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ABSTRACT

The latest World Bank estimates of real GDP per capita for China are significantly lower than previous ones. We review possible sources of this puzzle and conclude that it reflects a combination of factors, including substitution bias in consumption, reliance on urban prices which we estimate are higher than rural ones, and the use of an expenditure-weighted rather than an output-weighted measure of GDP. Taking all these together, we estimate that real per-capita GDP in China was 50% higher relative to the U.S. in 2005 than the World Bank estimates.

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1. Introduction

The International Comparison Program (ICP) is a collaborative effort of the World Bank and other international agencies to estimate the "real GDP" of countries, i.e. the value of their GDP when adjusted for price level differences across countries and priced in dollars. Because market exchange rates cannot be relied upon to provide the right conversion from national currencies to dollars, the ICP computes "purchasing power parity" (PPP) exchange rates, which compare local prices of a basket of goods with the U.S. prices of those same goods in a benchmark year. For China, the 2005 benchmark estimates from the World Bank show that real GDP per-capita for China was 40% smaller in 2005 than real GDP for the *same* year based on extrapolations from earlier rounds of the ICP. As Deaton and Heston (2010, p. 3) report:

> …the 2007 version of the World Development Indicators (WDI), World Bank (2007), lists 2005 per capita GDP for China as $6,757 and for India as $3,452, both in current international dollars. The 2008 version, World Bank (2008a), which includes the new [2005] ICP data, gives, for the same year, and the same concept $4,088 for China and $2,222 for India. For comparison, GDP per capita at market exchange rates is $1,721 for China and $797 for India.

Maddison (2007) argues that such a downward revision for China is implausible because extrapolating backwards it would imply per capita income below subsistence levels in early years[1]. This observation raises the questions of why the downward revision occurred and whether alternative calculations would give noticeably different results. The first of these questions has been addressed by Heston (2007) and Deaton and Heston (2010).[2] We will provide some theoretical structure to help understand their critique, and then address the second question:

[1] Using the Chinese national accounts growth rates would imply a real per capita GDP in 1970 of $400 at constant 2005 prices. The corresponding figure at the current 1970 prices is $93.

[2] See also the comments by Diewert (2010a).

whether alternative, theoretically consistent calculations of real GDP make a difference, for China or other countries.

Among the reasons provided by Deaton and Heston as to why the relative position of China was lowered in the most recent ICP round are the following:

1) The price data provided by China for the most recent ICP was for urban areas, and may have overstated the actual prices faced by rural consumers.

This first issue is a well-recognized feature of the price data provided for the 2005 ICP, which was the first time that China participated fully in the round[3]. While Deaton and Heston note that there is a theoretical issue of aggregating over large countries with diverse prices between regions, we do not address that issue here. Rather, we treat the urban bias in the prices reported from China to the 2005 ICP as an empirical issue to be investigated, in section 2.

2) Different index number methods imply different relative sizes of countries.

There are very substantial differences in the index numbers methods used by the World Bank, for example, and the methods used by Penn World Table (PWT). We focus here on just one aspect of those differences, namely, the use of fixed-weight indexes used in PWT with flexible-weight index used by the ICP. Neary (2004) has recently proposed an alternative that requires estimating the expenditure function across countries to obtain indexes of real consumption. The Neary approach was further developed by Feenstra, Ma and Rao (2009) and empirically implemented for data covering 124 countries. In section 2 we use all these methods, along with a recommendation by Barnett, Diewert and Zellner (2009), to calculate the size of real consumption in China. In addition to showing the differences between the various index number approaches we use two different sets of prices for China: the prices they reported to the

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[3] See Asian Development Bank (2007) for more details regarding price data from China used in the 2005 ICP Asia-Pacific region. It is clear that urban bias would have impacted on price data for consumption items.

2005 ICP, and our own estimates of alternative prices that adjust for urban versus rural differentials. We find that the impact of adjusting China's prices is quite large: real consumption in China is 10 to 20% higher using our adjusted prices than using the ICP prices.[4]

Closely related to the index number issue but conceptually distinct is:

3) There are several different concepts of real GDP that can be measured, each of which can imply different relative sizes of countries.

Shifting attention from just real consumption to real GDP, in section 3 we incorporate investment, government spending, and the trade balance. We draw on estimates of real GDP from Feenstra, Inklaar and Timmer (2011), which provides the basis for the "next generation" of PWT. They estimate real GDP^e per-capita in China for 2005 at $5,097, which is 25% larger than the estimate from the World Bank of $4,088. If the prices of consumption goods are adjusted based on our regression model, then real GDP^e per-capita rises to $5,543, or another 10% higher. Comparing these estimates to the World Bank's, we conclude that the World Bank estimate is too low by as much as 25 – 35%. In addition, real GDP in China is even higher once we incorporate the prices of exports and imports, in section 4.

Feenstra, Heston, *et al* (2009) have recently contrasted real GDP measured on the expenditure-side of the economy, as done by the World Bank and PWT, with real GDP measured on the output-side. These two concepts differ by countries' terms of trade, i.e. by the relative prices of their exports and imports. We provide calculations of China's real GDP in 2005 measured on the output-side, taking into account its terms of trade. We find that China's real GDP increases to $5,862 when measured in terms of its output, which exceeds expenditure-side real GDP due to China's low terms of trade. That measure of real GDP on the output-side is

[4] These differences in real consumption do not translate into major adjustments at the GDP level as consumption is only one component of total domestic expenditure which includes investments and government expenditure.

greater than the World Bank estimate of $4,088 by nearly 45%. Furthermore, we argue that if real GDP were corrected for substitution bias using a revenue function estimated across countries, analogous to the expenditure function approach to real consumption of Neary (2004), then China's real GDP could be even higher: we conclude that real GDP in China relative to the United States is quite plausibly 50% higher than estimated by the World Bank (2008a). Additional empirical results are in Appendix A and the proofs of propositions are in Appendix B.

2. Real Consumption

In Table 1 and the Appendix Table A1 we show various calculations of real consumption using data for 124 countries from the 2005 International Comparisons Project (ICP).[5] There are 12 categories of consumption goods that we aggregate to compute real consumption. We report results for selected countries in Table 1, with results for all 124 countries shown in Appendix Table A1.

2.1 Fixed and Flexible Weight Indexes

The first calculation in Table 1, column (2) is the GK (Geary, 1958, Khamis, 1970, 1972) system, as used by the Penn World Table (PWT), but applied here to only i =1,…,M final consumption goods, with prices p_{ij} and quantities q_{ij} across countries j = 1,…,C. The reference prices (denoted by *"e"* for expenditure) π_i^e and the purchasing power parities PPP_j^e are defined as the solution to the simultaneous system:

$$\pi_i^e = \sum_{j=1}^{C} (p_{ij} / PPP_j^e) q_{ij} \Bigg/ \sum_{j=1}^{C} q_{ij} \ , \qquad i = 1, ..., M. \qquad (1)$$

[5] The total number of countries in the 2005 ICP is 146, but we omitted 22 countries with missing expenditures or prices for some consumption goods, or for other data reasons. Details are available on request.

$$PPP_j^e = \sum_{i=1}^{M} p_{ij} q_{ij} \Big/ \sum_{i=1}^{M} \pi_i^e q_{ij} \quad , j = 1, ..., C. \qquad (2)$$

subject to a normalization. The PPP in (2) is used to adjust expenditure in national currency to obtain that in reference prices, or real consumption:

$$\sum_{i=1}^{M} \pi_i^e q_{ij} = \sum_{i=1}^{M} p_{ij} q_{ij} \ / \ PPP_j^e , \qquad j = 1,\ldots,C. \qquad (3)$$

Because real consumption for different countries is computed as in (3) using fixed quantities q_{ij}, we refer to it as a "fixed-weight" index. It is reported in column (2) of Table 1, relative to the United States. We see that real consumption in China is only 5.9% of that in the U.S. in 2005. This estimate is more than twice as large as what we get from comparing nominal consumption in U.S. dollars using official exchange rates in column (1), but is *much smaller* than the figure for *total* real GDP per capita (including C, I, G, and X–M) relative to the U.S. of 9.8% from the 2005 ICP (World Bank, 2008a),[6] let alone the estimate of 18.5% for real GDP per capita that Maddison (2007, Table 5) claims is needed to avoid having Chinese living standards below subsistence in past decades. So the conclusion is that per-capita real consumption is low for China, relative to other countries or relative to its GDP. We now investigate whether this finding depends on the index number method which is used to compute real consumption.

In column (3)-(5) we report various "flexible-weight" indexes, so named because they use index formulas that are known to be exact for underlying expenditure functions.[7] The first method,

[6] As explained in the introduction, World Bank (2008a) which uses the 2005 ICP data gives real GDP per capita in China of $4,088 in 2005, as compared to $41,674 in the United States. The ratio of these is 9.8%.

