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Ufuk Gunes Bebek

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Abstract

The concept of revealed comparative advantage (RCA) stands as a major pillar in empirical trade literature. Yet there is no absolute preference among the suggested RCA measures. Given that these are volume-based indices, results of any relevant empirical analysis would be heavily influenced by the choice of the RCA measure. Considering such an ambiguity, this paper critically evaluates the proposed measures of RCA to identify the ideal measure based on theoretical, statistical and empirical precedence. Its suggested that the Balassa Index and the two corresponding multiplicative normalised variants are more consistent and robust for RCA analysis.

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†School of Economics, University of Kent, Canterbury CT2 7NP
email:ugb2@kent.ac.uk

1 Introduction

Nobel Laureate Paul Samuelson's response to a nontrivial and meaningful outcome of economics has been the law of comparative advantage. Whether it is attributed to Robert Torrens for discovering it or to James Mill for providing Ricardo with the theory or to David Ricardo himself (Ruffin, 2002), the law of comparative advantage is still at the core of international trade theory.

In essence countries will become net exporters of goods they have a comparative advantage and by observing the sign of the difference between autarkic and free trade prices, one can determine the relative comparative state of countries for those goods. Although theoretical grounds have been provided (Deardorff, 1980) measurement of comparative advantage is not straightforward since autarkic prices are not observable. Nevertheless it has been an empirical convention to measure comparative advantage by revealing it using actual trade flows and their relative shares since popularised by Balassa (1965). Yet related empirical inconsistencies[1] along with the independence of such a measurement of comparative advantage from the underlying theory, prompted subsequent researchers[2] in altering the original revealed comparative advantage (RCA) index proposed by Balassa. Given the significant number of different RCA indices, the outcome of any empirical assessment within the RCA framework would crucially depend upon the employed index, as they are volume-based indices.

Although the proponents of the suggested alterations in the original index examined how the distribution of their indices differ from that of the original index, hence could form a basis for an argument on statistical superiority, they do not comprehensively account for all possible alterations. Thus, the crucial choice of the appropriate RCA index has been premised on rather limited grounds. The purpose of this paper is to critically evaluate the proposed RCA indices, in order to signify the ideal RCA index among the alternatives based on; theoretical precedence, statistical precedence and empirical precedence. Section 2 outlines the principles of RCA, its interpretation and inherent inconsistencies. In section 3 the alternative RCA measures are presented. Section 4 investigates the theoretical precedence among the proposed measures of RCA followed by arguments on the

[1] as discussed by Yeats (1985), Webster (1991), Hinloopen & Marrewijk (2001).

[2] e.g. Vollrath (1991), Dalum et al. (1998), Proudman & Redding (1998, 2000), Hoen & Oosterhaven (2006) and Yu et al. (2009).

statistical and empirical precedence. Section 5 concludes.

2 The Balassa Index and Inherent Inconsistencies

In his seminal work, Balassa (1965) asserted that the potential effects of trade liberalisation resulting from the Kennedy-round could be evaluated by presenting information on RCA. His proposed index can be written as,

$$BRCA_a^i = \frac{X_a^i}{X_a^w} \bigg/ \frac{X_t^i}{X_t^w} \tag{1a}$$

where subscript t refers to the aggregate of all traded commodities while superscripts i and w, respectively, represent the examined country and the world.

Although the traditional inference of the index is based on its quantification of the commodity-specific comparative advantage of a country vis-à-vis the other countries, Ballance et al. (1985) consider two additional inferences that the index should permit; namely, a commodity-specific ranking of countries and a demarcation between countries that enjoy a comparative advantage and those that do not. They refer to these inferences as the cardinal, ordinal and dichotomous measures of RCA, respectively.

Considering equation (1a), the numerator ranges from *0* to 1, the former indicating zero exports while the latter indicates an international monopoly for country i in commodity a. The denominator can also range from *0* to *1* depending on the size of the country *a propos* world exports. Yet the value of the index will range between *0* and $\frac{X_t^w}{X_t^i}$ because; while the theoretical upper bound is ∞ as $\lim_{X_t^i \to \infty} \left(X_t^w / X_t^i \right)$ indicates zero for country i's exports, the effective upper bound of the index is at $\frac{X_t^w}{X_t^i}$.

The demarcation of the index is given by $\frac{X_a^i}{X_a^w} = \frac{X_t^i}{X_t^w}$ and hence equals to unity while deviations from unity will indicate the relative comparative state. More precisely, country i will have a comparative advantage in commodity a if $\frac{X_t^w}{X_t^i} > BRCA_a^i > 1$ or will have a comparative disadvantage if $1 > BRCA_a^i > 0$. Considering these intervals, the index is evidently quite asymmetric having a variable upper bound, which can theoretically tend to ∞, and a fixed lower bound at *0*. This property of the Balassa Index is likely to skew its distribution and since the upper bound varies across countries and for each country across time, *ergo* will the distribution of the index. Furthermore μ_{BRCA} and σ_{BRCA} will also vary across both time and countries.

The asymmetry caused by the inequality of the intervals also indicates that the demarcation is not symmetric and the relative weight attached to the specialised sectors compared to unspecialised sectors would be unrestrained (Benedictis & Tamberi, 2002). For instance, in the case of a small country, if the country specialises in few sectors, which would then be characterised by high values of Balassa Index, it is quite likely that $\mu_{BRCA} > 1$ for this country, and any temporal inference vis-à-vis this μ_{BRCA} would be biased upwards for the changes in specialised sectors, while the opposite would hold for changes in the unspecialised sectors (Proudman & Redding, 1998).

