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Global Income Inequality and Cost-of-Living Adjustment: The Geary–Allen World Accounts

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Abstract

Standard ways of measuring real income are known to be inconsistent with consumer preferences. We provide preference-consistent estimates of real income, based on the income-specific price indices that are consistent with nonhomothetic preferences. We find that existing measures, such as Geary, GEKS and GAIA, create systematic biases: the poorer is a country, the more its income is overestimated by these measures. Consequently, international income inequality is underestimated by the same measures. (*JEL*: D01, D30 E01, F01)

1 Introduction

There are large differences between rich and poor people in the world, and there are untold millions of people living in poverty. However, different measures of real income

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would give different answers to the question of how large the global income inequality is. Ideally, we would like to study the world distribution of individual real incomes disregarding national borders. But income is reported in nominal values and cannot be compared without adjusting for price differences, and while many attempts have been made at making incomes comparable across countries, none of them is completely satisfactory. All proposals have used a country-specific price index for adjustment, but because consumers at different income levels choose different consumption baskets, such per country indices cannot fully respect individual preferences.

The so-called purchasing power parity methods were introduced to measure real incomes. The most commonly used set of purchasing power parity-adjusted incomes is the Penn World Table (PWT). The method underlying the PWT is the Geary method. For individuals with Leontief preferences, not willing to substitute away from goods as they become more expensive, the Geary method provides measures that are consistent with cost-of-living-based real income. The World Bank, the Eurostat and the OECD, on the other hand, use GEKS (Gini-EKS[1]) belonging to the flexible superlative indices that allow for substitution. However, these allow for nonhomothetic preferences only as approximations and for unknown intermediate utility levels (Diewert 1999).

That preferences are neither Leontief nor homothetic has been known from micro data for a long time (Engel 1895; Slutsky 1915). For some countries, especially some low- and medium-income countries, the Laspeyres and Paasche indices are quite far apart, indicating that there might be large substitution biases (see e.g., Deaton and Heston 2010). Neary (2004) suggested the Geary–Allen International Accounts (GAIA) to overcome this. Neary estimates a flexible demand system: the quadratic almost ideal demand system (Banks, Blundell, and Lewbel 1997) calculates reference "world"

[1]The method is due to (Gini 1924, 1931) and independently rediscovered by Eltetö and Köves (1964) and Szulc (1964).

prices using a modification of the Geary method and then compares per capita income levels using money metric utility at these reference prices.[2] However, because Neary's approach still calculates a single price index for each country, it does not take into account within-country income inequality; hence, it fails to respect how budget shares vary with income, even within countries.

We refer to the measure we develop in this paper as the Geary–Allen World Accounts (GAWA). GAWA extends GAIA to allow for nonhomothetic preferences by taking into account the within-country distributions of income, both in the estimation of the demand system and by constructing income- specific price deflators. The GAWA system allows us to construct new real income averages for each country and compare these to existing indices.

We report three main findings. First, the main results presented in Neary (2004) hold up with our replication that includes population weights; that is, GEKS and Geary overestimate incomes of poorer countries. Second, we show that there is a systematic difference between GAIA and GAWA: When allowing for within-country heterogeneity in income and subsequently cost of living, the dispersion in national incomes increases; that is, according to GAWA, the poorer a country is, the more GAIA also overestimates its income. Third, Geary, EKS and GAIA underestimate the inequality across people (i.e., world inequality) and the inequality across countries (i.e., international inequality).

[2] See also Feenstra, Ma, and Rao (2009) and Aten and Reinsdorf (2010) for further discussion and application of GAIA. This approach is not without precedence. Kravis, Heston, and Summers (1982, Table 9.8) calculated such indices based on the cost of obtaining the utility level associated with the consumption of the United States, using a more restrictive linear expenditure system.

2 The different price indices

This section gives an overview of existing price indices as well as our proposed GAWA system. First, we go through the formulas for the most frequently used standard indices, GEKS and Geary, and then we return to the welfare-consistent approaches, GAIA and GAWA.

Throughout the paper, there are n commodities indexed $i = 1,\dots,n$, and m countries indexed $j = 1,\dots,m$. For each country, there is a price vector $\boldsymbol{p}_j = (p_{ij})_i$ and corresponding per capita quantity vectors $\boldsymbol{q}_j = (q_{ij})_i$. $\boldsymbol{Q}_j = (Q_{ij})_i$ gives the total quantity amounts in a country. Per capita consumption is $z_j = \boldsymbol{p}_j \boldsymbol{q}_j$.

2.1 The standard indices

The two most frequently used indices for cross-country comparisons are the GEKS index used by the Eurostat, the OECD and the recent World Bank cross-country comparisons, and the Geary index, used for the Penn World Table.

The GEKS index can be thought of as the multilateral 'star' version of the Fisher, which is itself based on the Laspeyres and Paasche indices. The Laspeyres and Paasche bilateral indices are direct comparisons of expenditure using either the base country k's prices (Laspeyres) or the comparison country j's prices (Paasche):

$$I_{jk}^{\mathrm{La}} = \frac{\boldsymbol{p}_k \cdot \boldsymbol{q}_j}{\boldsymbol{p}_k \cdot \boldsymbol{q}_k}, \qquad I_{jk}^{\mathrm{Pa}} = \frac{\boldsymbol{p}_j \cdot \boldsymbol{q}_j}{\boldsymbol{p}_j \cdot \boldsymbol{q}_k}. \tag{1}$$

Because these indices give different answers depending on the choice of the base country, one often uses the Fisher index, a geometric mean of the Laspeyres and Paasche indices that provides a bilaterally consistent index:

$$I_{jk}^{\mathrm{Fi}} = \sqrt{I_{jk}^{\mathrm{La}} \cdot I_{jk}^{\mathrm{Pa}}}. \tag{2}$$