[7] See Balk (2008), Diewert (1976, 1999) and Neary (2004). Neary questions whether the exact results for bilateral comparisons extend to a multilateral context when tastes are non-homothetic.

which is used by the World Bank, is the so-called EKS system,[8] which starts from the Fisher quantity indexes in each country j relative to a base country k:

$$Q_{jk}^{F} \equiv \left(\frac{\sum_{i=1}^{M} p_{ij} q_{ij}}{\sum_{i=1}^{M} p_{ij} q_{ik}} \right)^{0.5} \left(\frac{\sum_{i=1}^{M} p_{ik} q_{ij}}{\sum_{i=1}^{M} p_{ik} q_{ik}} \right)^{0.5}, \qquad j,k = 1,2,\ldots,C.$$

Because this comparison between countries is not transitive in general, the EKS index takes the geometric mean of all possible bilateral comparisons to yield a transitive multilateral index:

$$Q_{jk}^{EKS} = \prod_{\ell=1}^{C} \left(Q_{j\ell}^{F} Q_{\ell k}^{F} \right)^{1/C}, \qquad j,k = 1,2,\ldots,C. \tag{4}$$

The EKS estimates of real consumption are shown in column (3), from which we see that China is 5.7% of the U.S., which is even lower than in the GK system. More generally, the GK estimates of real consumption understate the EKS estimate for rich countries and overstate the EKS estimates for poor countries. Specifically, when measured relative to the United States, the GK estimates are less than the EKS estimates for most countries with higher nominal GDP per capita than South Korea (ranked 31st out of 124 countries), and greater than the EKS estimates for most countries with lower nominal GDP per capita than Macedonia (ranked 61st out of 124), with a mixed pattern in-between. Those two countries are included in Table 1, and we will argue below that the GK reference prices can be thought of as lying in-between the prices of South Korea and the United States.

An alternative flexible-weight system is the CCD (Caves, Christensen, Diewert, 1982a,b) index, which makes use of the Törnqvist index instead of the Fisher index. The index of real consumption in country j relative to consumption in country k measured using the Törnqvist index is given by:

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[8] Or the GEKS system, after Gini, Eltetö and Köves, and Szulc. Rather than providing the historical references to the multilateral comparison methods we employ, we refer the reader to Balk (2008), which provides a modern treatment of them all.

$$Q_{jk}^{T} \equiv \prod_{i=1}^{M}\left(\frac{q_{ij}}{q_{ik}}\right)^{\frac{s_{ij}+s_{ik}}{2}} \quad \text{where} \quad s_{ij} = \frac{p_{ij}q_{ij}}{\sum_{i=1}^{M} p_{ij}q_{ij}}, \quad j,k = 1,2,\ldots,C.$$

It is easy to see that these quantity indexes are not transitive unless the expenditure shares are the same in all the countries. The CCD index is a transitive index generated from the matrix of all binary Törnqvist indexes and is defined as:

$$Q_{jk}^{CCD} = \prod_{\ell=1}^{C}\left(Q_{j\ell}^{T}Q_{\ell k}^{T}\right)^{1/C} \qquad j,k = 1,2,\ldots,C. \qquad (5)$$

The CCD indexes are reported in column (4) of Table 1, and are quite close to the EKS indexes.

Generally, the three indexes of real consumption discussed so far – the GK, EKS and CCD – give quite similar results especially for China. We conclude that the index number method cannot account for the very low level of real consumption in China that is obtained when we use the price collected for the 2005 ICP. But the validity of these prices themselves are open to question. It is clear from Asian Development Bank (2007) that the price surveys in China were restricted to 11 capital cities and the rural areas surrounding these 11 cities. The ADB, following the recommendation of an Expert Group, constructed a national average price using a method of extrapolation also described in ADB (2007). However, the extrapolation method did not make any explicit allowance for spatial price differences across different regions and across rural and urban regions of China. As a result the general consensus is that national average prices have a tendency to overstate the actual prices. Accordingly, in Appendix A we make an adjustment to the Chinese prices by predicting them from a simple model of price levels based on data for the other Asian countries. Of the 12 categories of consumption goods, we adjust five prices downwards (for food and non-alcoholic beverages; clothing and footwear; education; restaurants; and other goods and services), four prices upwards (for gross rent, fuel, power; medical and health services; transport; and recreation), and leave three prices unchanged due to lack of data to adjust them.

Real income comparisons based on the adjusted prices for China are presented at the bottom of Table 1. In the GK calculation, real consumption in China relative to the U.S. rises from 5.9% to 6.4%, which is a rise of 9% in Chinese real consumption. Similar increases are seen for the flexible-weight indexes using the EKS and CCD methods. We will find even larger increases due to the adjustment in Chinese prices as we next consider results based on the expenditure function.

2.2 Expenditure Function Approach

Neary (2004) has recently proposed that real consumption should be measured with an expenditure function. This avoids the substitution bias implied by fixed-weight indexes such as GK, and allows for departures from homotheticity. The measure of real consumption at reference prices π is:

$$e(\pi, u_j) = \sum_{i=1}^{M} \pi_i \, q_{ij}^{*}, \qquad j = 1,\ldots,C, \tag{6}$$

where we use an asterisk to denote optimally chosen quantities, as contrasted with the fixed quantities in (1). The real consumption in country *j* relative to country *k* is then given by,

$$\frac{e(\pi, u_j)}{e(\pi, u_k)}.$$

Neary argues that this formulation will give better estimates than using an index number method because quantities respond to the reference prices.

The expenditure function approach could be implemented in many alternative ways. Her we shall use the expenditure function corresponding to the Almost Ideal Demand System (AIDS) of Deaton and Muellbauer (1980), which is given by:[9]

$$\ln e(p,u) = \alpha_0 + \alpha' \ln p + \tfrac{1}{2}\sum_{i=1}^{M}\sum_{j=1}^{M}\gamma_{ij}\ln p_i \ln p_j + b(p)\ln u\,, \tag{7}$$

where $b(p) = \eta\prod_i p_i^{\beta_i}$. We impose "money metric scaling", which leads to the following restrictions on the parameters: $\alpha_0 = 0$, $\eta = 1$. To ensure that the expenditure function is homogeneous of degree one in prices we require that $\sum_i \alpha_i = 1$ and $\sum_i \beta_i = \sum_i \gamma_{ij} = 0$ for all *j*, and to ensure that expenditure is increasing in utility we require that $b(p) > 0$. We report the estimated parameter values using data on 124 countries and 12 commodity groups in Appendix Table A2.[10]

We assume that the parameters of the expenditure function are common across countries. Then it is immediate by computing $e(\pi, u_j)$ and $e(\pi, u_k)$ from (7) that the ratio of real consumption in country *j* relative to *k* is:

$$\frac{e(\pi,u_j)}{e(\pi,u_k)} = \left(\frac{u_j}{u_k}\right)^{b(\pi)}. \qquad j = 1,\ldots,C. \tag{8}$$

For any reference prices π, we refer to (8) as a measure of real consumption based on the expenditure function, and it depends on the reference price vector π.

To obtain a reference-price vector, Neary (2004) proposes that it should be computed as the solution to:

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[9] Estimates are also available on request for the QUAIDS expenditure function of Banks *et al*. (1997), which extends the AIDS model by adding a quadratic term in income. As in Neary (2004), this made relatively little difference in practice, and also lacks the convenient theoretical properties that we exploit in (8) and subsequently.
[10] These are estimated with the software provided in Neary (2004) for estimating the AIDS expenditure function using the semi-parametric approach of Diewert and Wales (1988).

$$\pi_i^{GAIA} = \sum_{j=1}^{C} (p_{ij} / PPP_j^*) q_{ij} \Bigg/ \sum_{j=1}^{C} q_{ij}^* \,, \qquad i=1,\ldots,\text{M}, \tag{9}$$

$$PPP_j^* = \sum_{i=1}^{M} p_{ij} q_{ij} \Big/ \sum_{i=1}^{M} \pi_i^{GAIA} q_{ij}^* = \frac{e(p_j, u_j)}{e(\pi^{GAIA}, u_j)}, \quad j=1,\ldots,\text{C}. \tag{10}$$

which extends the GK system in (1)-(2) by using optimal quantities q_{ij}^* in the denominators of (9) and (10). Notice that PPP_j^* is the ratio of the expenditure function at two different prices, but constant utility, so it can be viewed as an exact cost-of-living index in the spirit of the Allen index.[11] For this reason, Neary (2004) refers to (9)-(10) as the Geary-Allen International Accounts (GAIA).

We have computed the GAIA reference prices π^{GAIA} for the 124 countries and 12 consumption goods using Neary's software. We follow his procedure of first normalizing the prices of each goods by the arithmetic mean of the country prices, so that $\pi = 1$ is the sample mean of prices. In Table 2 we report this sample mean along with the actual U.S. prices, the Geary-Khamis reference prices π^{GK}, the GAIA reference prices π^{GAIA}, and the actual prices for South Korea. It can be seen that the GK and GAIA reference prices fall in between those of the United States and South Korea for most commodities.