This asymmetry of the Balassa Index could be argued to cause the inconsistencies that arise in cross-country comparisons of comparative advantage. Again in the case of a small country, if its world share in a particular commodity is equal to that of the larger country, the Balassa Index will likely reveal the smaller country as more specialised. Benedicts and Tamberi argue that, as different cardinal values of the Balassa Index could imply very different economic conditions for countries, there is a lack of clarity in cross-country comparison. This is due to the compositional effects of two simultaneous but separate factors that determine the informational content of the index. Because of the multiplicative nature of the index, higher or lower values of the index can be associated to the commodity's export share or to the country's overall export share in world or to both, namely the numerator and the denominator of the index.

Considering the compositional effect of these components, cross-industry comparisons would only depend on the first component whereas cross-country or cross-temporal comparisons would depend on both of the components. Thus one may come up with paradoxical results in cross-temporal or cross-country comparisons given a similar change in $\frac{X_a^i}{X_a^w}$ for two countries. Particularly, problems associated in cross-temporal comparisons were originally pointed out by Balassa (1965). Balassa argued that higher growth rates in export performances are associated with exports that are small in absolute terms, while countries that already enjoy large segments of certain exports may not expect significant increase in those shares.

Nevertheless it should always be taken into account that RCA analyses based on indices like the

Balassa Index are conditional on the relative position of countries and industries within the chosen reference benchmark. Hoen and Oosterhaven (2006) show that the number of the reference countries along with the level of aggregation not only would affect the distribution of the Balassa Index, but would also affect both μ_{BRCA} and $\frac{X_t^w}{X_t^i}$, namely its mean and upper bound. Within a two-country two-good case, given that a country's comparative advantage in one good would imply the other country's comparative advantage in the other good, industries would be evenly distributed around the neutral state, whereas in cases with more than two countries such symmetry may disappear. Furthermore, decreasing the level of aggregation will likely to increase both μ_{BRCA} and $\frac{X_t^w}{X_t^i}$ given the fixed lower boundary and the variable upper boundary of the index.

3 Proposed Alternatives

Given the asymmetric nature and the variable mean of the Balassa Index, several methods were proposed to re-normalise the original index around a stable mean having a symmetric distribution. Probably the most basic approach would be to log-normalise the Balassa Index as suggested by Vollrath (1991),

$$LRCA_a^i = \ln\left(BRCA_a^i\right) \tag{2a}$$

in which the demarcation of the index moves to 0 and the index will be theoretically[3] symmetric around this value. For $\infty > LRCA_a^i > 0$, country i will have a comparative advantage in commodity a, while for $0 > LRCA_a^i > -\infty$ the country will have a comparative disadvantage. However if country i's exports in commodity a are zero, then $LRCA_a^i$ will be undefined. Although this may not pose a problem at high levels of aggregation, it can still be problematic when applied to a very heterogeneous group of countries, in which some are likely to have zero exports for particular commodities. Furthermore, the proposed logarithmic transformation attributes greater weight to changes above unity, which forces $LRCA_a^i$ to be symmetric around its demarcation.

[3] $\lim\limits_{X_t^i \to \infty} \left(X_t^w / X_t^i\right) = \infty$ and hence $\ln \lim\limits_{X_t^i \to \infty} \left(X_t^w / X_t^i\right) = \infty$, while the effective bounds of the index would be at $\ln\left(X_t^w / X_t^i\right) > LRCA_a^i > -\infty$, and hence the index will still have a variable upper bound, across countries and for each country across time.

To avoid such undefined index values, Dalum et al. (1998) propose a quasi-logarithmic transformation, which is the linear approximation of (2a). That is,

$$SRCA_a^i = \left(BRCA_a^i - 1\right)/\left(BRCA_a^i + 1\right) \tag{3a}$$

which will again have demarcation at *0*, but now for $1 > SRCA_a^i > 0$ country i will have a comparative advantage in commodity a while for $0 > SRCA_a^i > -1$ the country will have comparative disadvantage. Similar to $LRCA_a^i$, $SRCA_a^i$ is also theoretically[4] symmetric around its demarcation and although $LRCA_a^i$ fails to define zero export values, $SRCA_a^i$ will define them at the lower boundary of the index. Furthermore such a transformation attributes changes below unity the same weight as those above unity.

Although both $LRCA_a^i$ and $SRCA_a^i$ offer a symmetric index and hence equal deviations from their demarcations would indicate equally large comparative advantage or disadvantage, they still have a variable mean which may still obscure their cross-country and cross-temporal comparisons. To isolate the variation in countries' expected degree of specialisation from that of individual sectors, Proudman and Redding (1998; 2000) normalised the Balassa Index by its cross-sectional mean. That is,

$$WRCA_a^i = BRCA_a^i/\left[\frac{1}{A} \cdot \sum_{a=1}^{A} BRCA_a^i\right] \tag{4a}$$

which will range from *0* to $\left[\frac{A}{\sum_{a=1}^{A}\left(X_a^i/X_a^w\right)}\right]$[5]. The demarcation of the index is given by $\left(X_a^i/X_a^w\right) = \left(1/A\right)$ and hence equals to unity, while deviations in the index from unity will again indicate the relative comparative state. More precisely country i will have a comparative advantage in commodity

[4]As $\lim\limits_{X_t^i \to \infty}\left(X_t^w/X_t^i\right) = \infty$ and hence $\dfrac{\lim\limits_{X_t^i \to \infty}\left(X_t^w/X_t^i\right) - 1}{\lim\limits_{X_t^i \to \infty}\left(X_t^w/X_t^i\right) + 1} = 1$, while the effective bounds of the index would be at $\frac{\left(X_t^w/X_t^i\right)-1}{\left(X_t^w/X_t^i\right)+1} > SRCA_a^i > -1$ and similar to $LRCA_a^i$, $SRCA_a^i$ will also have an upper bound that varies across countries and for each country across time.