With more than two countries, however, we have no guarantee that income comparisons are transitive, in the sense that $I_{13} = I_{12} \cdot I_{23}$. GEKS is constructed to provide this transitivity property because it takes the geometric mean of the Fisher indices over all possible comparisons:

$$I_{jk}^{\text{GEKS}} = \prod_{s=1}^{m} \left(\frac{I_{js}^{\text{Fi}}}{I_{ks}^{\text{Fi}}} \right)^{1/m}. \tag{3}$$

The Geary index, also known as the Geary–Khamis index, is based on the idea of evaluating quantities, not by actual prices, but by a vector of average prices, $\boldsymbol{\pi}$:

$$I_{jk}^{\text{Geary}} = \frac{\boldsymbol{\pi} \cdot \boldsymbol{q}_j}{\boldsymbol{\pi} \cdot \boldsymbol{q}_k}. \tag{4}$$

The average prices are determined by a consistency requirement on how world expenditure is calculated: a direct and an indirect valuation of world expenditure on each good. The direct valuation evaluates world expenditure on commodity i by using the average world prices π_i: $\sum_j \pi_i Q_{ij}$. The indirect valuation converts nominal expenditure in each country at an "exchange rate", which is a Laspeyres price index between each country and the average world price vector: $\boldsymbol{\pi} \cdot \boldsymbol{q}_j / \boldsymbol{p}_j \cdot \boldsymbol{q}_j$. The consistency requirement provides n equations of the form:

$$\sum_{j=1}^{m} \pi_i Q_{ij} = \sum_{j=1}^{m} p_{ij} Q_{ij} \frac{\boldsymbol{\pi} \cdot \boldsymbol{q}_j}{\boldsymbol{p}_j \cdot \boldsymbol{q}_j}, \quad \text{for all } i = 1, \ldots, n. \tag{5}$$

These n linear equations in $\boldsymbol{\pi}$ determine the n world prices (up to a normalization).

2.2 Geary–Allen International and World Accounts

To evaluate the welfare consistency of the standard indices, we resort to the standard assumptions of optimizing behavior based on stable preferences. Studying price indices, we most often add the assumption that consumers in all countries share the same preferences, which can be expressed either by a direct utility function $u(\boldsymbol{q})$ or its indirect equivalent $v(\boldsymbol{p},z) = \max_{\boldsymbol{q}}\{u(\boldsymbol{q})|\boldsymbol{p}\cdot\boldsymbol{q} \leq z\}$.[3] Given that we knew these functions, we could ask whether a particular index would rank countries the same way as consumers would.

A first-best way out seems to be that we use actual preferences and rank countries by these. Because we would like cardinal measures of income to evaluate inequality, it seems natural that, if we had a reference price vector $\boldsymbol{\pi}$, we could evaluate utility of a consumer with income z_j facing prices $\boldsymbol{p}_j$, as the money metric utility, $m(\boldsymbol{\pi},\boldsymbol{p}_j,z_j) = e(\boldsymbol{\pi},u_j) = e(\boldsymbol{\pi},v(\boldsymbol{p}_j,z_j))$, where e is the expenditure function. The corresponding bilateral income indices can be defined as:

$$I_{jk}^{\text{GAIA}} = \frac{e(\boldsymbol{\pi},v(\boldsymbol{p}_j,z_j))}{e(\boldsymbol{\pi},v(\boldsymbol{p}_k,z_k))}. \tag{6}$$

This is the approach taken by Neary (2004), and such ratios of money metric utilities are known as Allen Quantity indices.

However, if preferences are not homothetic, the consumption basket depends on income. Consequently, the overall cost of living will depend not only on prices, but also on income. Moreover, with nonhomothetic preferences, individual demand and aggregate per capita demand do not coincide; expenditure shares in the national accounts will, except in special cases, depend on within-country distribution of income. If the income distribution within a country is represented by a list of people with different incomes z_{jl} and individuals within country j are indexed by $l = 1,\ldots,L_j$, indices of the form (6) can no longer be applied since there is no unique money metric utility for an average individual. Each individual's money metric utility is now given by

[3]We also make use of the expenditure function, the minimum cost of attaining a given utility level, $e(\boldsymbol{p},u) = \min_{\boldsymbol{x}}\{\boldsymbol{p}\cdot\boldsymbol{x}|u(\boldsymbol{x}) \geq u\}$ and its minimizing argument, the Hicksian compensated demand function, $\boldsymbol{h}(\boldsymbol{p},u)$.

$e(\boldsymbol{\pi}, v(\boldsymbol{p}_j, z_{jl}))$.

A natural extension of the GAIA system, which fully allows for nonhomothetic preferences, is to take for each country the average of the individual money metric utilities:

$$I_{jk}^{\text{GAWA}} = \frac{N_j^{-1} \sum_{l=1}^{N_j} e(\boldsymbol{\pi}^{\text{GAWA}}, v(\boldsymbol{p}_j, z_{jl}))}{N_k^{-1} \sum_{l=1}^{N_k} e(\boldsymbol{\pi}^{\text{GAWA}}, v(\boldsymbol{p}_l, z_{kl}))}. \tag{7}$$

We call this system of income indices Geary–Allen World Accounts (GAWA), with 'World' replacing 'International' to signify that each individual counts in terms of his/her income and prices, not as a citizen of a country with a particular mean income.

To make this idea operational, the utility function must be quantified. Before we turn to the estimation procedure, there are three issues of implementation that have to be discussed. First, we need to choose a formula to identify world reference prices, π^{GAWA}. Second, we need to choose whether to weight by population size, as the traditional Geary method does, or whether we want to follow Neary's original GAIA formula, in which all countries have equal weight. Third, we need to find a way to consistently aggregate the demand system. In the following subsections, we discuss these issues, in turn.