From (8), it is evident that real income at any reference prices π^B can be computed from real income at any other reference prices π^A by:

$$\frac{e(\pi^B, u_j)}{e(\pi^B, u_k)} = \left[\frac{e(\pi^A, u_j)}{e(\pi^A, u_k)} \right]^{b(\pi^B)/b(\pi^A)}, \tag{11}$$

[11] Neary uses the reciprocal of (10), which he calls a "real exchange rate." We instead follow the PWT convention of using the purchasing power parity, defined as expenditure at domestic prices relative to expenditure at reference prices.

so it is very easy to make the transformation between one reference price vector to another, as noted by Feenstra, Hong and Rao (2009). At the bottom of Table 2 we report the values of $b(\pi^{GK})$=0.996 and $b(\pi^{GAIA})$=1.026, which can be compared to $b(1)=1$ at the sample mean. With these values, we can easily make the transformation between the real consumption based on the *GK* reference prices in column (5) of Table 1, and real consumption based on Neary's *GAIA* reference prices reported in column (6). Using either the GK or GAIA reference prices, we see in columns (5) and (6) of Table 1 that real consumption per capita in China is increased by 21% due to the adjustment in prices, which is even more than what we found for the consumption indexes in column (2)–(4).

A final reference-price calculation we shall make is due to a suggestion by Barnett, Diewert and Zellner (2009). To compare the real consumption of two countries *j* and *k*, they recommend that *every country's price vector* p_ℓ, ℓ =1,…,C, be used, and then take the geometric mean of the resulting comparisons. From (9), this procedure results in:

$$\left[\prod_{\ell=1}^{C}\frac{e(p_\ell,u_j)}{e(p_\ell,u_k)}\right]^{1/C}=\left[\prod_{\ell=1}^{C}\left(\frac{u_j}{u_k}\right)^{b(p_\ell)}\right]^{1/C}=\left(\frac{u_j}{u_k}\right)^{\sum_{\ell=1}^{C}b(p_\ell)/C}. \qquad (12)$$

Thus, it is apparent that in the AIDS case this recommendation corresponds to the use of reference prices π^D where $b(\pi^D)=\frac{1}{C}\sum_{\ell=1}^{C}b(p_\ell)$;we refer to these as "Diewert reference prices" for brevity. For our sample of 124 countries we obtain $b(\pi^D)$= 0.988, and it turns out that $b(\pi^D)\approx[b(\pi_{us})b(\pi_{kor})]^{0.5}$, which means that the Diewert reference prices are equivalent to using the geometric mean of the U.S. and South Korean prices. With these values for $b(\pi^D)$ column (7) of Table 1 is readily computed. Like the other expenditure function methods, real consumption in China is revised upwards by about 21% due to the adjustment in its prices. Using these prices, we find that real consumption per capita in China is 6.6% of that in the United States, which is the highest of any consumption estimate shown in Table 1.

We conclude that the downward bias in real consumption from the ICP's use of urban prices for China is quite substantial: roughly 10% for the consumption indexes and 20% when using the expenditure function. The question we address next is how these higher estimates for real consumption influence the total measure of real GDP.

3. Real GDP on the Expenditure Side

PWT defines real GDP by using the fixed-weight index in (3) to convert nominal exports and imports, or nominal GDP, to real GDP measured in dollars across countries:

$$\begin{aligned} RGDP_j^e &\equiv (\text{Nominal } GDP_j)/PPP_j^e \\ &= \sum_{i=1}^{M} \pi_i^e q_{ij} + (X_j - M_j)/PPP_j^e \end{aligned} \qquad (13)$$

where the equality follows from nominal $GDP_j = \sum_{i=1}^{M} p_{ij} q_{ij} + (X_j - M_j)$, where X_j and M_j are the nominal values of export and imports. Note that q_{ij} and PPP_j^e are defined as in (2) and (3), but now computed over all final goods, i.e. for consumption, investment and government expenditures. We use the superscript *e* on real GDP^e to stress that this is an expenditure-based measure, since the price used to compute PPP_j^e are those for final goods only. As discussed by Feenstra, Heston *et al* (2009), this measure of real GDP is intended to reflect the *living standards* or *consumption possibilities* of an economy. In the next section we will discuss an alternative output-based measure, real GDP^o, that reflects the *production possibilities* of an economy.

3.1 Estimates of Real GDP^e in 2005

Feenstra, Inklaar and Timmer (2011) compute (13) for all countries included in the 2005 ICP. The preliminary results of this calculation for China and selected other countries are shown in column (8) of Table 1. For China, *without* making any adjustment to the ICP prices, we find that real GDP^e per-capita is $5,097 in 2005, or 25% larger than the estimate of $4,088 from the World Bank (2008a). The difference between these two estimates can only come from one of two sources: (i) the use of the EKS method by the ICP/World Bank, rather than the GK method used here; (ii) the fact that the ICP/World Bank does not compute the real GDPs over all countries simultaneously, but rather, used certain "link" countries across regions and then computes regional and intra-regional real GDP based on the linking methodology described by Diewert (2010b). Heston (2007) and Deaton and Heston (2010) argue that this linking method probably leads to an understatement of Chinese real GDP, which we confirm. Surprisingly, however, the understatement of real GDP for India is not as large, which we report as $2,423 in Table 1 or about 10% larger than the estimate of $2,222 from the World Bank (2008a).

We also compute real GDP^e using the same adjustment to the Chinese prices for final consumption goods used in the earlier sections. This adjustment to the final consumption goods is combined with *unadjusted* prices for investment and government expenditures, since these were not subject to the same urban bias in their collection, obtaining the results reported at the bottom of Table 1. Using the adjusted prices for final consumption goods, we find that real GDP^e per-capita in China is $5,543, or a further 8.8% higher than the unadjusted estimate of $5,097. Comparing these estimates with the World Bank (2008a) figure of $4,088, we conclude that the World Bank underestimates real GDP^e in China by fully 25 – 35%.

3.2 Comparison with PWT 7.0

Given the very large difference between our estimate of real GDP^e in China and that of the World Bank, it is useful to compare our estimates to those from PWT version 7.0, available online since June 3, 2011, at: http://pwt.econ.upenn.edu/. PWT reports two sets of estimates for China, labeled as “China version 1”, with per-capita real GDP of $4,736 in 2005, and “China version 2” with per-capita real GDP of $5,218. Both of those estimates use the GK system, and the difference between them is for an adjustment to the ICP prices for China: “version 2” lowers all the prices for Chinese consumption goods by 20%, as described in the online documentation “Description of PWT 7.0 (June 3, 2011),” resulting in a 10% increase in real GDP.

We find a slightly lower 8.8% increase when adjusting the prices of consumer goods, from $5,097 to $5,543, but of roughly the same magnitude as PWT. That gives us confidence in the specific adjustments to the consumer prices that we made. Still, our estimates of real GDP – both with and without the adjustment to consumer prices – are higher than reported in PWT version 7. Because all estimates use the GK system, this difference must be due to differing reference prices, which in turn are quite sensitive to the set of countries used in the calculation. Feenstra, Inklaar and Timmer (2011) compute real GDP as in (13) for all countries included in the 2005 ICP, and in addition, all countries that were included in any former ICP benchmarks but were not used in 2005. The latter set of countries have their ICP prices for C, I and G aggregated within the benchmark year and then moved up to 2005 using those respective rates of inflation relative to the United States. So in the end, 167 countries are used to compute real GDP in 2005.

In contrast, PWT encompasses a broader group of 189 countries, some 22 of which have never been included in an ICP benchmark, and with various extrapolation methods used to infer what the ICP-equivalent prices in these countries would be. Because the GK calculation in PWT is made over this broader set of countries, and those being added are lower-income countries, that will move the reference prices in the direction of developing countries' prices. When China's real GDP is computed with reference prices more typical of developing countries, its real GDP will fall.[12] We believe this factor accounts for the differing estimates of real GDP in Feenstra, Inklaar and Timmer (2011) and PWT version 7.0.[13]

4. Real GDP on the Output-Side

We will now establish results for real GDP on the output-side. Suppose that the *M* final goods now include those used for consumption, investment and government purchases, all of which are non-traded. In addition, suppose that there are i =M+1,…,M+N intermediate inputs that can be both imported and exported (imports and exports are different varieties). This convention that all traded goods are by definition intermediate inputs follows the "production approach" to modeling imports and exports of Diewert and Morrison (1986) and Kohli (2004), or the "middle products" approach of Sanyal and Jones (1982).

Specifically, let us denote three groups of commodities:

- those for final domestic demand (quantities $q_{ij} \geq 0$ and prices $p_{ij} > 0$, for $i = 1,\ldots,M$);
- those for exports (quantities $x_{ij} \geq 0$ and prices $p_{ij}^{x} > 0$, for $i = M+1,\ldots,M+N$);
- imported intermediate inputs (quantities $m_{ij} \geq 0$ and prices $p_{ij}^{m} > 0$, $i = M+1,\ldots,M+N$).

[12] Samuelson (1974) summarizes this principle as "it always looks better to ride the other fellow's horse", or in the words of Robert Summers, "the grass is greener on the other side," meaning that real GDP tends to be higher when prices different from a country's own are used. It is an illustration of what is called more formally the Gershenkron (1951) Effect.