[5]Similar to $BRCA_a^i$, $WRCA_a^i$ also has a theoretical upper bound at ∞ as $\lim\limits_{X_t^i \to \infty}\left(X_t^w/X_t^i\right) = \infty$ while its effective upper bound is equal to that of $BRCA_a^i$ divided by its mean and is equal to $\left[\frac{A}{\sum_{a=1}^{A}\left(X_a^i/X_a^w\right)}\right]$, and hence will still vary across countries and for each country across time.

a if $\left[A/\sum_{a=1}^{A}(X_a^i/X_a^w)\right] > WRCA_a^i > 1$ or a comparative disadvantage if $1 > WRCA_a^i > 0$.

Although $WRCA_a^i$ is asymmetric around its demarcation, it has a stable mean which corresponds to the demarcation of the index. Thus the average commodity will be at the comparative-neutral state and for commodities whose export shares are more than the average commodity, the index will yield a comparative advantage while opposite will hold for commodities having a comparative disadvantage.

Even though having a fixed mean might be appealing for cross-temporal comparisons, achieving this by dismissing the overall country effects may not be plausible, as it will obscure the underlying country dynamics. Given the asymmetric nature of the index it is quite likely that it will also have a skewed distribution and giving too much importance on the first moment of such a distribution may not be appropriate (Mukherjee et al., 1998).

Furthermore, concerning the consistency of the index as a dichotomous measure, there is a serious drawback in normalising the Balassa Index with its cross-sectional mean. If $\mu_{BRCA} = 1$, then the commodities' comparative state given by $WRCA_a^i$ will correspond to those given by $BRCA_a^i$. However it is quite likely that $\mu_{BRCA} \neq 1$ and if e.g. $\mu_{BRCA} < 1$, then all commodities with Balassa Index $1 > BRCA_a^i > \mu_{BRCA}$ will be revealed to have a comparative advantage by $WRCA_a^i$ while the opposite will hold if $\mu_{BRCA} > 1$ (Benedictis & Tamberi, 2002). Thus there is a serious inconsistency concerning the interpretation of the index, which will be highly pronounced for commodities that have index values close to the mean of the distribution.

On the other hand the multiplicative nature of such indices were also argued as a cause of the associated inconsistencies. With that regard Hoen and Oosterhaven (2006) proposed an additive RCA index. That is,

$$ARCA_a^i = \frac{X_a^i}{X_t^i} - \frac{X_a^w}{X_t^w} \tag{5a}$$

where the index is equal to the difference of the share of a commodity within the total exports of the examined country and that of the world. The demarcation of the index is at *0* and positive deviations from this point would signify a comparative advantage for country i while negative deviations would suggest a comparative disadvantage. As the index is additive in commodities,

$\mu^i_{ARCA} = 0$, which would also mean that the average commodity will have a neutral comparative advantage similar to that of $WRCA^i_a$ but unlike the former index, $ARCA^i_a$ will correspond to the original index as a dichotomous measure.

The index has a lower bound at $-\frac{X^w_a}{X^w_t}$[6], corresponding to zero exports in commodity a for country i while it will have an upper bound at $\left(1 - \frac{X^{i=w}_a}{X^w_t}\right)$, which would correspond to an international monopoly in commodity a for country i. Thus both the upper and lower bound are now variable across industries and for each industry across time, which may obscure the temporal and cross-industry comparison of the index. Furthermore there is no consistent cardinal value for a country having no specialisation in a particular commodity or being fully specialised in that commodity, which should technically be at the lower and upper bounds of the index, respectively.

Similar to the multiplicative $BRCA^i_a$ index, $ARCA^i_a$ can also be derived in a similar fashion using Kunimato's (1977) probabilistic framework. Considering all the different alterations of the Balassa Index and the original index itself, they all have a consensus on the comparative-neutral state and that the deviations from the expected export level at this state are zero (Yu et al., 2009). Thus instead of calculating the deviations as shares, additive indices define them in absolute terms. However, because such an index will reveal the relative comparative state in absolute terms, it will be dependent on the size of the industry, country and year at hand. Thus it needs to be scaled down with an appropriate scaling factor. Considering equation (5a), $ARCA^i_a$ can be rewritten as,

$$ARCA^i_a = \frac{\left[X^i_a - E\left(X^i_a\right)\right]}{X^i_t} \tag{5b}$$

in which the deviations of country i's exports in commodity a from its expected level, which would correspond to the comparative-neutral level in a distortion free world, is scaled down by the total trade of country i.

Although the term in the brackets has an intuitive justification and can be consistent with $BRCA^i_a$ to an extent, because the scaling factor will change from country to country, the index will produce biased values, which would particularly affect cross-industry and cross-temporal comparisons. With regard to this inconsistency, Yu et al. (2009) derive a similar index but they normalise

[6] Although Hoen and Oosterhaven argue that the lower bound will be at *-1*, this will be the case if only commodity a was traded.

the term in brackets with the total level of world exports. That is,

$$NRCA_a^i = \frac{\left[X_a^i - E\left(X_a^i\right)\right]}{X_t^w} = \left(\frac{X_a^i}{X_a^w}\right) - \left(\frac{X_a^i \cdot X_a^w}{X_t^w \cdot X_t^w}\right) \tag{6a}$$

where the index measures the deviations of country i's exports in commodity a from its comparative-neutral levels scaled down by the total world exports. The demarcation of the index is at *0* and positive deviations from this point would signify a comparative advantage for country i while negative deviations would suggest a comparative disadvantage. As $NRCA_a^i$ is additive across both commodities and countries, level of aggregation in data has no influence on the measurement of comparative advantage and $\mu_{NRCA}^{i,a} = 0$, which corresponds to its demarcation.

