Comment on "The Choice of Exchange Rate on Modelling the Impact of Climate Change: A Response to the Castles-Henderson Critique of the IPCC" by John Quiggin

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1. Introduction

Quiggin (2005) has written an interesting critical review on the critique of the IPCC (International Panel on Climate Change) SRES (Special Report on Emissions Scenarios) modeling strategy made by Ian Castles and David Henderson (2004).[2] In this note, we comment on Quiggin's critique of the Castles and Henderson critique.

Quiggin summarizes the Castles-Henderson critique as follows:

"As regards exchange rates, the main points of the Castles-Henderson critique may be summarised as follows

- the use of market exchange rates in the SRES scenarios is inappropriate and PPP exchange rates should always be used
- the effect of using market exchange rates is to overstate the income gap between poor and rich countries and therefore the rate of growth required to achieve convergence over any given time period
- the result is to inflate the likely level of emissions
- these effects are so substantial as to invalidate the SRES exercise.

The fourth point is crucial in considering public discussion of the Castles- Henderson critique. There are many debatable assumptions in any modelling procedure, but most make only a modest difference to the results. In his initial critique, Castles referred to "fantastic assumptions", "astronomical" projections of growth rates and "extraordinary results". These characterisations have been widely publicised." John Quiggin (2005; 6-7).

The Quiggin counterattack on the Castles-Henderson critique can be summarized as follows:

"In this submission, it is argued, contrary to the claims of Castles and Henderson that

- In a fully-disaggregated multi-sector general equilibrium model, aggregate index numbers play no role and the choice between PPP and MER conversion of income levels does not arise
- In an aggregate model with consistent specification, the effects of the choice of conversion measure on energy demand should approximately cancel out, and the sign of the net effect is unpredictable.

[1] The author thanks Ian Castles and John Quiggin for helpful comments on early drafts of this note.
[2] See also Castles and Henderson (2005) and Henderson (2005) for additional material on the Castles and Henderson critique.

- Available evidence suggests that the effects of projected emissions arising from the choice between PPP and ME exchange rates are small in comparison to the uncertainties represented by the range of scenarios and to the likely impacts of other debatable modelling choices." John Quiggin (2005; 6-7).

Although Quiggin's first point is theoretically correct, it seems to be somewhat irrelevant to the problem at hand, which is: *given the assumption that poor countries will catch up to rich countries in the next 50-100 years in terms of per capita real income, what does this catch up process imply for per capita energy consumption (and hence emissions)?*[3] This question leads to the next question: *how exactly should we model the catch up process with respect to the implied increased energy consumption.* Thus although Quiggin is theoretically correct to say that in a fully specified general equilibrium model, aggregate index numbers play no role, this is not particularly helpful to modeling the catch up process. In any practical model of the catch up process, index numbers are bound to play a role.[4]

Given the above questions, we can recognize three modeling strategies:

- The IPCC (International Panel on Climate Change) SRES (Special Report on Emissions Scenarios) modeling strategy, which uses market exchange rates in order to estimate per capita income gaps between rich and poor countries. Once these gaps have been estimated, an estimated relationship between energy consumption and real income is used to project the increase in emissions that closing the gap would imply.
- The Castles-Henderson modeling strategy, which suggests the use of IPC (International Price Comparison) project PPP's (Purchasing Power Parities) in order to estimate per capita income gaps between rich and poor countries in place of market exchange rates. Once these gaps have been estimated, the same methodology as suggested in the SRES could be used to estimate the implied increase in emissions.
- The Quiggin modeling strategy, which works directly with per capita energy consumption gaps between rich and poor countries and then looks at the increase in energy consumption that would be implied if per capita energy consumption in poor countries equaled rich country per capita consumption. The advantage of this strategy is that we do not have to worry about income comparisons between countries at all; we need only compare energy consumptions, which is relatively easy to do and the index number problems associated with these comparisons are very small compared to full blown real income comparisons between countries.

[3] The convergence hypothesis is somewhat questionable to say the least; see the discussion on this point by Stegman and McKibbin (2005). However, discussing the merits of various convergence hypotheses is not the purpose of this note.

[4] Professor Quiggin (2005; 7) essentially recognizes this point: "In practice, no real-world model achieves this degree of disaggregation and nearly all use an income variable as an argument in demand functions."