[13] Having found that our own estimates are not that different from PWT, the remaining feature is that both sets of estimates differ in a consistent manner from the World Bank (2008a). As noted above, that difference must come from one of two sources: (i) the use of the EKS method by the ICP/World Bank, rather than the GK method used here; (ii) the fact that the ICP/World Bank does not compute the real GDPs over all countries simultaneously, but rather, used certain "link" countries across. PWT version 7.0 assesses the first of these reasons by providing another measure of real GDP, called "cgdp2" and referred to as "average GEKS-CPDW." This calculation uses the EKS method. For "China version 1," per-capita real GDP is $4,813 in 2005, and for "China version 2," per-capita real GDP is $5,366 that year. Both of these estimates exceed that obtained by PWT using the GK system. Evidently, the use of EKS by the World Bank cannot explain its low estimate for China's real GDP, which leaves the use of "link countries" – or other unknown factors – as the culprit.

The world price vectors for exports and imports are p_j^x and p_j^m in country *j*, and domestic prices are $p_j^x + s_j$ and $p_j^m + t_j$. We use s_j and t_j to denote the vectors of export subsidies and import tariffs respectively, though differences between home and world prices may also reflect natural trade costs. The column vector of prices is then $P_j = (p_j, p_j^x + s_j, p_j^m + t_j)$, and we let $y_j \equiv (q_j, x_j, -m_j)$ denote the corresponding column vector of outputs and inputs. Then the revenue function for the economy is defined as:

$$r_j(P_j, v_j) \equiv \max_{q_{ij}, x_{ij}, m_{ij} \geq 0,} \left\{ P_j ' y_j \;\middle|\; F_j(y_j, v_j) = 1 \right\}, \tag{14}$$

where $F_j(y_j, v_j)$ is a transformation function for each country, which depends on the vector v_j representing primary factor endowments in country *j,* and also depends in the subscript *j* representing differences in technologies across countries.

4.1 Real Output with Reference Prices

We will distinguish the reference prices π_i for final goods, *i* =1,…,M, and two sets of reference prices π_i^x, π_i^m for exports and imported intermediate inputs, *i* =M+1,…,M+N. Denote the M+2N dimensional vector of reference prices by $\Pi = (\pi, \pi^x, \pi^m)$. We suppose that the country is engaged in *free trade* at these reference prices, and evaluate GDP on the output-side using the revenue function:

$$RGDO_j^*(\Pi) \equiv r_j(\Pi, v_j) \equiv \max_{q_{ij}, x_{ij}, m_{ij} \geq 0,} \left\{ \Pi ' y_j \;\middle|\; F_j(y_j, v_j) = 1 \right\}. \tag{15}$$

Provided that $F_j(y_j, v_j)$ is sufficiently concave we can expect (15) to have a well-defined solution, which we denote by $q_{ij}^*, x_{ij}^*, m_{ij}^*$. Let us make this assumption on the revenue function:

<u>Assumption 1</u>: For all $\Pi > 0$, $r_j(\Pi, v_j)$ is positive, bounded above and continuously differentiable.

In economic terms, the assumption that the revenue function is positive implies that, even if the price of an imported intermediate input is very high, the country can economize on its imports to still produce positive revenue; while the assumption that it has an upper bound means that the economy cannot make arbitrarily high revenue by importing some inputs and exporting other goods.

To obtain real GDP on the output-side, we shall use the reference prices Π to obtain final demands, net outputs, exports and imports as $q_{ij}^* \equiv \partial r_j(\Pi, v_j) / \partial \pi_i$, i =1,…,M, and, $x_{ij}^* \equiv \partial r_j(\Pi, v_j) / \partial \pi_i^x$, $-m_{ij}^* \equiv \partial r_j(\Pi^*, v_j) / \partial \pi_i^m$, i =M+1,…,M+N. We assume that the sum across countries of each of these quantities is strictly positive:

<u>Assumption 2:</u>

For all $\Pi > 0$, $\sum_{j=1}^{J} q_{ij}^* > 0$, i = 1,…,M, and $\sum_{j=1}^{J} m_{ij}^* > 0$, $\sum_{j=1}^{J} x_{ij}^* > 0$, for i = M+1,…,N.

Notice that this assumption applies to the observed prices $P_j > 0$ and quantities, too.

Consider computing the reference prices as a weighted average of free-trade prices:

$$\pi_i = \sum_{j=1}^{J} (p_{ij} / PPP_j^*) q_{ij} \Big/ \sum_{j=1}^{J} q_{ij}^* , \qquad i = 1,\ldots,M, \tag{16}$$

$$\pi_i^x = \sum_{j=1}^{J} (p_{ij}^x / PPP_j^*) x_{ij} \Big/ \sum_{j=1}^{J} x_{ij}^* , \qquad i = M+1,\ldots,M+N, \tag{17}$$

$$\pi_i^m = \sum_{j=1}^{J} (p_{ij}^m / PPP_j^*) m_{ij} \Big/ \sum_{j=1}^{J} m_{ij}^* , \qquad i = M+1,\ldots,M+N, \tag{18}$$

and, $$PPP_j^* = \frac{r_j(P_j, v_j)}{r_j(\Pi, v_j)}, \quad j = 1, \ldots, C. \tag{19}$$

Thus, in (16)–(19) we use the *optimal* quantities in the denominators, but the *observed* quantities in the numerators. In (19), the purchasing power parity on the output-side, PPP_j^*, is computed by comparing nominal GDP to real GDP at free-trade reference prices. The system defined in (16)–(19) is an extension of the GAIA system in Neary (2004) by introducing exports and imports explicitly into the system. In order to be able to use this system, we need to demonstrate the existence of a positive solution for π_i, π_i^x, π_i^m and PPP_j^*. We follow Neary (2004) in proving the following result.

<u>Proposition 1</u>

Under Assumptions 1 and 2, there exists a positive solution for π_i, π_i^x, π_i^m and PPP_j^* satisfying the system (16) – (19).

Proof: See Appendix B.

Using the reference prices coming from Proposition 1, or any other, we can make comparisons across countries of real GDP on the output-side – or *real output* for short – using the ratio of revenue functions:

$$\frac{r_j(\Pi, v_j)}{r_k(\Pi, v_k)}. \tag{20}$$

We first show how this can be implemented using a fixed-weight index, and then discuss in Section 4.3 the implications of estimating the revenue function directly.

4.2 Fixed-Weight Index on the Output-side

The measure of real GDP on the output-side, or real GDP^o, is defined by Feenstra, Heston *et al* (2009) using reference prices for final outputs π_i^o, exports π_i^x and imports π_i^m, as:

$$RGDP_j^o \equiv \sum_{i=1}^{M} \pi_i^o q_{ij} + \sum_{i=M+1}^{M+N} (\pi_i^x x_{ij} - \pi_i^m m_{ij})$$
$$= \sum_{i=1}^{M} \pi_i^o q_{ij} + (X_j / PPP_j^x) - (M_j / PPP_j^m), \qquad (21)$$

where the equality follows by defining the PPPs of exports and imports, over the traded goods $i = M+1,\ldots,M+N$:

$$PPP_j^x = \sum_{i=M+1}^{M+N} p_{ij}^x x_{ij} \Big/ \sum_{i=M+1}^{M+N} \pi_i^x x_{ij} \text{ and } PPP_j^m = \sum_{i=M+1}^{M+N} p_{ij}^m m_{ij} \Big/ \sum_{i=M+1}^{M+N} \pi_i^m m_{ij}. \qquad (22)$$

The measurement of real GDP^o requires disaggregate prices for traded goods, p_{ij}^x and p_{ij}^m, which are used to obtain the reference prices as a weighted average of observed prices:

$$\pi_i^o = \sum_{j=1}^{C} (p_{ij} / PPP_j^o) q_{ij} \Big/ \sum_{j=1}^{C} q_{ij}, \qquad i = 1,\ldots,M, \qquad (23)$$

$$\pi_i^x = \sum_{j=1}^{C} (p_{ij}^x / PPP_j^o) x_{ij} \Big/ \sum_{j=1}^{C} x_{ij}, \qquad i = M+1,\ldots,M+N, \qquad (24)$$

$$\pi_i^m = \sum_{j=1}^{C} (p_{ij}^m / PPP_j^o) m_{ij} \Big/ \sum_{j=1}^{C} m_{ij}, \qquad i = M+1,\ldots,M+N, \qquad (25)$$

and,

$$PPP_j^o = \frac{\text{Nominal GDP}_j}{\sum_{i=1}^{M} \pi_i^o q_{ij} + \sum_{i=M+1}^{M+N} (\pi_i^x x_{ij} - \pi_i^m m_{ij})}, \; j = 1,\ldots,C. \qquad (26)$$

As in the GK system (1)–(2), one normalization is needed in the system (21)–(26). This system *extends* the GK system by adding information on export and import prices and quantities.