While the theoretical upper and lower bounds of the index are fixed at *0.25* and -*0.25*, respectively[7] and hence the index will be symmetric around its demarcation, the effective bounds will be at $-\frac{X_a^{i=w}}{X_t^w} \cdot \left[1 - \frac{X_a^{i=w}}{X_t^w}\right]$ and $-\left[\frac{X_t^i \cdot X_a^w}{X_t^w \cdot X_t^w}\right]$ corresponding to an international monopoly and zero exports in commodity a for country i, respectively, indicating that both upper and lower bounds of the index vary across both industries and countries; and for each industry and country across time.

4 Precedence Among Alternative Measures of RCA

4.1 Theoretical Precedence

As emphasised, although the theoretical foundations of comparative advantage has been well established by Deardorff (1980), its measurement does not retain strong theoretical grounds. In fact, the independence of the measurement of comparative advantage from the underlying theory provided that certain degree of freedom for the subsequent researchers in altering the original Balassa Index. Nevertheless Kunimoto's (1977) probabilistic framework and Hillman's (1980) theoretical relation can be employed to denote the theoretical precedence among the alternative indices of RCA.

[7] *Quod vide* appendix in Yu et al. (2009).

4.1.1 Kunimoto's Probabilistic Framework

Kunimoto (1977) argues that within a hypothesised post-autarkic world where countries do not possess a comparative advantage, exports of a particular commodity would be distributed among countries in proportion to their shares in total world exports such that, each country's expected level of exports in that particular commodity would be the product of the share of that commodity within world trade and the country's total exports. Hence, in a distortion free world, the equivalence of the expected trade with the actual level of trade would indicate a neutral comparative advantage.

Furthermore the actual-to-expected trade ratio can be used to express the Balassa Index, which corresponds to comparative neutral state at its demarcation, the unity. Hence deviations of the Balassa Index above (below) unity would indicate a comparative advantage (disadvantage). Although this latter notion can be applied for all four multiplicative constructs of RCA, the additive indices define the relative comparative states in absolute terms instead of as shares, and hence positive (negative) deviations of the indices from the comparative neutral state, which was zero for the additive constructs, would indicate a comparative advantage (disadvantage). Furthermore, as the dimension of the deviations in actual-to-expected trade would be in absolute terms, they are scaled down to be comparable.

In light of such notion and dimensional inferences the indices allow, precedence among the alternative measures of RCA could be based on not only their degree of coherence across those dimensions; cross-industry, cross-country and cross-temporal dimensions, as the ideal measure should be unbiased hence be coherent across those dimensions; but also on their coherence in terms of being cardinal, ordinal and dichotomous measures.

Considering the construct of the multiplicative RCA measures, with the exception of $WRCA_a^i$[8], none of them pose any consistency issues and produce unbiased RCA values although each alteration corresponds to a different cardinal value. On the other hand, the proposed additive RCA indices are down scaled variants of absolute deviations in actual-to-expected trade. Hence the choice of the employed scaling factor would be crucial, as any inconsistency in that scaling factor regarding those dimensions, would bias the index.

[8]concerning the inconsistency arising as a dichotomous measure.

Considering this critique, none of the proposed additive RCA measures provide complete consistency. That is, scaling of absolute deviations in actual-to-expected trade with total trade of countries makes $ARCA_a^i$ inconsistent across industries and time whereas using total world trade as the scaling factor, makes $NRCA_a^i$ inconsistent across countries and industries.

4.1.2 Monotonicity of RCA Indices

By assuming identical homothetic preferences among the reference countries, Hillman (1980) derived a necessary and sufficient condition for the consistency between RCA identified by the Balassa Index and relative autarkic prices, in cross-country industry comparisons. Although as Hillman notes,"whether this condition obtains is a matter for empirical investigation", it may only be employed for other subsequent normalised multiplicative indices, while it may not be employed for the proposed additive RCA indices.

Thus following Hillman, Bebek (2011) derived similar monotonicity conditions for the additive RCA measures proposed by Hoen and Oosterhaven (2006) and Yu et al. (2009), where it is argued that monotonicity conditions for the additive indices will hold as long as the indices are positive hence reveal a comparative advantage whereas the indices revealing a comparative disadvantage will always violate such monotonicity conditions, which creates an ambiguity in using them.

Considering Kunimoto's probabilistic framework and Hillman's condition, the multiplicative constructs of RCA seem to precede the additive constructs of RCA. Nevertheless such notion based on criteria that are either conditional on strict identical homothetic preferences assumption in two-country-two goods setting or distortion-free trade space assumption, may not allow for an absolute preference of one RCA measure over another.