2.2.1 Identifying the reference prices

Peter Neary proposes a consistency requirement on the international accounts that determines the reference prices in much the same way as the Geary approach, but it is different in two ways. First, corresponding to the left-hand side of (5), world expenditure is calculated in Hicksian compensated quantities, $\sum_j \pi_i h_i(\boldsymbol{\pi}, u_j)$, the quantities that would have prevailed as the cost-minimizing way for consumers to reach their indifference curve at the reference prices. Second, corresponding to the right-hand side of (5), the Laspeyres price index is replaced by the true cost-of-living index, $e(\boldsymbol{\pi}, u_j)/z_j$.

Consequently, the equations that determine the reference world prices $\boldsymbol{\pi}^{\text{GAIA(Neary)}}$ are now:

$$\sum_{j=1}^{m} \pi_i^{\text{GAIA(Neary)}} h_i(\boldsymbol{\pi}^{\text{GAIA(Neary)}}, u_j) = \sum_{j=1}^{m} p_{ij} q_{ij} \frac{e(\boldsymbol{\pi}^{\text{GAIA(Neary)}}, u_j)}{z_j} \quad \text{for all } i = 1, \ldots, n. \tag{8}$$

We refer to this as GAIA(Neary) because this is identical to what Neary implemented. We also calculate a population-weighted version of this, which we refer to as GAIA (this is discussed in Section 2.2.2). This nonlinear system of n equations determines world prices in the GAIA system just as the (linear) system (5) determines prices and incomes for the Geary system.

To take account of within-country distributions of income, we extend (8) to this case by treating each individual as a country of his or her own, and define reference prices for this case as solutions to the equations:

$$\sum_{j=1}^{m} \pi_i^{\text{GAWA}} \sum_{l=1}^{N_j} h_i(\boldsymbol{\pi}^{\text{GAWA}}, u_{jl}) = \sum_{j=1}^{m} p_{ij} \sum_{l=1}^{N_j} q_{ijl} \frac{e(\boldsymbol{\pi}^{\text{GAWA}}, u_{jl})}{z_{jl}} \quad \text{for all } i. \tag{9}$$

Calculating the reference prices and income indices in this disaggregated setting seems to imply that we have data not only on per capita prices and quantities, but also on individual-level expenditure data. But if we retain the assumption that we know preferences and hence, the demand functions, it is possible to impute data on quantities at all income levels using only distributional data on incomes.

2.2.2 Population weighting

In our presentation of the Geary method, we emphasized that the quantities Q_{ij} are total and not per capita quantities for country j. The GAIA approach, as formulated by Neary (2004), relies on the metaphor of the country being an individual, and hence a per capita interpretation of the virtual quantities. Indeed, Neary (2004) implements both GAIA and Geary as per capita indices with no population weighting in the determination of world prices.

Much of the applied macro literature using cross-sections of countries weigh countries equally regardless of country size. A standard defense of this is that countries are equally important as realizations of the underlying data-generating process. However, this defense does not apply to calculating world prices. Neary (2004, p. 1414) emphasizes that income measures should be *matrix consistent*, in the sense that real income can consistently be disaggregated by good and country. In the literature, however, such consistency is often understood in a more radical sense, namely as a property that real incomes in third countries should not change if a large country is split into two smaller ones (see e.g., Diewert 1999, p. 47). Using (5), the two smaller countries would share the weight previously given to the large country and world prices would not be affected. Neary's per capita approach without weighting means that the prices in the original country now have double the weight in the determination of world prices and hence, incomes in third countries would be affected.

We propose a population-weighted version of the system, which we refer to as GAIA.[4] If N_j is the size of the population in country j, then GAIA gives world prices from the following population-weighted modification of (8):

$$\sum_{j=1}^{m} N_j \pi_i^{\text{GAIA}} h_i(\boldsymbol{\pi}^{\text{GAIA}}, u_j) = \sum_{j=1}^{m} N_j p_{ij} q_{ij} \frac{e(\boldsymbol{\pi}^{\text{GAIA}}, u_j)}{z_j} \quad \text{for all } i. \tag{10}$$

The corresponding bilateral income index follows on the same form as (6).

[4]It does not automatically follow that the lack of population weighting would have a large quantitative effect. Size of country in terms of population is not automatically related to income per capita, and it could be that a lack of such correlation means that the overweighting of small countries is of little consequence.

2.2.3 Consistent aggregation

To estimate preferences, we estimate a world demand system expressing budget shares as functions of income and relative prices. If there is within-country income inequality, estimation of such a demand system using only national accounts budget shares will not identify the parameters. With within-country income inequality, there is in fact no guarantee that national accounts data will satisfy the weak axiom of revealed preference. It is, however, always possible to integrate individual demand over the income distribution to find total demand, which, divided on total expenditure, corresponds to budget shares as recorded in national accounts data. If the income distribution is denoted by the distribution function F while the budget share of good i at an income level z is $\omega_i(\boldsymbol{p}, z)$, the aggregate budget share $\tilde{\omega}_i$ can be calculated as:

$$\tilde{\omega}_i(\boldsymbol{p}, F) = \frac{\int_0^\infty z \cdot \omega_i(\boldsymbol{p}, z) dF(z)}{\int_0^\infty z dF(z)}. \tag{11}$$

With particular assumptions about preferences, (11) might simplify to functional forms that resemble the individual demand functions, and classes of such demand systems have been characterized (Muellbauer 1975, 1976). In the general case, aggregate quantities and budget shares need not correspond to those of any single real or hypothetical consumer.