We follow Feenstra, Heston *et al* (2009) in rewriting $RGDP_j^o$ to give a clear interpretation of the difference between it and $RGDP_j^e$. Notice that $RGDP_j^o$ in (21) can be decomposed as:

$$RGDP_j^o = \left(\frac{\sum_{i=1}^{M}\pi_i^o q_{ij}}{\sum_{i=1}^{M} p_{ij}q_{ij}}\right)\sum_{i=1}^{M} p_{ij}q_{ij} + \left(\frac{\sum_{i=M+1}^{M+N}\pi_i^x x_{ij}}{\sum_{i=M+1}^{M+N} p_{ij}^x x_{ij}}\right)X_j - \left(\frac{\sum_{i=M+1}^{M+N}\pi_i^m m_{ij}}{\sum_{i=M+1}^{M+N} p_{ij}^m m_{ij}}\right)M_j . \quad (27)$$

We can define the three ratios appearing in (27) as the inverse of the PPP's for final expenditure, exports and imports, the latter two already given in (22):

$$PPP_j^q \equiv \left(\frac{\sum_{i=1}^{M} p_{ij}q_{ij}}{\sum_{i=1}^{M}\pi_i^o q_{ij}}\right).$$

It will be convenient to work instead with the associated *price levels* for final goods, exports and imports, obtained by dividing the PPP's by the nominal exchange rate E_j:

$$PL_j^e \equiv \frac{PPP_j^e}{E_j}, \quad PL_j^q \equiv \frac{PPP_j^q}{E_j}, \quad PL_j^x \equiv \frac{PPP_j^x}{E_j}, \quad PL_j^m \equiv \frac{PPP_j^m}{E_j}.$$

Comparing (13) and (27), it is immediate that the difference between $RGDP_j^e$ and $RGDP_j^o$ is:

$$\frac{RGDP_j^e - RGDP_j^o}{RGDP_j^e}$$

$$= \left(1 - \frac{PL_j^e}{PL_j^q}\right)\left(\frac{\sum_{i=1}^{M} p_{ij}q_{ij}}{GDP_j}\right) + \left(1 - \frac{PL_j^e}{PL_j^x}\right)\left(\frac{X_j}{GDP_j}\right) - \left(1 - \frac{PL_j^e}{PL_j^m}\right)\left(\frac{M_j}{GDP_j}\right). \quad (28)$$

We will find in practice that PL_j^e and PL_j^q are quite similar, since they are both computed from final expenditures, but with different reference prices. If these two deflators for final expenditure are equal, then either $PL_j^x > PL_j^e$ or $PL_j^m < PL_j^e$ is needed to have real GDP_j^e exceed real GDP_j^o, and both inequalities holding is sufficient for this. To interpret these conditions, having export prices above their reference level and import prices below their reference level will contribute towards $RGDP_j^e$ exceeding $RGDP_j^o$. For example, proximity to markets that allow for higher export prices would work in this direction, but being distant from markets leading to high import prices would work in the opposite direction, raising PL_j^m and tending to make $RGDP_j^e$ less than $RGDP_j^o$.

Empirical implementation of the fixed weight index from the output-side described in equations (23)-(26) is currently being undertaken as a part of the next generation PWT methodology described in Feenstra, Inklaar and Timmer (2011), using the 2005 ICP benchmark. Earlier results for 1996 are reported in Feenstra, Heston *et al* (2009), who use the normalization that $RGDP_j^e$ equals $RGDP_j^o$ when summed across the 1996 sample of countries. China was not included in the 1996 ICP benchmark, but we can give preliminary results for 2005 from Feenstra, Inklaar and Timmer (2011), using the same normalization that $RGDP_j^e$ equals $RGDP_j^o$ when summed across the 2005 sample of countries.[14] The complete results are shown in the final column of Table A1, and results for selected countries are in Table 1.

We see from Table 1 that per-capita $RGDP_j^o$ for China exceeds $RGDP_j^e$, so China is even bigger when viewed from its ability to produce goods. To see where this calculation comes from, we compute (28) as:

$$\frac{RGDP_j^e - RGDP_j^o}{RGDP_j^e} = \left[\;0\;\right]0.95 + \left[1 - \left(\frac{0.32}{0.45}\right)\right].36 - \left[1 - \left(\frac{0.32}{0.68}\right)\right]0.31 \approx -0.06.$$

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[14] As noted in section 3.2, Feenstra, Inklaar and Timmer (2011) compute real GDP^e and real GDP^o for countries in the 2005 ICP and any earlier benchmark, by carrying forward prices for C, I and G for the latter group of countries using their respective rates of inflation relative to the U.S. Thus, while the 2005 ICP includes 146 countries, their calculations are over a broader set of 167 countries. For brevity in Appendix Table A1, we report results only for the 124 countries that had complete data on consumption prices, and therefore already appear in the table.

The first term appearing on the right of (28) is zero, because the price levels PL_j^e and PL_j^q, both computed over final goods only, are equal at 0.32. The price level for Chinese exports is 0.45, or slightly less than one-half of the reservation prices for exports, while the price level for imports is 0.68. That means the *terms of trade* for China is 0.45/0.68 < 1, so $RGDP_j^e$ is less than $RGDP_j^o$. This holds even though nominal exports are larger than nominal imports, which would tend to make $RGDP_j^e$ exceed $RGDP_j^o$ (i.e. as would occur if the price levels for exports and equal were equal but above that for final goods). So we see that real GDP on the output side for China is higher than that on the expenditure side, by about 6%. This means that $RGDP_j^o$ exceeds the World Bank estimate of real GDP by more than 40%.[15]

Finally, recall that this estimate of real GDP is based on the normalization that world GDP is the same whether calculated on the output or expenditure basis. Mirroring the fact that China and other developing countries have higher real GDP from an output perspective, Table 1 also shows that real GDP on the output-side for the United States falls relative to real GDP on the expenditure-side, from $41,553 to $39,550 per-capita. Thus, taking the ratio of real GDP on the output-side for China relative to the U.S., we obtain $5,862/$39,550 or 15%, using the adjusted Chinese prices. That is fully 50% higher than the ratio of real GDP from the World Bank in 2005, which is $4,088/$41,674 or 9.8%. On this basis, we conclude that real GDP in China relative to the United States is quite plausibly 50% higher than estimated by the World Bank (2008a).

[15] This estimate is not significantly affected by the nominal undervaluation of the Chinese currency. If the renminbi were to appreciate, this would raise the absolute values of the price levels of both exports and imports, 0.45 and 0.68. This would be neutral if trade were balanced, and would raise real GNP on the expenditure side relative to that on the output side slightly (as measured by these fixed-weight indexes) reflecting a relatively small wealth transfer to Chinese consumers (both public and private).

The finding that $RGDP_j^o$ exceeds $RGDP_j^e$ holds for the other developing countries and newly-industrialized countries in Table 1, with the reverse comparison holding for the developed countries. This illustrates the tendency for the developed countries to have strong terms of trade which tend to make (28) positive. There are many exceptions to this tendency, however. Norway, for example, has the highest value of $RGDP_j^o$, at \$58,842 per-capita in Table A1, which is more than 25% above its per-capita $RGDP_j^e$, at \$46,242. This result comes from a low term of trade for Norway, which can be traced to unusually high import prices. Conversely, Chad has $RGDP_j^o$ at \$4,030 per-capita in Table A1, which is 25% below its per-capita $RGDP_j^e$, at \$5,373. That result, in turn, can be traced to a strong terms of trade. So the terms of trade faced by countries are positively but only weakly correlated with the real GDP.

4.3 Revenue Function Approach

The fixed-weight estimates in the previous sub-section do not take account of substitution bias on the production side. However, we do not view it as feasible to estimate the revenue function in (14) across a comprehensive set of countries in the same way that Neary (2004) estimates the expenditure function. The reason for this is that (14) depends on a full set of factor endowments v_j that differ across countries, and also depends on the subscript j representing differences in technologies across countries. Both of these features represent formidable hurdles to estimation. But there is one theoretical result we can provide which suggests that real GDP in China would be *even bigger* if measured using the revenue function approach.

To obtain this result, let $\Pi = (\pi, \pi^x, \pi^m)$ denote the reference prices used to compute $RGDP_j^o(\Pi)$ in (21). Then because the quantities in (21) are feasible to produce but not optimal at the prices Π, it follows that:

$$RGDP_j^o(\Pi) \le r_j(\Pi, v_j). \tag{29}$$

Using this inequality we can obtain a result on the comparison of real GDP on the output-side across countries. Consider reference prices that equal the observed prices of a high-income country *j*, $\Pi = P_j = (p_j, p_j^x, p_j^m)$. Then it is immediate that $RGDP_j^o = r_j(P_j, v_j)$, while $RGDP_k^o(P_j) \le r_k(P_j, v_k)$ for all other countries *k*. It follows that,

$$\frac{RGDP_k^o(P_j)}{RGDP_j^o(P_j)} \le \frac{r_k(P_j, v_k)}{r_j(P_j, v_j)}. \tag{30}$$

That is, with reference prices close to those of a high-income country *j*, the ratio of output-side real GDP for any lower-income country *k* relative to country *j* will be *even greater* using the revenue function than in the fixed-weight GK approach. In particular, this suggests that real GDP in China relative to the U.S. could be even higher using the revenue function, if this approach were feasible to implement.