4.2 Statistical Precedence

The inconsistency of the Balassa Index in measuring comparative advantage has been well examined by both theoretical and empirical studies. Furthermore many of the alternative RCA indices indeed are developed to address the measuring bias of the Balassa Index and some of the desirable statistical properties of those alternative indices are resulted from the nature of that the alternative indices

Table 1: RCA Indices and Their Statistical Properties

Index	Effective Bounds and Demarcation	Mean
$BRCA_a^i$	$\frac{X_t^w}{X_t^i} > BRCA_a^i > 1$, 1	Variable Mean
$LRCA_a^i$	$\ln\left(X_t^w / X_t^i\right) > LRCA_a^i > -\infty$, 0	Variable Mean
$SRCA_a^i$	$\frac{\left(X_t^w / X_t^i\right)-1}{\left(X_t^w / X_t^i\right)+1} > SRCA_a^i > -1$, 0	Variable Mean
$WRCA_a^i$	$\left[\frac{A}{\sum_{a=1}^{A}(X_a^i / X_a^w)}\right] > WRCA_a^i > 0$, 1	Fixed Mean Across Countries at 1
$ARCA_a^i$	$\left(1 - \frac{X_a^{i=w}}{X_t^w}\right) > ARCA_a^i > -\frac{X_a^w}{X_t^w}$, 0	Fixed Mean Across Countries at 0
$NRCA_a^i$	$-\frac{X_a^{i=w}}{X_t^w} \cdot \left[1 - \frac{X_a^{i=w}}{X_t^w}\right] > NRCA_a^i > -\left[\frac{X_t^i \cdot X_a^w}{X_t^w \cdot X_t^w}\right]$, 0	Fixed Mean Across Countries & Industries at 1

mitigate the bias in the original index. Nevertheless proposed alternatives, while mitigating certain biases, introduce further ones that impede the index's consistency.

Considering the previous arguments on the sources of the inconsistencies, these can be grouped into four headings; the Balassa Index has a variable upper bound and a mean that vary across countries and for each country across time; the index has an asymmetric distribution that is skewed to the right; the demarcation of the index is also asymmetric leaving the relative weight attached to the specialised industries unrestrained compared to the unspecialised sectors; and the interpretation of the index is obscured due to the compositional affect of two unique components. Thus, the desired statistical properties intuitively should include having; fixed effective bounds; a stationary mean; a symmetric distribution with a symmetric demarcation and lastly a clear and unique interpretation of the index value. In order to compare the alternative measures with the Balassa Index, key statistical properties of the indices are outlined in table 1.

Although RCA analyses based on indices like the Balassa Index were argued to be conditional on the relative position of countries and industries within the chosen reference benchmark, the inherent properties of the data would only mitigate the observed biases that result from the properties of the individual indices and not completely eliminate them. Thus, the rationale for the statistical precedence is based on these properties rather than results that are conditional on a certain data.

4.2.1 Fixed Effective Bounds

For a robust comparison of RCA index values across industries, countries or time, the relative position of that index value within the index's range should be consistent. Thus the effective bounds of the indices should be finite and do not vary across industries, countries or time. All multiplicative RCA indices including the Balassa Index have a fixed lower boundary while suffering from an upper boundary that varies across countries and time. Hence neither cross-country nor cross-temporal comparison of these indices will be robust. This bias would particularly affect comparisons involving specialised industries, which do fall within the upper boundary and demarcation of the relevant index.

As for the two recently proposed additive indices, they both suffer from variable upper and lower bounds. Although the construct of $ARCA_a^i$ resolves the variability of the upper bound across countries, it introduces variation conditional on industries in both upper and lower bounds as well as variation conditional on time. Hence neither cross-industry nor cross-temporal comparison of this index would be robust. Furthermore, unlike the multiplicative constructs, the bias is pronounced regardless of the comparative state of the examined industries. On the other hand both the upper and lower bounds of $NRCA_a^i$ suffer from variability across countries, industries and time and hence neither cross-country, cross-industry nor cross temporal comparisons of the index would be robust and the bias is pronounced for both specialised and unspecialised RCA values.

4.2.2 Mean Stationarity

Hoen and Oosterhaven (2006) argue that for a robust comparison of RCA indices, the expected value of the comparative neutral sector should be identical across space and time. Thus the proposed index should have a stable mean. Furthermore, they suggest that the average industry should not have a comparative advantage or disadvantage because countries cannot be specialised vis-à-vis comparative advantage in each industry. Considering this notion, a stationary mean around the demarcation of the index not only suffices a robust comparison but also allows a sound economic interpretation.

With the exception of $WRCA_a^i$, all multiplicative RCA indices have means that vary across countries and time whereas the former index has a mean that is stationary around its demarcation across countries. As for the additive constructs of RCA, $ARCA_a^i$ has a mean that is stationary around its demarcation across countries whereas $NRCA_a^i$ has a mean that is stationary across both countries and industries. Thus none of the proposed measures of RCA allow a consistent comparison robust to the three dimensions the indices evolve around.

When the extent of variability in proposed indices' means and effective bounds are considered together, it can be observed that correcting either of the biases leads a bias in the non-altered property and that neither of the proposed alterations allow an unbiased index that would allow for a robust comparison across time and space. This notion is not particularly novel considering that these indices are volume-based measures of comparative advantage and hence their distribution is likely to change across time and space.

4.2.3 Symmetry of the Index and its Demarcation

When the symmetry of the indices are considered, one could assess the relative position of the demarcation to the theoretical bounds at their limits while bearing in mind that such a notion would not be precise as the actual symmetry would be conditional on the employed countries unless the index by construct has fixed bounds. With the exception of the Balassa Index and $WRCA_a^i$, all the proposed measures of RCA are theoretically symmetric around their demarcation, while these two indices are highly skewed to the right.