In the following section, we will consider the above alternative modeling strategies in a very simple model. The final section draws some conclusions based on our very crude models.

2. A Simple Model

How much difference will it make if we choose the above alternative modeling strategies? It will be helpful if we construct a very simple model to illustrate the differences that the different modeling strategies generate.

Consider a comparison between a rich country and a poor country. Initially, we have only two finally demanded commodities in each country: traded goods t and nontraded goods and services n. In the rich country, we choose units of measurement so that the per capita quantity consumed is 1 for each commodity. For the poor country, the per capita quantities consumed are the positive fractions f_t and f_n for traded and nontraded commodities respectively. We use the market exchange rate to express poor country prices in terms of the rich country's currency. The rich and poor country price for the traded good is 1, the price of the nontraded commodity in the rich country is the positive price p and the price of the nontraded commodity in the poor country is αp where α is a positive fraction. This assumption reflects the fact that untraded goods and services tend to be cheaper in developing countries compared to the corresponding exchange rate adjusted prices in developed countries. The price and quantity data for our "world" economic model can be summarized as follows:

Table 1: Basic Price and Per Capita Quantity Data for the Rich and Poor Countries

	Poor country		Rich country	
	Prices	Quantities	Prices	Quantities
Traded	1	f_t	1	1
Nontraded	αp	f_n	p	1

Note that we are assuming the law of one price for traded commodities. The value of output at exchange rate adjusted market prices for the poor and rich countries, V^P and V^R, can be defined as follows:

(1) $V^P \equiv f_t + \alpha p f_n$;
(2) $V^R \equiv 1 + p$.

We will assume that nontraded commodities are relatively more plentiful in poor countries as compared to rich countries so that the fraction f_n is bigger than the fraction f_t; i.e., we assume that:

(3) $0 < f_t < f_n < 1$.

As mentioned above, we also assume that the nontraded commodity is relatively cheaper in the poor country so that

(4) $0 < \alpha < 1.$

We now look at real income gaps between the poor and rich countries using various possible index number formulae. We start off by defining the *market exchange rate inverse gap*, γ_M,[5] which is simply exchange rate adjusted per capita income of the poor country divided by the corresponding rich country exchange rate adjusted per capita income:

$$
\begin{aligned}
(5)\ \gamma_M \equiv V^P/V^R &= [f_t + \alpha p f_n]/[1 + p] \\
&< [f_t + p f_n]/[1 + p] && \text{using (4)} \\
&< [f_n + p f_n]/[1 + p] && \text{using (3)} \\
&= f_n.
\end{aligned}
$$

Thus the per capita inverse real income gap between the poor and rich country using the market exchange rate method, γ_M, is bounded from above by f_n, the per capita gap in living standards between poor and rich, using nontraded goods as the standard.

We now define the *Laspeyres inverse real income gap*, γ_L, between the poor and rich countries as the Laspeyres quantity index, which uses the prices of the rich country as weights:

$$
\begin{aligned}
(6)\ \gamma_L &\equiv [f_t + p f_n]/[1 + p] \\
&> [f_t + \alpha p f_n]/[1 + p] && \text{since } \alpha < 1 \text{ using (4)} \\
&= \gamma_M.
\end{aligned}
$$

In a similar fashion, define the *Paasche inverse real income gap*, γ_L, between the poor and rich countries as the Paasche quantity index, which uses the prices of the poor country as weights:

$$
\begin{aligned}
(7)\ \gamma_P &\equiv [f_t + \alpha p f_n]/[1 + \alpha p] \\
&> [f_t + \alpha p f_n]/[1 + p] && \text{since } 0 < \alpha < 1 \text{ using (4)} \\
&= \gamma_M.
\end{aligned}
$$

Thus the Laspeyres and Paasche (per capita) quantity indexes are both larger than the market exchange rate inverse gap and hence, if we regard the true per capita income gap between rich and poor countries as some number that is between the Laspeyres and Paasche quantity indexes, we see that under our assumptions (3) and (4), the market exchange rate gap *exaggerates* the true gap in living standards between rich and poor countries.

A bit of algebra will show that under our assumptions, the Laspeyres inverse gap is larger than the corresponding Paasche inverse gap; i.e., we can show that

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[5] We term this an inverse gap because the *larger* γ_M is, the *closer* is the poor country's per capita real income to that of the rich country. Thus as γ_M increases, the income gap narrows.