5. Conclusions

In this paper we have analyzed the revision to real GDP for China made by the World Bank using prices from the 2005 round of the International Comparison Program. Because those prices were higher than expected for China, the corresponding estimate of real GDP in China was lowered: from \$6,757 per-capita in World Bank (2007) to \$4,088 in World Bank (2008a). Possible reasons for this downward revision have been discussed by Deaton and Heston (2010), and here we provide a quantitative evaluation of the possibilities.

Our first objective was to examine the sensitivity of real consumption comparisons to the choice of the index number methods used. We included the fixed-weight GK index, three variations of flexible weight indexes, the EKS and CCD indexes along with the index suggested by Barnett, Diewert and Zellner (2009), and finally, the expenditure function approach of Neary (2004). In all cases we compare estimates for real consumption in China after making adjustments to prices reported in the 2005 ICP comparisons in the Asia-Pacific region. Making use of a regression model to explain commodity-specific price levels as a function of real per capita income in other Asian countries, and applying the resulting adjustments to price data for China, we measure the revisions to be anywhere between 9% to 21% depending upon the index number method used. Our results confirm that an upward revision of real consumption in China somewhere between 10 to 20 percent is quite realistic.

We then moved to calculation of total real GDP, including investment, government and the trade balance. We find that the GK estimate of real GDP on the expenditure-side for China is \$5,097 in 2005, which is 25% larger than the estimate from the World Bank of \$4,088. If we adjust the prices of consumption goods, then real GDP^e per-capita rises to \$5,543, or another 10%. Furthermore, from Feenstra, Inklaar and Timmer (2011), preliminary estimates of real GDP measured on the output-side for China are obtained, which are \$5,433 per-capita without the adjustment to consumption prices and \$5,862 with this adjustment. The latter estimate is nearly 45% higher than the World Bank figure of \$4,088. Furthermore, the same calculation, switching from expenditure to output, lowers U.S. real per-capita GDP from \$41,553 to \$39,550. Relative to this, China's real GDP per capita is \$5,862/\$39,550 or 15%, using the adjusted Chinese prices, fully 50% higher than the ratio of real GDP from the World Bank in 2005. Thus our final estimate of real per-capita GDP in China relative to the United States in 2005 is that is 50% higher than estimated by the World Bank (2008a).

Appendix A: Data and Estimates

In Table A1 we report the calculations of real consumption for all 124 countries. In Table A2 we report the estimates of the AIDS expenditure function, listing first the R^2 values for the share equations for each product and then the parameters α, β and Γ.[16]

In Table A3 we report the correction made to Chinese prices for 2005. As noted in the text, we used a regression approach to determine predicted prices for China. A simple regression model is used with the price level (ratio of PPP to exchange rate) for each commodity group is expressed as a function of the real income per capita index. The real income per capita index is computed using the real per capital income estimates from the ICP Asia-Pacific 2005 which are based on the EKS index number formula. The real incomes are expressed as index relative to the Asian Region =100. All the relevant data are drawn from the Final Report of the ICP Asia-Pacific (ADB, 2007) and the sample is restricted to all Asian countries except China. The total number of countries in the Asia-Pacific comparison was 23 including China..[17]

A log-linear model with a dummy variable for Fiji is our chosen model, and a separate regression is run for each of the commodities except alcoholic beverages.[18] The predicted prices from these regressions are shown in Table A2. Using these predicted or "adjusted" prices for China we also re-estimated the AIDS expenditure function, but it is essentially unchanged from Table A1 because data for only one country out of 124 has been adjusted. Using the AIDS estimates we can compute the estimated shares for China, using actual or predicted prices. These are shown in Table A2 together with the actual shares. It can be seen that the adjustment to the

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[16] These estimates are taken from Feenstra, Ma and Prasada Rao (2009).

[17] As fixity of the regional comparisons was maintained in the global comparisons and that there could be regional differences in the regression relationships, it was decided that only data on countries from the Asian region would be utilized in the regressions.

[18] A linear model with a dummy variable for Fiji also performed well, and gave results quite similar to those obtained with the log-linear model. The rationale for excluding Fiji is that, as an island economy where most consumer and investment goods are imported, its national price level is a lot higher than comparable economies, so it is an outlier in terms of the theory explaining national price levels.

shares is not that large, but nevertheless, the estimated shares using predicted prices are closer to the actual shares for food and non-alcoholic beverages, recreation, and restaurants.

Table A1: Comparisons of Real Consumption and real GDP, 2005
(USA = 1 except in final two columns)

Countries	Nominal consump. per capita	Consumption indexes			Using AIDS expenditure fcn. and reference prices from:			$RGDP^e$ per capita ($)	$RGDP^o$ per capita ($)
		Geary-Khamis	EKS	CCD	Geary-Khamis	Neary, GAIA	Diewert		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Albania	0.068	0.137	0.14	0.143	0.14	0.132	0.142	5,340	5,459
Angola	0.016	0.022	0.022	0.022	0.019	0.017	0.02	3,093	2,979
Argentina	0.099	0.232	0.237	0.243	0.239	0.229	0.242	10,654	10,640
Armenia	0.038	0.121	0.119	0.121	0.12	0.113	0.122	6,004	6,528
Australia	0.722	0.678	0.701	0.702	0.703	0.695	0.704	35,139	35,365
Austria	0.814	0.758	0.779	0.792	0.768	0.761	0.769	32,147	29,769
Azerbaijan	0.025	0.095	0.094	0.095	0.094	0.088	0.096	5,805	6,402
Bahrain	0.277	0.414	0.387	0.393	0.385	0.374	0.388	33,916	36,556
Belarus	0.061	0.233	0.22	0.222	0.218	0.208	0.22	11,095	12,164
Belgium	0.735	0.653	0.671	0.679	0.671	0.663	0.673	31,596	24,360
Benin	0.015	0.033	0.033	0.034	0.03	0.027	0.031	1,402	1,435
Bolivia	0.024	0.09	0.089	0.089	0.087	0.081	0.089	4,387	4,178
Bosnia & Herzeg.	0.099	0.208	0.21	0.215	0.212	0.202	0.214	6,317	7,143
Botswana	0.057	0.1	0.098	0.096	0.095	0.089	0.097	13,864	12,387
Brazil	0.101	0.174	0.177	0.18	0.185	0.175	0.187	8,235	8,421
Bulgaria	0.091	0.239	0.24	0.244	0.242	0.232	0.244	10,223	10,950
Burkina Faso	0.01	0.025	0.025	0.026	0.025	0.022	0.026	1,126	1,197
Cambodia	0.012	0.043	0.039	0.039	0.036	0.033	0.037	1,812	1,880
Cameroon	0.022	0.043	0.045	0.045	0.044	0.04	0.045	2,006	2,014
Canada	**0.731**	**0.722**	**0.735**	**0.733**	**0.739**	**0.733**	**0.741**	**33,975**	**32,159**
Cape Verde	0.06	0.08	0.082	0.082	0.083	0.077	0.084	3,047	2,899
Central African R.	0.01	0.019	0.02	0.021	0.018	0.016	0.019	752	752
Chad	0.013	0.03	0.029	0.027	0.026	0.024	0.027	5,373	4,030
Chile	0.144	0.225	0.231	0.234	0.237	0.227	0.24	11,276	11,314
China	**0.023**	**0.059**	**0.057**	**0.057**	**0.053**	**0.049**	**0.054**	**5,097**	**5,433**
Colombia	0.063	0.136	0.137	0.139	0.137	0.129	0.139	7,277	7,303
Congo, Dem. Rep.	0.003	0.004	0.004	0.005	0.004	0.003	0.004	298	n.a.
Congo, Rep.	0.018	0.034	0.032	0.032	0.028	0.025	0.029	3,769	3,096
Côte d'Ivoire	0.019	0.033	0.034	0.035	0.033	0.03	0.034	1,516	1,552
Croatia	0.226	0.341	0.347	0.353	0.349	0.338	0.352	14,432	14,612
Cyprus	0.597	0.647	0.67	0.691	0.667	0.659	0.669	21,957	21,271
Czech Republic	0.238	0.425	0.429	0.436	0.432	0.421	0.434	20,285	21,837
Denmark	0.982	0.663	0.685	0.69	0.686	0.678	0.688	32,530	31,954
Ecuador	0.061	0.135	0.14	0.142	0.14	0.132	0.142	6,481	6,630
Egypt, Arab Rep	0.035	0.12	0.119	0.121	0.12	0.113	0.122	5,173	5,679
Equatorial Guinea	0.062	0.09	0.089	0.09	0.086	0.08	0.088	24,389	21,498
Estonia	0.22	0.366	0.378	0.384	0.38	0.369	0.383	16,243	18,159