3 Data and estimation

In the following, we outline the source of our data and how we estimate the demand system.

3.1 Data

We use the 2005 International Comparison Project (ICP) data (International Comparison Program 2008b). The ICP data consist of purchasing power parities for each goods group, and these represent in principle an average of the prices of goods in this category in each country in each benchmark year. Conceptually, these are prices for good i in country j relative to the international price of good i, P_{ij}/π_i, where the international prices are calculated as Geary prices by the ICP. Corresponding to these purchasing power parities are nominal expenditures in local currency units, which conceptually are prices multiplied by quantities, $E_{ij} = P_{ij}Q_{ij}$. Dividing the nominal expenditures by the purchasing power parities we get $Q_{ij}\pi_i$, quantities measured in units of expenditure at world prices. These price levels and quantities can again be divided by the purchasing power parity of the base country, which gives us price levels and quantities. We can write the prices and quantities as:

$$p_{ij} := \frac{P_{ij}/\pi_i}{P_{bj}/\pi_i}, \tag{12}$$

$$q_{ij} := \frac{E_{ij}}{P_{ij}} P_{ib}, \tag{13}$$

where the choice of the base country b is arbitrary (it is customary to use the United States as the base country).

We follow International Comparison Program (2008a) and use a 12-good classification.[5] The ICP 2005 benchmark data cover 146 countries. To incorporate within-country distributions of income, we use the data provided by Milanovic (2005). His dataset consists of average income in each of the 20 equally sized income groups. We

[5]The 12 categories are: "Food and nonalcoholic beverages", "Alcoholic beverages, tobacco and narcotics", "Clothing and footwear", "Housing, water, electricity, gas and other fuels", "Furnishings, household equipment and maintenance", "Health", "Transport", "Communication", "Recreation and culture", "Education", "Restaurants and hotels" and "Miscellaneous goods and services".

treat each of these five percentiles as if they were internally homogeneous with respect to income. Not all countries are covered by both the ICP and Milanovic's distributional numbers, and we end up using 103 countries with a total population of 5 698 million. In the following, when we refer to the "global" distribution, we refer to these 103 countries.

3.2 Implementation issues

To implement GAIA and GAWA, we need parameterization of preferences. Neary (2004) presents estimates with several different demand systems, but his preferred estimates rely on the QUAIDS system (Banks et al. 1997). This system allows for flexible (quadratic) Engel curves in addition to flexible substitution patterns. For an individual, the budget share for any good i can be written as:

$$\omega_{ij} = \alpha_i + \sum_{h=1}^{n} \gamma_{ih} \log p_{hj} + \beta_i \log y_j + \frac{\lambda_i}{\beta(\boldsymbol{p}^j)} (\log y_j)^2, \tag{14}$$

where $y_j = z_j/\alpha(\boldsymbol{p}^j)$, and $\alpha(\boldsymbol{p}^j)$ and $\beta(\boldsymbol{p}^j)$ are price indices. In total, there are $(n+6)(n-1)/2$ free parameters. For a large number of goods (Neary uses 11 goods), there are quite a few parameters to estimate (85 in Neary's case). Neary applies equation (14) to estimate the preferences needed to implement the GAIA indices (6) and (8).

With the QUAIDS system, it implies that the national accounts budget shares (such as those in the ICP data) can be expressed as:

$$\widetilde{\omega}_{ij} = \alpha_i + \sum_{h=1}^{n} \gamma_{ih} \log p_{hj} + \beta_i \frac{\overline{y_j \log y_j}}{\overline{y_j}} + \frac{\lambda_i}{\beta(\boldsymbol{p}^j)} \frac{\overline{y_j (\log y_j)^2}}{\overline{y_j}}, \tag{15}$$

where an overbar represents an average over the population. Since the logarithm is a concave function, $\overline{y_j \log y_j}$ and $\overline{y_j (\log y_j)^2}$ depend on the distribution and not only on the average level of income in a country. Hence, with distributional information on income, parameters can be recovered from national accounts budget shares.

We estimate the system in (15) and calculate both the GAIA and GAWA incomes based on these. We refer to these as GAIA and GAWA(QUAIDS). Based on this, we compare the GAIA and the GAWA incomes. To guarantee regularity, we also provide estimates for an alternative system, namely the globally regular rank three system proposed by McLaren and Wong (2009). We refer to this as GAWA(McL–W); see Appendix A for a discussion of this system.

For estimation, we assume normally distributed measurement errors, we exclude one budget share from estimation and estimate a SUR system with the covariance matrix of the measurement errors concentrated out (Davidson and MacKinnon 1993, p. 637). Like Neary (2004), we follow Blundell and Robin (1999) in estimating parameters in an iterative manner using the Moschini (1998) parameterization of the Cholesky decomposition of the (mean) Slutsky matrix. Doing so, we find that increasing the approximation of the Slutsky matrix above rank $k = 8$ does not improve the likelihood much, and we keep the $k = 8$ approximation.

4 Results

The different real income indices discussed in this paper provide us with different sets of cross-country comparable real incomes. For completeness, all these sets are displayed in a table in Appendix B. In this section, we discuss the broad and systematic differences across the indices that constitute the main findings of the paper.

4.1 The different real income measures

Figure 1 shows our first and second main findings. The upper panel displays the relationship between the GAIA income, relative to that of GEKS versus the GEKS income. We see that the richer the country (measured by GEKS), the larger is the GAIA measured income relative to that of GEKS. This indicates that the GAIA estimates a larger dispersion in national incomes than does GEKS. The middle panel displays the relationship between GAIA income, relative to that of Geary versus the GEKS income. Just as for the GEKS case, we see that the richer the country (measured by GEKS), the larger is the GAIA measured income, relative to that of Geary. Hence, the two upper panels constitute our first main finding: the main results presented in Neary (2004) hold up with our replication that includes population weights, namely that GEKS and Geary underestimate the dispersion in the distribution of national incomes.

