38,580	143,508
Energy Consumption/Labor	0.07	0.04	0.16	0.07	0.26	0.26	0.01	0.74	0.27	0.37
Carbon Emission/Energy Consumption	97.6	74.0	65.8	79.0	65.94	74	89.0	74.0	73.7	74.7
Carbon Emissions/Population	3.87	1.3	3.6	1.8	7.0	9.8	0.31	12.0	8.0	10.6

Table 2: Carbon emission and energy consumption.

Data Sources: Gronningen Center for Growth and Development; 2004 Energy Statistics Yearbook, United Naions; Carbon Dioxide Information Analysis Center, United States Department of Energy

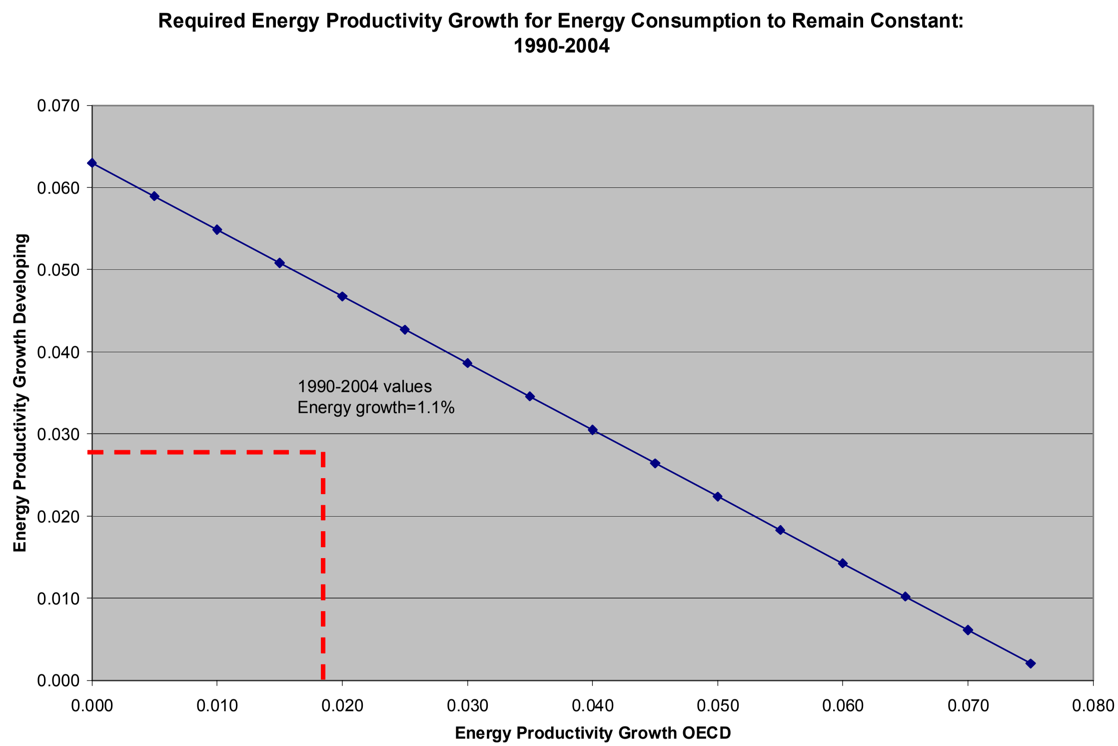

Figure 2: Energy productivity growth rates required to hold overall growth of energy use to zero, 1990-2004.