Fiji	0.092	0.115	0.115	0.115	0.121	0.114	0.123	4,732	4,688
Finland	0.773	0.601	0.623	0.63	0.62	0.611	0.623	29,191	29,095
France	0.775	0.693	0.716	0.726	0.704	0.696	0.706	28,342	26,451
Gabon	0.067	0.103	0.098	0.098	0.092	0.085	0.093	16,265	14,333
Georgia	0.033	0.107	0.103	0.103	0.102	0.095	0.104	4,716	5,236
Germany	0.727	0.662	0.67	0.684	0.669	0.66	0.671	30,168	30,419
Greece	0.541	0.61	0.637	0.667	0.629	0.62	0.631	23,355	22,184
Guinea	0.007	0.021	0.02	0.02	0.016	0.014	0.017	1,191	1,197
Guinea-Bissau	0.006	0.012	0.013	0.012	0.012	0.011	0.013	1,136	1,180
Hong Kong, China	0.504	0.643	0.634	0.635	0.634	0.625	0.636	35,220	48,773
Hungary	0.237	0.391	0.399	0.404	0.403	0.392	0.406	16,556	16,936
Iceland	**1.248**	**0.767**	**0.794**	**0.795**	**0.79**	**0.784**	**0.791**	**38,592**	**37,640**
India	**0.014**	**0.048**	**0.046**	**0.047**	**0.046**	**0.042**	**0.047**	**2,423**	**2,479**
Indonesia	0.028	0.072	0.073	0.074	0.074	0.068	0.075	3,647	3,676
Iraq	0.021	0.067	0.06	0.059	0.059	0.054	0.06	3,809	3,648
Ireland	0.843	0.638	0.662	0.648	0.663	0.655	0.665	34,931	39,707
Israel	0.422	0.501	0.516	0.52	0.516	0.506	0.519	23,554	21,462
Italy	0.679	0.622	0.636	0.648	0.631	0.623	0.634	26,941	26,439
Japan	0.743	0.626	0.618	0.625	0.658	0.65	0.66	30,596	30,922
Jordan	0.07	0.128	0.122	0.125	0.125	0.117	0.127	4,754	5,486
Kazakhstan	0.066	0.21	0.195	0.195	0.195	0.186	0.197	11,221	11,680
Kenya	0.015	0.038	0.038	0.039	0.037	0.034	0.038	1,413	1,489
Kyrgyz Republic	0.014	0.068	0.063	0.064	0.06	0.055	0.061	3,134	3,676
Lao PDR	0.01	0.037	0.035	0.035	0.032	0.029	0.033	1,927	2,148
Latvia	0.153	0.302	0.305	0.31	0.307	0.297	0.31	13,065	14,521
Lebanon	0.169	0.284	0.277	0.283	0.285	0.274	0.287	10,712	11,016
Lesotho	0.026	0.058	0.055	0.054	0.053	0.048	0.054	1,508	1,523
Liberia	0.004	0.01	0.008	0.008	0.007	0.006	0.007	404	400
Lithuania	0.179	0.357	0.368	0.373	0.372	0.362	0.375	14,542	14,810
Luxembourg	1.071	0.925	0.919	0.924	0.912	0.909	0.913	73,405	67,921
Macao, China	0.236	0.34	0.348	0.36	0.345	0.334	0.348	35,754	37,889
Macedonia, FYR	**0.076**	**0.192**	**0.192**	**0.195**	**0.193**	**0.184**	**0.196**	**7,374**	**8,240**
Madagascar	0.008	0.025	0.024	0.023	0.021	0.019	0.022	963	994
Malawi	0.006	0.017	0.016	0.016	0.014	0.012	0.014	662	767
Malaysia	0.084	0.177	0.176	0.18	0.177	0.168	0.18	12,169	12,361
Mali	0.011	0.022	0.023	0.023	0.021	0.019	0.022	1,287	1,273
Malta	0.397	0.548	0.573	0.593	0.575	0.565	0.577	19,524	16,821
Mauritius	0.123	0.244	0.247	0.249	0.247	0.237	0.25	10,984	12,185
Mexico	0.175	0.289	0.292	0.298	0.29	0.279	0.292	12,824	12,551
Moldova	0.026	0.107	0.097	0.097	0.093	0.087	0.095	3,313	4,314
Mongolia	0.018	0.059	0.052	0.051	0.05	0.045	0.051	3,268	3,431
Montenegro	0.087	0.174	0.174	0.175	0.173	0.164	0.175	8,319	n.a.
Morocco	0.044	0.072	0.073	0.075	0.074	0.069	0.076	3,481	3,492
Namibia	0.064	0.095	0.094	0.095	0.094	0.087	0.095	5,539	5,591
Nepal	0.009	0.031	0.029	0.029	0.029	0.026	0.03	1,072	1,116
Netherlands	**0.756**	**0.696**	**0.72**	**0.736**	**0.697**	**0.689**	**0.699**	**33,626**	**31,065**
New Zealand	0.606	0.574	0.59	0.599	0.594	0.585	0.597	24,488	24,594
Niger	0.006	0.013	0.014	0.014	0.013	0.011	0.013	594	626
Nigeria	0.019	0.039	0.04	0.039	0.034	0.03	0.034	2,019	1,920
Norway	1.100	0.737	0.758	0.768	0.755	0.749	0.757	46,242	58,842

Oman	0.153	0.249	0.237	0.24	0.237	0.227	0.239	22,122	23,827
Paraguay	0.031	0.101	0.105	0.107	0.11	0.103	0.112	4,083	4,546
Peru	0.063	0.136	0.141	0.145	0.143	0.135	0.145	6,369	6,268
Philippines	0.026	0.069	0.07	0.071	0.07	0.064	0.071	3,027	3,083
Poland	0.183	0.332	0.329	0.335	0.33	0.319	0.333	14,393	14,800
Portugal	0.441	0.489	0.501	0.515	0.501	0.491	0.504	19,499	18,635
Romania	0.113	0.227	0.231	0.233	0.233	0.223	0.236	9,219	10,130
Russian Fed,	0.093	0.243	0.248	0.253	0.255	0.245	0.258	13,439	13,408
Rwanda	0.007	0.019	0.018	0.019	0.019	0.017	0.019	1,094	1,169
São Tomé, Prin.	0.023	0.042	0.044	0.044	0.042	0.038	0.043	2,628	3,157
Senegal	0.021	0.039	0.041	0.042	0.038	0.034	0.039	1,558	1,571
Serbia	0.09	0.217	0.212	0.214	0.21	0.201	0.213	8,352	9,396
Sierra Leone	0.009	0.025	0.023	0.023	0.018	0.016	0.019	917	1,011
Singapore	0.377	0.506	0.498	0.503	0.506	0.495	0.508	43,182	35,300
Slovak Republic	0.179	0.354	0.354	0.36	0.355	0.344	0.358	16,628	17,897
Slovenia	0.378	0.484	0.499	0.505	0.503	0.493	0.506	22,161	23,479
South Africa	0.118	0.18	0.185	0.188	0.19	0.181	0.193	8,363	8,426
South Korea	**0.297**	**0.375**	**0.375**	**0.378**	**0.381**	**0.37**	**0.383**	**24,044**	**26,774**
Spain	0.582	0.624	0.648	0.677	0.632	0.623	0.634	25,732	24,774
Sri Lanka	0.029	0.082	0.087	0.088	0.088	0.081	0.089	4,079	4,342
Sudan	0.025	0.05	0.054	0.051	0.052	0.047	0.053	2,007	2,090
Swaziland	0.05	0.096	0.093	0.092	0.09	0.083	0.091	4,947	5,015
Sweden	0.838	0.67	0.693	0.696	0.693	0.686	0.695	32,695	32,636
Switzerland	1.043	0.726	0.739	0.749	0.749	0.743	0.751	36,786	30,869
Syrian Arab Rep	0.036	0.095	0.094	0.089	0.097	0.09	0.099	4,519	4,966
Taiwan, China	0.324	0.566	0.549	0.554	0.572	0.563	0.575	n.a.	n.a.
Tajikistan	0.009	0.06	0.047	0.045	0.039	0.036	0.04	3,718	4,115
Thailand	0.054	0.146	0.147	0.151	0.145	0.137	0.147	6,747	6,801
Togo	0.013	0.027	0.027	0.028	0.026	0.023	0.027	829	902
Tunisia	0.068	0.14	0.14	0.144	0.139	0.131	0.141	7,143	7,294
Turkey	0.116	0.183	0.183	0.185	0.183	0.174	0.186	11,095	11,551
Ukraine	0.04	0.167	0.155	0.158	0.157	0.148	0.159	7,458	8,084
United Kingdom	**0.895**	**0.772**	**0.793**	**0.807**	**0.778**	**0.772**	**0.779**	**32,401**	**30,637**
United States	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**41,553**	**39,550**
Uruguay	0.122	0.214	0.22	0.223	0.224	0.215	0.227	9,228	9,549
Venezuela, RB	0.089	0.163	0.167	0.17	0.167	0.158	0.169	9,491	10,590
Vietnam	0.013	0.05	0.043	0.042	0.039	0.035	0.04	2,728	2,898

Source: Authors' calculations as explained in the text, and Feenstra, Inklaar and Timmer (2011).