As for the symmetry of the demarcation in terms of the relative weight attached to the specialised sectors and unspecialised sectors, the Balassa Index and $WRCA_a^i$ suffer from unrestrained weights attached to specialised sectors compared to unspecialised sectors. That is, both indices are heavy on their denominators and exhibit disproportionate scaling. For an algebraic demonstration, the geometric appraisal of intra-industry trade in Azhar and Elliot (2006) can be employed. Following their methodology, equation (1a) is rewritten as

$$BRCA_a^i = f(r, R) = r/R \text{ where } r = \left(X_a^i/X_t^i\right) \text{ and } R = \left(X_a^w/X_t^w\right). \tag{1b}$$

To find whether the scaling is proportionate or disproportionate the rate of change in $BRCA_a^i$

with respect to both r and R will be calculated at their limits. Hence

$$\lim_{r\to 0} \frac{\partial f(r,R)}{\partial r} = \lim_{r\to 0} \frac{1}{R} = \frac{1}{R} \quad \text{and} \tag{1c}$$

$$\lim_{R\to 0} \frac{\partial f(r,R)}{\partial R} = \lim_{R\to 0} -\frac{r}{R^2} = -\infty. \tag{1d}$$

These partials verify that the change in the Balassa Index with respect to the change in industry a's share in country i (r) is not similar to the change in the index with respect to the change in industry a's share in the whole world (R). Hence the Balassa Index exhibits a disproportionate scaling. As for $LRCA_a^i$[9],

$$\lim_{r\to 0} \frac{\partial f(r,R)}{\partial r} = \lim_{r\to 0} \frac{1}{r} = \infty \quad \text{and} \tag{2b}$$

$$\lim_{R\to 0} \frac{\partial f(r,R)}{\partial R} = \lim_{R\to 0} -\frac{1}{R} = -\infty. \tag{2c}$$

Hence the change in $LRCA_a^i$ with respect to the change in industry a's share in country i (r) is similar but in opposite direction to the change in the index with respect to the change in industry a's share in the whole world (R) and the index exhibits a proportionate scaling. As for $SRCA_a^i$[10],

$$\lim_{r\to 0} \frac{\partial f(r,R)}{\partial r} = \lim_{r\to 0} \frac{2R}{r+R^2} = \frac{2}{R} \quad \text{and} \tag{3b}$$

$$\lim_{R\to 0} \frac{\partial f(r,R)}{\partial R} = \lim_{R\to 0} -\frac{2r}{r+R^2} = -\frac{2}{r}. \tag{3c}$$

Hence similar to the previous index, the change in $SRCA_a^i$ with respect to the change in industry a's share in country i (r) is similar but in opposite direction to the change in the index with respect to the change in industry a's share in the whole world (R) and the index exhibits a proportionate scaling. As for $WRCA_a^i$[11],

$$\lim_{r\to 0} \frac{\partial f(r,R)}{\partial r} = \lim_{r\to 0} \frac{1}{\bar{C}} \cdot \frac{1}{R} = \frac{1}{\bar{C}} \cdot \frac{1}{R} \quad \text{and} \tag{4b}$$

[9] where $LRCA_a^i = f(r,R) = ln(r/R)$.

[10] where $SRCA_a^i = f(r,R) = \frac{r-R}{r+R}$.

[11] where $WRCA_a^i = f(r,R) = \frac{r}{R} \cdot \frac{1}{\bar{C}}$.

$$\lim_{R \to 0} \frac{\partial f(r,R)}{\partial R} = \lim_{R \to 0} -\frac{1}{\bar{C}} \cdot \frac{r}{R^2} = -\infty. \tag{4c}$$

Similar to the Balassa Index, the change in $WRCA_a^i$ with respect to the change in industry a's share in country i (r) is not similar to the change in the index with respect to the change in industry a's share in the whole world (R). Hence the index exhibits a disproportionate scaling. As for $ARCA_a^i$[12],

$$\lim_{r \to 0} \frac{\partial f(r,R)}{\partial r} = \lim_{r \to 0} 1 = 1 \quad \text{and} \tag{5c}$$

$$\lim_{R \to 0} \frac{\partial f(r,R)}{\partial R} = \lim_{R \to 0} -1 = -1. \tag{5d}$$

Hence the change in $ARCA_a^i$ with respect to the change in industry a's share in country i (r) is similar but in opposite direction to the change in the index with respect to the change in industry a's share in the whole world (R) and hence the index exhibits a proportionate scaling. As for $NRCA_a^i$[13],

$$\lim_{r \to 0} \frac{\partial f(r,R)}{\partial r} = \lim_{r \to 0} \frac{X_t^i}{X_t^w} = \frac{X_t^i}{X_t^w} \quad \text{and} \tag{6b}$$

$$\lim_{R \to 0} \frac{\partial f(r,R)}{\partial R} = \lim_{R \to 0} -\frac{X_t^i}{X_t^w} = -\frac{X_t^i}{X_t^w}. \tag{6c}$$

Hence similar to $ARCA_a^i$, the change in $NRCA_a^i$ with respect to the change in industry a's share in country i (r) is similar but in opposite direction to the change in the index with respect to the change in industry a's share in the whole world (R) and hence the index exhibits a proportionate scaling.

4.2.4 Uniqueness of the Index Value

The last property emphasised for the ideal RCA index was the uniqueness of the index value. As mentioned before, the informational content of the Balassa Index was conditional on two simultaneous but separate factors and due to the multiplicative construct of the index, higher or lower index values can be associated to the industrys export share in the country or its export share in

[12] where $ARCA_a^i = f(r,R) = r - R$.
[13] where $NRCA_a^i = f(r,R) = (r - R) \cdot (X_t^i / X_t^w)$

world or to both, namely the numerator and the denominator of the index as indicated by equation (1b)[14].