(8) $\gamma_L > \gamma_P$.

The Fisher (1922) ideal quantity index is my preferred method for making bilateral quantity comparisons[6] so define the *Fisher inverse gap in living standards*, γ_F, as the geometric mean of the Paasche and Laspeyres inverse gap indexes:

(9) $\gamma_F \equiv [\gamma_L \, \gamma_P]^{1/2}$.

The above definitions and the inequalities (6)-(8) imply the following relationships between all of our suggested inverse gap measures:

(10) $\gamma_L > \gamma_F > \gamma_P > \gamma_M$.

Thus the Laspeyres, Fisher and Paasche inverse gap measures all suggest smaller gaps in living standards compared to the gap obtained by using the market exchange rate method. To get some idea of big the differences in the various inverse gaps could be, set p = 1 and consider the following table of differences as functions of f_t, f_n and α.

Table 2: Inverse Living Standard Gaps between Rich and Poor Countries

f_t	f_n	α	γ_L	γ_F	γ_P	γ_M
.01	.05	.1	.0300	.0202	.0136	.0055
.1	.3	.2	.2000	.1633	.1333	.0800

The first line in Table 2 looks at a comparison of a very poor country with a rich country. For this very poor country, the per capita consumption of tradables is only 1% of the rich country's level and only 5% for nontradables. Using exchange rate adjusted per capita incomes, the level of per capita income in the very poor country relative to the rich country, γ_M, is only .55%. Thus using the market exchange rate method of comparison, the rich country's per capita income is about 182 times the level of the very poor country's per capita income. But if we look at the Fisher index method of comparing real per capita incomes, the level of per capita income in the very poor country relative to the rich country, γ_F, is 2.02%. Thus using the Fisher index method of comparison, the rich country's per capita income is about 49 times the level of the very poor country's per capita income. This is a very substantial difference between the two methods of comparison!

The second line in Table 2 looks at a comparison of a poor country with a rich country. For this poor country, the per capita consumption of tradables is 10% of the rich country's level and 30% for nontradables. The price of nontradables in the poor country is only 20% of the corresponding exchange rate adjusted price in the rich country. Using exchange rate adjusted per capita incomes, the level of per capita income in the very poor

[6] The Fisher index has strong justifications from the viewpoint of both the economic and axiomatic approaches to index number theory; see Diewert (1976) (1992).

country relative to the rich country, γ_M, is only 8%. Thus using the market exchange rate method of comparison, the rich country's per capita income is 12.5 times the level of the poor country's per capita income. But if we look at the Fisher index method of comparing real per capita incomes, the level of per capita income in the very poor country relative to the rich country, γ_F, is 16.33%. Thus using the Fisher index method of comparison, the rich country's per capita income is about 6 times the level of the very poor country's per capita income. Again, *the market exchange rate method for estimating real income differences between countries substantially overstates the real income gap between the rich and the poor country*.

At this point, we would have to conclude that Castles and Henderson were more or less right in their criticisms of SRES. And I think that Castles and Henderson are right to assert that the differences are not small between the two methods. But the contribution of Quiggin is in a different direction: *he essentially questions the second part of the SRES methodology*. Quiggin notes that we do not have to work out the emission consequences of an assumed convergence in real income standards between rich and poor countries by first working out present real income differences and then working out the implications on energy consumption by assuming that there is a relationship between energy consumption and real income levels. Instead, we can directly compare per capita energy consumption between rich and poor and work out the consequences of equalization by assuming that rich and poor countries end up with the same per capita energy demands. There is no need for complicated and distracting index number complications![7]

To see how this "new" methodology would work in the context of our simple example, let us make another simplifying assumption: namely, that the per capita energy consumption in the poor country relative to the rich country is equal to f_t, the per capita consumption of traded goods in the poor country relative to the rich country. The new "energy" inverse gap γ_E between the poor and rich country using per capita energy consumption as the metric of comparison is simply equal to f_t; i.e., we have:

(11) $\gamma_E \equiv f_t$
$= [f_t + \alpha p f_t]/[1 + \alpha p]$
$< [f_t + \alpha p f_n]/[1 + \alpha p]$ using $f_t < f_n$; see (3) above