The lower panel displays the relationship between the GAWA(QUAIDS) measured income, relative to that of GAIA versus the GEKS income. Here, we are also able to identify an upward sloping relationship, indicating that GAWA(QUAIDS) measures a larger dispersion in national incomes than does GAIA. This constitutes our second main finding: the GAWA(QUAIDS) system reveals that, because of the failure to fully incorporate nonhomothetic preferences, the GAIA system systematically underestimates the dispersion in the national income distribution; that is, the poorer a country is, the more GAIA overestimates its income.

[Figure 1 about here]

4.2 Evaluation of the different indices

One way to discuss how well the different indices perform in practice is to compare the calculated national incomes to those of the welfare-consistent GAWA system. One way to do such a comparison quantitatively is to look at the distance between the real income sets resulting from the different indices and the GAWA index. Table 1 shows one such distance analysis; it shows the pairwise differences between the different income measures, as measured by the Euclidean distance between vectors containing all the 103 country incomes. We see that the GEKS index comes substantially closer to the GAWA index than the Geary index does. Hence, if we use the GAWA incomes to evaluate the other income indices, we conclude that GEKS is doing better empirically than Geary. As such, our findings suggest that the recent change from using Geary to GEKS, as undertaken by the World Bank, seems to be a good idea.[6] Moreover, we see that the distance between GAIA and GAWA is of the same magnitude as the difference between GAIA and GEKS and Geary, respectively, at least when considering the globally regular McLaren–Wong demand system. The distances are in general comparable to those that are found in other studies on price indices in the literature Deaton and Dupriez (see, e.g., 2011).

[Table 1 about here]

[6]The Penn World Table still uses the Geary index, but GEKS was recently included as one of its real income indices, see Penn World Table version 6.3, 7.0 and 7.1 (Heston, Summers, and Aten 2009, 2011, 2012). Note that both the Eurostat and the OECD have used GEKS for a longer period (see, e.g., OECD 2006).

4.3 Inequality in the world

The main finding that GEKS, Geary and GAIA underestimate the dispersion in the distribution should indicate that they also underestimate international and global inequality. Table 2 shows the resulting inequality from the different real income index systems. Three different concepts of inequality are displayed. First, the *international inequality* gives focus to inequality across countries; it simply compares the mean income across countries. Second, the *weighted international inequality* also gives focus to the inequality in mean income across countries, but it weights each country mean by its population. Third, *global inequality* calculates the inequality across all world citizens; that is, it compares the income of each world citizen by taking into account within-country income distributions of income (see, e.g., Milanovic (2005) for a discussion of these inequality concepts). All the inequality concepts are measured by the Gini index.

We can see that the GAWA indices indicate larger inequality than all the other indices for all the three concepts. Hence, the results confirm that, according to GAWA, both international and global inequality are underestimated by the traditional GEKS and Geary indices as well as the GAIA index. This constitutes our third main finding. Further, we see that the increase in the Gini index from GAIA to GAWA is comparable to the increase from GEKS to GAIA.

[Table 2 about here]

5 Concluding remarks

Traditional indices used for cross-country comparisons of real income fail to be consistent with observed preferences. Although previous studies have discussed the welfare consistency of international real income comparisons (see, e.g., Almås 2012; Deaton and Heston 2010; Dowrick and Quiggin 1997; Dowrick and Akmal 2005; Hill 2000; Neary 2004; Nuxoll 1994), none of these studies has constructed the income-specific price indices that are consistent with nonhomothetic preferences. In this paper, we suggest the GAWA system, which fully takes into account that preferences are not homothetic. This system reveals that both the traditional measures, such as Geary and GEKS, and the GAIA system underestimate international and global income inequality.

In this analysis, focus has been given to the consumption part of GDP. We suggest a welfare-consistent cost-of-living index and estimate a demand system by using the ICP data on consumption prices and quantities. Although the GEKS index is not guaranteed to provide welfare-consistent measures, our findings suggest that the index does quite well empirically: The GEKS national incomes come quite close to the welfare-consistent GAWA national incomes, and at least, they outperform the Geary national incomes. When measuring the total GDP by introducing investments and government consumption, in addition to private consumption, other issues of concern, such as adding-up properties, are also important. However, consumption is a considerable fraction of GDP and hence, our analysis provides some support to the recent shift to using the GEKS index for international comparisons.

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Table 1: Pairwise differences between the different income measures

Income measure	1	2	3	4	5	6	7
1: GEKS	0.000						
2: Geary(Neary)	0.542	0.000					
3: Geary	0.586	0.094	0.000				
4: GAIA(Neary)	0.361	0.840	0.883	0.000			
5: GAIA	0.352	0.833	0.876	0.012	0.000		
6: GAWA(QUAIDS)	0.412	0.881	0.926	0.081	0.090	0.000	
7: GAWA(McL–W)	0.312	0.733	0.773	0.414	0.404	0.467	0.000

Note: The pairwise differences between the different income measures are calculated as the Euclidean distance between the 103-long $\log(y)$ vectors. Row and column numbering correspond to the same list of measures. The abbreviation "GEKS" refers to the Gini-EKS index, "Geary(Neary)" corresponds to Neary's way of calculating Geary prices without population weighting, whereas "Geary" introduces the standard population weights. "GAIA(Neary)" replicates Neary (2004) without population weighting in world price calculations, "GAIA" adds population weighting. "GAWA(QUAIDS)" incorporates within-country distributions of income, uses consistent aggregation and is based on the QUAIDS demand system. "GAWA(McL–W)" is constructed as "GAWA(QUAIDS)", except that it is based on the McLaren–Wong demand system.