Considering the construction of the proposed RCA indices, higher or lower values of the index could indeed be associated to either the industry's export share in the country or its export share in world or to both. Thus none of the index values are unique in that sense. However the Balassa index also suffers from the fact that, changes in either industry's export share in the country or its export share in world does not correspond to a unique change in the index value.

In the case of a small and a large country, if the countries' exports in a particular industry increase by the same ratio, the change in the RCA of the small country as indicated by the Balassa Index would be equal to that of the large country. Put it differently; to have an equal change in the countries' relative RCA as indicated by the Balassa Index, the large country should have a much larger change in its export volume compared to that of the small country. Hence the economic interpretation of a relative change in countries' RCA as indicated by Balassa Index values would not be explicit. To asses the extent of this bias, the geometrical relationship between industry a's share in country i (r) and industry as share in the whole world (R) can be examined. Following Azhar and Elliott (2008) and considering equation (1b),

$$r = BRCA_a^i \cdot R \tag{1e}$$

which shows that for every $BRCA_a^i$ index, there is a unique straight line with a slope of $BRCA_a^i$ and y-intercept of *0* implying that the $BRCA_a^i$ value will be the same for every point (R,r) on the same line. However it is important to note that the slopes of these lines are conditional on the index value and hence any change in R would correspond to a different change in r along different Equi-Balassa[15] lines. As for the other three multiplicative RCA indices, a similar outcome emerges. Using the same approach, the following geometric relationships can be constructed for those indices.

[14] The previous comment on the ambiguity in the informational content of the Balassa Index was based on its construct as indicated by equation (1a). That is higher or lower values of the index were argued to be associated to the industrys export share or to the countrys overall export share in world or to both, namely the numerator and the denominator of the index. Although equations (1a) and (1b) would correspond to the same outcome, the economic interpretation of these fractions differs of which the latter corresponds to the additive constructs of RCA and that the deviations from the expected export level at comparative-neutral state are zero.

[15] on which the Balassa Index values are constant.

That is;

$$r = e^{LRCA_a^i} \cdot R, \tag{2d}$$

$$r = \frac{\left(1 + SRCA_a^i\right)}{\left(1 - SRCA_a^i\right)} \cdot R \text{ and} \tag{3d}$$

$$r = \frac{WRCA_a^i}{\bar{C}} \cdot R. \tag{4d}$$

Similar to the Balassa Index, for every $LRCA_a^i$, $SRCA_a^i$ and $WRCA_a^i$ index, there is a unique straight line with slopes conditional on the index value and y-intercept of *0*, implying that the index values will be the same for every point (R,r) on the same line. Nevertheless any change in R would correspond to a different change in r along different Equi-RCA[16] lines. As for the proposed additive RCA indices, a totally different outcome emerges. The following geometric relationships can be constructed for the additive indices.

$$r = R + ARCA_a^i \text{ and} \tag{5e}$$

$$r = R + NRCA_a^i \cdot \left(\frac{X_t^w}{X_t^i}\right). \tag{6d}$$

Hence for every $ARCA_a^i$ and $NRCA_a^i$, there is a unique straight line with a slope of unity and y-intercept conditional on the index value implying that the index values will be the same for every point (R,r) on the same line[17]. Furthermore changes in R will be matched by an equal change in r along different Equi-RCA lines. Hence unlike the multiplicative constructs of RCA, additive constructs of RCA would not aggravate the associated change in the RCA index due to a change in a country's exports in an industry conditional on the size of the country. Considering the case of the small and large countries, if the countries' exports in a particular industry increase by the same ratio, the change in the RCA of the small country as indicated by the additive RCA indices would

[16] on which the RCA index values are constant.
[17] As neither X_t^i nor X_t^w change across countries.

not be aggravated and will be less than that of the large country and hence to have an equal change in the countries' relative RCA as indicated by the additive indices, the large country should have a relatively smaller change in its export volume compared to that of the small country. Hence the additive indices mitigate this bias, which results from the multiplicative construct of the Balassa Index.

Considering the four argued properties that the ideal RCA index should have, none of the proposed indices including the Balassa Index meet such criteria. Furthermore the alterations for correcting certain biases in the original index generate further biases that still prevent robust comparison using the indices. Hence, one cannot generalise a statistical precedence among the proposed measures of RCA that is not conditional on the employed data.

4.3 An Empirical Approach for Precedence

Considering the arguments put forward with regard to the theoretical and statistical precedence among the proposed measures of RCA, none of them provide very strong substantiation that would designate any of the proposed measures as the ideal. Instead, they constitute guidelines and a framework, which may be then used to prioritise the applicability of the proposed indices. As these would be conditional on certain assumptions or objectives, one may not be able to argue for an absolute factuality. And since there is no clear hierarchy in the desired properties or the underlying assumptions, neither the assessment of theoretical precedence nor the statistical precedence allow a benchmark. On the other hand, an empirical assessment on the extent of mitigation that each proposed index allows may provide such a benchmark.

Although the proponents of the various measures of RCA do provide empirical evidence, their methods are limited to the assessment of the distribution of the index rather than the investigation of the extent of mitigation in the related biases. As mentioned before, the proposed alterations generate further biases while reducing or eliminating others. Thus it would not be very irrational to choose an inherent bias existing within the RCA framework that has not been directly targeted by the proponents of the alternative RCA measures as a benchmark, such as the skewness or the upper bound variability of the Balassa Index. Hence instead of concentrating on biases that are generated due to the structures of the indices, biases resulting from the informational content of the indices that are not directly related to the indices' structures can be investigated to formalise an unconditional benchmark.