Notes: Table 1 reports results for selected countries, shown here in bold.

n.a. not available due to missing data

Table A2: Parameter Estimates for AIDS

Category	R^2	alpha	beta	gamma											
Food and non-alcoholic beverages	0.736	0.183	-0.193	0.050	-0.035	-0.012	-0.047	0.001	-0.021	-0.023	0.013	0.034	-0.062	0.079	0.024
Alcoholic beverages and tobacco	0.172	0.033	0.004	-0.035	-0.017	0.011	-0.030	0.003	-0.016	0.037	-0.008	0.025	0.009	0.012	0.010
Clothing and footwear	0.075	0.050	-0.005	-0.012	0.011	0.009	-0.007	-0.010	-0.011	0.011	0.025	-0.029	0.016	0.020	-0.022
Gross Rent, water, fuel and power	0.407	0.158	0.017	-0.047	-0.030	-0.007	0.108	0.005	-0.002	0.011	-0.003	-0.016	-0.005	0.004	-0.017
Household furnishings	0.123	0.053	0.007	0.001	0.003	-0.010	0.005	-0.027	-0.008	-0.003	0.004	0.043	0.009	0.017	-0.033
Medical and health services	0.407	0.093	0.029	-0.021	-0.016	-0.011	-0.002	-0.008	0.021	0.029	0.001	-0.007	0.008	-0.002	0.010
Transport	0.218	0.104	0.035	-0.023	0.037	0.011	0.011	-0.003	0.029	-0.041	0.001	0.051	-0.066	-0.047	0.041
Communication	0.167	0.027	0.008	0.013	-0.008	0.025	-0.003	0.004	0.001	0.001	-0.009	0.006	-0.001	-0.006	-0.023
Recreation	0.641	0.070	0.044	0.034	0.025	-0.029	-0.016	0.043	-0.007	0.051	0.006	-0.061	0.027	-0.025	-0.046
Education	0.136	0.078	-0.001	-0.062	0.009	0.016	-0.005	0.009	0.008	-0.066	-0.001	0.027	0.005	0.025	0.035
Restaurants	0.325	0.057	0.017	0.079	0.012	0.020	0.004	0.017	-0.002	-0.047	-0.006	-0.025	0.025	-0.111	0.035
Other goods and services	0.507	0.093	0.038	0.024	0.010	-0.022	-0.017	-0.033	0.010	0.041	-0.023	-0.046	0.035	0.035	-0.014

Table A3: Chinese Prices and Consumption Shares

	Chinese prices		Chinese Consumption Shares		
Category	Actual	Predicted	Actual	Estimated with actual prices	Estimated with predicted prices
Food and non-alcoholic beverages	0.742	0.557	0.241	0.333	0.318
Alcoholic beverages and tobacco	0.976	0.976	0.020	0.030	0.031
Clothing and footwear	0.950	0.573	0.064	0.052	0.052
Gross Rent, water, fuel and power	0.775	0.840	0.146	0.147	0.148
Household furnishings	0.837	0.837	0.039	0.044	0.044
Medical and health services	0.252	0.399	0.062	0.072	0.075
Transport	0.692	0.781	0.041	0.072	0.074
Communication	0.435	0.435	0.042	0.018	0.018
Recreation	0.521	0.606	0.046	0.035	0.039
Education	0.424	0.295	0.097	0.081	0.081
Restaurants	0.850	0.758	0.053	0.046	0.049
Other goods and services	0.821	0.743	0.149	0.068	0.070

Appendix B: Proof of Proposition 1

We first derive a reduced system either in the international prices vector, *Π*, or in the output-based real exchange rates, *RO*. Following Neary (2004), we start with an international price vector Π^0 which is positive. Then using Π^0 in (19), we get a value for RO_j for j=1,2,…,C. Substituting these RO_j*'s* into (16), (17) and (18) yields a new price vector Π^1. Thus we have a function that maps Π^0 to Π^1. We represent this relationship by:

$$\Pi^1 = H(\Pi^o) \text{ or in general, } \Pi^t = H(\Pi^{t-1}) \qquad \text{(A1)}$$

Equation (A1) represents a system of non-linear simultaneous equations. We can state the following general properties of H: (i) H is positive for all $\Pi^0 > 0$; (ii) H is linearly homogeneous; and (iii) H is a continuous function. These properties follow from the structure of the equations (16) to (19) and the assumed properties of the revenue function.

Further we observe that if Π is a solution to equations (16) to (19), then kΠ is also a solution for any k>0. This means that we can have a solution that is unique up to a factor of proportionality. Thus we can restrict ourselves to solutions of (A2) up to a linear restriction $\sum_{i=1}^{M+2N} \pi_i = 1$ with $\pi_i > 0$. This basically means the mapping H in (A2) is a mapping from the unit simplex into itself. Further H is continuous. From Brower's fixed point theorem there exists a fixed point Π^* such that $\Pi^* = H(\Pi^*)$. We note here that uniqueness of the fixed point is not guaranteed by this theorem.[19]

[19] Likewise, Neary (2004) proves the existence of a unique positive solution to the Geary system but only shows the existence of a positive solution to the GAIA system.

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Table 1: Comparisons of Real Consumption and real GDP per Capita, 2005

(USA = 1 except in final two columns)

Countries	Nominal consump. per-capita	Consumption Indexes			Using AIDS expenditure function, and reference prices from:			RGDP^e per-capita ($)	RGDP^o per-capita ($)
		Geary-Khamis	EKS	CCD	Geary-Khamis	Neary, GAIA	Diewert		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Iceland	1.248	0.767	0.794	0.795	0.790	0.784	0.791	38,592	37,640
United States	1.000	1.000	1.000	1.000	1.000	1.000	1.000	41,553	39,550
United Kingdom	0.895	0.772	0.793	0.807	0.778	0.772	0.779	32,401	30,640
Netherlands	0.756	0.696	0.720	0.736	0.697	0.689	0.699	33,626	31,065
Canada	0.731	0.722	0.735	0.733	0.739	0.733	0.741	33,975	32,159
South Korea	0.297	0.375	0.375	0.378	0.381	0.370	0.383	24,044	26,774
Macedonia	0.076	0.192	0.192	0.195	0.193	0.184	0.196	7,374	8,240
China	0.023	0.059	0.057	0.057	0.053	0.049	0.054	5,097	5,433
India	0.014	0.048	0.046	0.047	0.046	0.042	0.047	2,423	2,479
With adjusted Chinese prices:									
China		0.064	0.062	0.063	0.064	0.059	0.066	5,543	5,862
% Difference from China above		9.0	8.8	9.5	21.1	21.0	20.9	8.8	7.9

Source: Authors' calculations.

Notes: Column (1) gives the nominal consumption expenditure (obtained using exchange rates for converting national currency data into US dollars) per capita in 2005, relative to the US. Column (2) gives the Geary-Khamis calculation of real consumption. Columns (3)-(4) present flexible weight measures of real consumption expenditure per capita, using respectively the EKS, and CCD methods, as defined in the text in equations (4)-(5). Columns (5) to (7) show measures of real consumption based on the estimated AIDS expenditure function, using different reference prices: column (5) uses the Geary-Khamis reference prices; column (6) uses the GAIA reference prices; and column (7) uses every country's prices as reference and then takes the geometric mean of the results, as in Diewert (2009). Column (8) shows real GDP^e per capita on the expenditure-side, while column (9) shows GDP^o per capita on the output-side. The results in the second-last row use adjusted prices for China as described in Appendix A, and the percentage in the final row is computed relative to the China estimate above.

Table 2: Actual and Reference Prices

Category	Sample Mean	United States	Geary-Khamis	GAIA	South Korea
Food and non-alcoholic beverages	1	1.100	1.319	1.134	1.627
Alcoholic beverages and tobacco	1	1.395	1.257	1.343	1.162
Clothing & footwear	1	1.136	1.270	1.113	1.257
Gross rent, water, fuel and power	1	1.889	1.389	1.316	1.446
Household furnishings	1	1.302	1.309	1.271	0.988
Medical and health services	1	2.995	1.494	1.554	1.047
Transport	1	0.950	1.231	1.291	1.023
Communication	1	1.128	1.015	0.921	0.641
Recreation	1	1.231	1.182	1.169	1.121
Education	1	3.412	1.395	1.595	1.602
Restaurants	1	1.025	1.239	1.182	1.310
Other goods and services	1	1.632	1.400	1.400	1.215
$b(p)$	1	1.054	0.996	1.026	0.930

Source: Authors' calculations.

Notes. Listed are the reference prices used in the calculations for Table 1 and Appendix Table A1. Since all prices have been normalized by the sample mean (over 124 countries), the prices p = 1 represent the sample mean. The second set of prices considered are those for the U.S. The third set of reference prices considered are the GK prices computed as in equations (1)-(2), the fourth set are the GAIA reference prices computed as in (11)-(12), and the final set of prices are for South Korea. The final row is computed using as $b(p) = \prod_i p_i^{\beta_i}$ using the β estimates from Appendix Table A2.