Table 2: **Different concepts of inequality**

	Concept of inequality		
	International	Weighted International	Global
GEKS	0.526	0.542	0.680
Geary	0.518	0.534	0.674
GAIA	0.529	0.549	0.686
GAWA(QUAIDS)	0.530	0.551	0.689
GAWA(McL–W)	0.532	0.552	0.687

Note: The table displays the Gini index for three different concepts of inequality. International inequality refers to the Gini over the mean incomes of all countries. The weighted international inequality refers to the Gini over the mean incomes of all countries, weighted by population size. Global inequality refers to the Gini over the incomes of all individuals. The latter is calculated by using the income distributions provided by Branko Milanovic (Milanovic 2005).

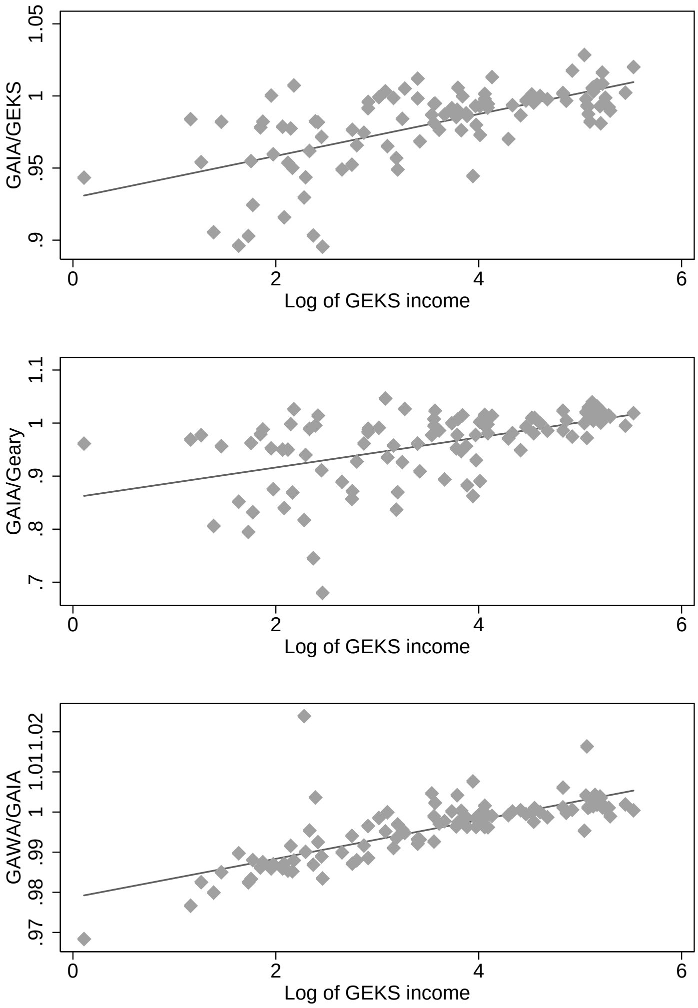

Figure 1: **Relative income measures vs GEKS income.** The upper panel displays the relationship between the GAIA and the GEKS incomes as a function of GEKS income; the middle panel displays the relationship between the GAIA and the Geary incomes as a function of GEKS income; the lower panel displays the relationship between the GAWA and the GAIA incomes as a function of the GEKS income. All slope coefficients are significantly different from zero ($p < 0.001$).

Appendix A Effectively globally regular demand

The QUAIDS and similar systems such as its parent, the Almost Ideal Demand System (Deaton and Muellbauer 1980) and the Translog system (Jorgenson, Lau, and Stoker 1980), are developed to be flexible approximations around a point. It is easy to impose on estimates of the QUAIDS system that the demand system should be regular (in the sense of being consistent with utility maximization), but although such regularity can be imposed at a point, and is in fact imposed at the mean of all data, it does not follow that regularity covers the full estimating sample (Caves and Christensen 1980), and the importance of testing for regularity has been emphasized by Salvanes and Tjøtta (1998). Replicating the QUAIDS estimates of Neary (2004) for our sample, only for Hungary and Croatia do the estimated Slutsky substitution matrices (at the aggregate budget shares) have only nonpositive eigenvalues; hence, they are not negative semidefinite and, not compatible with utility maximization.[7]

An estimated demand system that is irregular at some of the data points need not be a critical failure so long as one primarily is concerned with prediction. But in the GAIA and the GAWA systems, the analytical expression for the expenditure function is used to evaluate welfare. It is not clear that the expressions for the expenditure function have any sensible interpretation at points that cannot be a solution to a utility maximization procedure.

Cooper and McLaren (1996) and McLaren and Wong (2009) show how to construct demand systems that are effectively globally regular, meaning that they are globally regular so long as the minimum expenditure level is above a critical value. In particular, McLaren and Wong (2009) present a rank 3 effectively globally regular system, which means that it allows some flexibility with respect to the shape of the Engel curves. We

[7]For a vector of eigenvalues, $\boldsymbol{\xi}$, we say that the matrix is negative semidefinite if $\max_j \xi_j / \max_k |\xi_k| < 0.001$ (allowing for numerical inaccuracies).

define:

$$V_1(\boldsymbol{p},z) = \theta \frac{z}{P_1(\boldsymbol{p})} + (1-\theta)\frac{[(z/\tau P_2(\boldsymbol{p}))^{\mu} - 1]}{\mu},$$
$$V_2(\boldsymbol{p},z) = \left(\frac{z}{P_3(\boldsymbol{p})}\right)^{\eta}.$$