[7] The thrust of Quiggin's methodology is explained by him as follows: "As observed by Castles and Henderson, the use of market exchange rates in converting currencies will lead to an overstatement of the initial gap between rich and poor countries, relative to World Bank or other PPP conversions. This in turn increases the measured rate of growth required for the poor countries to catch up. Castles and Henderson infer that total projected world GDP is pushed up; and this in turn is reflected in higher projected emissions. The problem with this claim is that the choice of conversion measure also affects the estimated relationship between income and energy consumption. Since measurements of energy consumption are made in physical terms and are not affected by the choice of income unit, the larger the measured gap in income between poor and rich countries, the lower must be the estimated elasticity of energy consumption relative to income. The two effects will work in opposite directions, and with approximately offsetting impacts. Since different data transformations imply different estimation procedures it is unlikely that they will cancel exactly, but there is no presumption as to which effect will dominate when simulation is undertaken outside the range on which parameters were originally estimated. John Quiggin (2005; 8-9).

$\equiv \gamma_P$ using definition (7).

Thus (11) and the previously established inequalities (10) imply the following inequalities:

(12) $\gamma_L > \gamma_F > \gamma_P > \gamma_E$.

Hence, when we switch to a direct comparison of per capita energy usage between rich and poor countries, our old Paasche, Fisher and Laspeyres measures are too high compared to the "true" direct measure (under our assumptions), γ_E.

What about a comparison of the direct inverse energy gap measure γ_E (equal to f_t under our assumptions) with the market exchange rate inverse gap measure γ_M defined by (5) above? It turns out that the assumptions made so far do not imply any definite inequality between the two measures. Recall that we assumed that $f_t < f_n$ and $\alpha < 1$. These assumptions are very likely to be satisfied. However, I believe that the following further inequality is *likely* to be satisfied empirically:

(13) $\alpha f_n < f_t$.

The meaning of (13), along with our other assumptions, is that final demand expenditures on nontraded commodities in the poor country are less than the expenditures on traded commodities in the poor country. This means that even though the ratio of the per capita quantity of nontradables relative to tradables in the poor country is higher than the corresponding ratio in the rich country (so that nontradables are relatively abundant in the poor country), the relative price of nontradables is so low in the poor country that the ratio of per capita expenditures on nontradables relative to tradables in the poor country is lower than the corresponding ratio in the rich country. In any case, if we assume (13), we can derive the following inequality:

(14) $\gamma_M = [f_t + \alpha p f_n]/[1 + p]$ using definition (5)
$< [f_t + p f_t]/[1 + p]$ using (13)
$= f_t$
$= \gamma_E$ using definition (11).

Thus if assumption (13) holds, then we can combine the inequality (14) with our earlier inequalities (10) and (11) in order to obtain the following inequalities:

(15) $\gamma_L > \gamma_F > \gamma_P > \gamma_E > \gamma_M$.

We can assess how far γ_E and γ_M are from each other using the data in Table 2. In fact, since γ_E equals f_t, the results can be read directly from the first and last columns in Table 2. Thus for the very poor country, we have the energy inverse gap γ_E equal to 1.00% and the market exchange rate gap γ_M equal to .55%. Thus for this first example, the market exchange rate is *not* a close approximation to the direct energy comparison gap.[8] For the poor country, we have the energy inverse gap γ_E equal to 10% and the market exchange rate gap γ_M equal to 8%. Thus for this second example, the market exchange rate *is* a reasonable approximation to the direct energy comparison gap.

3. Conclusion

What conclusions can we draw from the above algebra? It seems possible to draw the following tentative conclusions:

- Castles and Henderson are right to criticize the first part of the SRES modeling strategy, which relies on market exchange rates to calculate per capita real income differences between countries. It would be much better to use ICP PPP's for this first part of the SRES modeling strategy. The differences between PPP's and market exchange rates can be very large so their criticism is not a negligible one.
- Quiggin is right to implicitly criticize the entire SRES modeling strategy. It would be simpler to abandon the two stage modeling strategy and make direct comparisons of energy intensities across countries and assume energy convergence rather than real income convergence.
- Either way, the SRES model should be reestimated.

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[8] Note that the size of the difference between γ_M and γ_E is basically unpredictable; it depends on the gap between f_t and αf_n which is difficult to predict a priori.

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