The indirect utility function of their system can then be written as:

$$v(\boldsymbol{p},z) = V_1(\boldsymbol{p},z) \cdot V_2(\boldsymbol{p},z). \tag{16}$$

So long as P_1, P_2 and P_3 are regular price indices, and with some conditions on θ, τ, μ and η, this system is regular for all $z > \tau P_2(\boldsymbol{p})$. Of course, without a way to impose regularity on the individual price indices, this is not directly helpful. But by choosing globally regular price indices, one can guarantee globally regular demand. We provide an extension of the GAWA system where we follow the suggestion of McLaren and Wong (2009, Section 4,) and choose P_1 to be a Cobb–Douglas price index and P_2 and P_3 to be CES price indices. This system has $3(1+n)$ free parameters. Consequently, for 12 goods, there are 39 free parameters compared with the 99 of the QUAIDS system. The budget shares, as a function of the parameters, follow from Roy's identity. Unfortunately, there is no analytical expression for the expenditure function, but it can easily be evaluated by numerical methods. We refer to this extended GAWA system as GAWA(McL–W).

Appendix B Real incomes from all the different measures

Country	GEKS	Geary (Neary)	Geary	GAIA (Neary)	GAIA	GAWA (QUAIDS)	GAWA (McL–W)
Congo, Dem. Rep.	1.11	1.09	1.09	1.05	1.05	1.02	1.18
Guinea-Bissau	3.19	3.21	3.24	3.13	3.14	3.06	3.31
Niger	3.54	3.46	3.45	3.36	3.38	3.32	3.62
Malawi	4.00	4.45	4.49	3.61	3.62	3.55	3.93
Mozambique	4.32	4.39	4.43	4.23	4.24	4.17	4.40
Guinea	5.12	5.37	5.39	4.58	4.59	4.54	5.19
Sierra Leone	5.64	6.32	6.40	5.08	5.09	5.00	5.68
Mali	5.78	5.74	5.74	5.51	5.52	5.43	5.85
Madagascar	5.89	6.45	6.54	5.43	5.44	5.38	5.80
Burkina Faso	6.34	6.33	6.34	6.19	6.21	6.12	6.45
Comoros	6.50	6.38	6.46	6.37	6.38	6.30	6.62
Chad	7.06	7.43	7.41	7.04	7.06	6.96	8.19
Nepal	7.20	7.85	7.89	6.90	6.91	6.82	6.93
Bangladesh	7.90	8.08	8.14	7.72	7.73	7.62	7.82
Congo, Rep.	8.02	8.69	8.75	7.33	7.35	7.25	7.88
Benin	8.32	8.35	8.35	7.92	7.94	7.82	8.50
Cote d'Ivoire	8.55	8.39	8.37	8.34	8.36	8.29	8.63

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Country	GEKS	Geary (Neary)	Geary	GAIA (Neary)	GAIA	GAWA (QUAIDS)	GAWA (McL–W)
Lao PDR	8.70	9.43	9.51	8.25	8.27	8.15	8.67
Mauritania	8.83	8.63	8.66	8.88	8.89	8.78	9.42
Cambodia	9.76	11.06	11.11	9.06	9.08	9.29	9.37
Nigeria	9.91	9.88	9.95	9.33	9.35	9.25	10.31
Senegal	10.29	9.95	10.01	9.89	9.90	9.86	10.38
Vietnam	10.68	12.87	12.95	9.63	9.65	9.52	9.91
São Tomé and Principe	10.91	10.76	10.77	10.71	10.72	10.76	11.12
Cameroon	11.19	10.89	10.83	10.97	10.99	10.90	11.30
India	11.59	12.36	12.35	11.24	11.26	11.13	11.37
Tajikistan	11.70	15.10	15.41	10.46	10.48	10.31	11.28
China	14.18	15.05	15.13	13.45	13.46	13.32	13.83
Bhutan	15.64	17.18	17.38	14.88	14.89	14.80	15.06
Kyrgyz Republic	15.70	17.40	17.60	15.32	15.34	15.14	16.06
Pakistan	16.41	16.96	17.09	15.83	15.85	15.66	16.21
Philippines	17.60	17.77	17.84	17.14	17.15	17.01	17.41
Morocco	18.33	18.51	18.49	18.16	18.17	18.11	18.23
Indonesia	18.35	18.48	18.47	18.26	18.28	18.07	18.26
Cape Verde	20.41	20.42	20.57	20.38	20.39	20.36	20.75
Sri Lanka	21.75	21.12	20.85	21.81	21.82	21.71	22.05
Bolivia	22.19	23.14	22.90	21.41	21.42	21.42	21.41
Syrian Arab Republic	23.56	24.43	24.57	23.52	23.53	23.32	23.86
Moldova	24.23	27.33	27.71	23.18	23.19	23.04	23.19

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Country	GEKS	Geary (Neary)	Geary	GAIA (Neary)	GAIA	GAWA (QUAIDS)	GAWA (McL–W)
Gabon	24.54	26.51	26.78	23.28	23.29	23.22	23.99
Georgia	25.69	27.21	27.30	25.28	25.29	25.18	25.35
Paraguay	26.33	25.86	25.78	26.45	26.47	26.33	26.23
Egypt, Arab Rep.	29.87	30.92	31.01	29.81	29.82	29.61	29.90
Armenia	29.90	31.09	31.48	30.25	30.26	30.02	30.60
Jordan	30.55	32.88	32.55	29.58	29.59	29.39	30.01
Colombia	34.36	34.80	34.70	33.90	33.91	34.07	33.70
Ecuador	35.10	34.66	34.18	34.43	34.44	34.40	34.45
Albania	35.12	35.09	35.10	34.91	34.92	34.66	35.10
Peru	35.47	34.80	34.49	35.28	35.29	35.37	35.26
Thailand	36.95	37.30	36.60	36.07	36.08	35.98	35.95
Ukraine	39.00	42.68	43.06	38.48	38.49	38.40	38.30
Venezuela, RB	41.88	41.83	41.54	41.52	41.52	41.53	41.24
Montenegro	43.76	44.74	45.28	43.11	43.12	42.97	42.76
Malaysia	44.13	45.26	44.72	43.71	43.71	43.89	43.22
Brazil	44.45	44.59	44.38	44.70	44.70	44.58	44.81
Turkey	45.96	46.99	47.37	44.86	44.87	44.88	44.85
South Africa	46.52	46.21	45.84	46.51	46.51	46.43	46.55
Macedonia, FYR	48.22	49.36	49.81	47.64	47.64	47.58	47.48
Kazakhstan	48.67	53.77	54.38	47.99	48.00	47.82	47.50
Iran, Islamic Rep.	51.54	56.35	56.44	48.67	48.68	49.05	47.52
Bosnia and Herzegovina	52.88	53.50	53.71	52.51	52.51	52.43	51.94

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Country	GEKS	Geary (Neary)	Geary	GAIA (Neary)	GAIA	GAWA (QUAIDS)	GAWA (McL–W)
Serbia	53.20	55.44	56.06	52.12	52.13	51.93	51.20
Uruguay	55.15	54.89	54.63	54.75	54.75	54.73	55.19
Belarus	55.30	59.68	60.41	53.80	53.81	53.72	53.37
Romania	57.93	58.24	58.12	57.82	57.82	57.60	57.29
Chile	57.94	57.59	57.14	58.02	58.03	58.12	58.31
Argentina	59.66	59.60	59.32	59.17	59.17	59.12	58.79
Bulgaria	59.81	60.86	60.65	59.48	59.48	59.25	58.98
Russian Federation	62.24	62.19	62.19	63.05	63.05	62.99	62.28
Mexico	73.11	74.40	73.04	70.92	70.92	70.87	71.78
Latvia	76.11	76.95	77.09	75.63	75.63	75.64	75.24
Poland	82.48	84.95	85.76	81.38	81.38	81.42	81.90
Croatia	86.96	87.25	87.30	86.68	86.68	86.64	85.94
Lithuania	92.12	91.53	91.32	92.22	92.22	92.20	91.68
Korea, Rep.	93.88	96.00	95.28	93.44	93.44	93.22	89.58
Estonia	94.64	93.75	93.34	94.25	94.25	94.35	93.65
Hungary	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Czech Republic	107.43	108.76	108.76	107.19	107.19	107.05	106.65
Slovenia	125.20	123.79	122.60	125.45	125.46	125.61	125.45
Singapore	125.29	130.01	127.26	125.47	125.48	126.24	121.45
Israel	129.40	128.31	128.32	128.97	128.97	128.95	131.76
Taiwan, China	137.22	144.83	143.31	139.63	139.64	139.72	130.93
Japan	154.66	160.28	159.07	159.04	159.06	158.32	149.89

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Country	GEKS	Geary (Neary)	Geary	GAIA (Neary)	GAIA	GAWA (QUAIDS)	GAWA (McL–W)
Finland	157.08	154.58	153.63	156.72	156.74	157.39	162.34
Hong Kong, China	158.55	164.32	162.00	157.45	157.47	160.04	154.21
Italy	160.37	160.19	158.04	159.17	159.19	159.35	161.19
Greece	160.63	156.75	154.14	158.60	158.62	158.82	159.47
Spain	163.43	160.59	157.73	160.50	160.52	160.74	164.82
Ireland	167.04	164.05	161.59	167.91	167.94	168.27	172.85
Belgium	168.79	167.89	166.42	169.77	169.80	170.05	174.46
Germany	169.02	170.29	168.77	169.52	169.55	169.96	174.29
Denmark	171.87	169.90	169.23	172.97	172.99	173.73	179.38
Sweden	173.94	171.53	171.13	175.04	175.07	175.63	181.11
Australia	175.30	173.27	171.27	176.64	176.67	176.99	179.42
France	180.50	178.50	176.82	179.18	179.21	179.91	186.18
Netherlands	181.77	179.06	178.18	178.30	178.33	178.95	190.86
Switzerland	184.48	185.10	183.57	187.44	187.48	187.84	191.20
Canada	184.91	185.72	183.82	186.45	186.48	186.70	187.82
Norway	190.26	188.71	187.65	189.98	190.02	190.18	193.57
Austria	196.69	194.96	192.40	195.13	195.17	195.38	199.05
United Kingdom	199.41	197.78	195.06	197.34	197.39	197.18	203.61
Luxembourg	231.77	237.38	233.45	232.22	232.29	232.74	238.24
United States	251.03	256.26	251.39	255.97	256.07	256.18	267.92

Table 3: Incomes (per capita) calculated using different methods, with Hungary as base. The abbreviation "GEKS" refers to the Gini-EKS index, "Geary(Neary)" cor-

responds to Neary's way of calculating Geary prices without population weighting, whereas "Geary" introduces the standard population weights. "GAIA(Neary)" replicates Neary (2004) without population weighting in world price calculations, "GAIA" adds population weighting. "GAWA(QUAIDS)" incorporates within-country distributions of income, uses consistent aggregation and is based on the QUAIDS demand system. "GAWA(McL–W)" is constructed as "GAWA(QUAIDS)" except that it is based on the McLaren–Wong demand system. The countries are sorted by values of the GEKS index.

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20/12 October, **Ingvild Almås** and **Erik Ø. Sørensen**, “Global Income Inequality and Cost-of-Living Adjustment: The Geary–Allen World Accounts”.

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