Yeats (1985) argued that the traditional country-industry approach to RCA analysis fails to identify the leading industries, based on his findings of insignificant rank correlations between ordered Balassa Index values and the positions of the corresponding industries in the relevant country's industry distribution. Furthermore only one industry in his sample complied a perfect ordering and Yeats asserted that previous findings based on traditional RCA analysis could be challenged given this imprecise ordinal measurement of comparative advantage. On the other hand Laursen (1998) argues that Yeats had overestimated the problem and suggested a higher level of significance for the calculated rank correlations. Nevertheless, Yeats' critique on the informational content of the Balassa Index and hence the related bias in the ordinal measurement of comparative advantage could be assessed for the proposed measures of RCA, which would then may constitute an unconditional[18] benchmark for precedence among the proposed indices.

4.3.1 Methodology and Employed Data

While deriving the relevant RCA indices, they were shown to be normalised with the total world trade allowing for the assessment of global comparative advantage, whereas such an empirical pursuit may not yield sound results as the countries therein will be quite heterogeneous regarding the market conditions that their trading partners face. Thus instead of taking the world as a whole, as the reference countries, EU15[19] countries will be employed, as they are rather homogenous concerning the distortions that their exports face as well as the competition policies applied. As for the destination, EU15 countries' exports to the whole world will be considered, as choosing a particular country or group of countries may bias the results. As for exports, only those of manufacturing industries will be considered. For trade data, OECD's STAN Bilateral Trade Database will be employed. It uses ISIC Rev. 3 classification covering 22 industries at the lowest level of aggregation yielding 6,248 observations for the period between 1989 and 2008.

Similar to Yeats and Laursen, rank correlations between industries' ordered RCA values and

[18] Although such an analysis will be conditional on the employed data, the emphasis here is on the bias not being directly conditional on the structure of the index.

[19] These are, Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, United Kingdom.

Table 2: Rank Correlations for the Pooled Sample

Sample	$BRCA_a^i$	$WRCA_a^i$	$ARCA_a^i$	$NRCA_a^i$
Pooled Sample	0.823	0.811	0.776	0.773
Average Across Industries	0.856	0.841	0.799	0.813
Average Across Countries	0.845	0.849	0.788	0.769
Average Across Years	0.826	0.813	0.777	0.776

All calculated rank correlations are significant at 0.01.

their positions within their corresponding country's distributions will be calculated for both the multiplicative and additive indices. However as most indices' RCA orderings correspond, the rank correlations will be calculated for only, $BRCA_a^i$, $WRCA_a^i$, $ARCA_a^i$ and $NRCA_a^i$[20]. Given the dimensions of the data, the rank correlations will first be calculated for the pooled sample, then across industries and countries for the pooled sample and lastly across industries and countries for each year. This way not only the overall performance of the indices can be assessed but also to what extent they mitigate the bias due to their structural form can be examined.

4.3.2 Empirical Results

Table 2 summarises the rank correlations for the pooled sample. The second row of table 2 indicates rank correlations for the indices for the whole sample. Similar to Laursen's finding (*0.80*), rank correlations for the pooled sample are high particularly for the multiplicative indices compared to the additive ones. Furthermore the original Balassa Index and the corresponding indices show the highest correlations and hence perform better. Considering the third row of table 2, the average rank correlations across industries for the pooled sample again reveal similar results. The original Balassa Index and the corresponding indices obtain the highest rank correlations and the multiplicative indices again show higher correlations compared to the additive indices. As for cross-country rank correlations, estimated spearman correlations are summarised in row four of table two.

Similar to the previous analysis, multiplicative RCA indices again obtain higher rank correlations compared to their additive counterparts, yet unlike cross-industry analysis, $BRCA_a^i$ and $NRCA_a^i$ obtain lower correlations than $WRCA_a^i$ and $ARCA_a^i$, respectively. These outcomes are

[20]As ordering of $BRCA_a^i$ corresponds to that of $LRCA_a^i$ and $SRCA_a^i$.

not surprising considering that $WRCA_a^i$ is a normalised variant of $BRCA_a^i$, with its cross-sectional mean, whereas the scaling factor employed in $ARCA_a^i$ was consistent across countries, while the scaling factor employed in $NRCA_a^i$ was consistent across industries.

The average rank correlations across years for the pooled sample are presented in the fifth row of table 2. Similar to the previous analyses, multiplicative RCA indices again obtain higher rank correlations compared to their additive counterparts. While $BRCA_a^i$ obtains higher correlations compared to $WRCA_a^i$, similar to the cross-industry analysis, $ARCA_a^i$ and $NRCA_a^i$ obtain close rank correlations. Analogous to the previous argument, $WRCA_a^i$ obtains lower rank correlations across years, as it normalises $BRCA_a^i$ with its cross-sectional mean. On the other hand, since the scaling factors employed in both additive indices are not consistent across years, they obtain close rank correlations that are lower than their multiplicative counterparts.

Lastly, the rank correlations are calculated for individual years across industries and countries, for which table 3 presents the summary percentages of rank correlations across industries.The first five rows of table 3 present the percentage of rank correlations (ρ) above the indicated levels while the last four rows present the percentage of rank correlations (ρ) at the critical significance levels. When the shares of ρ values above the critical levels are calculated, the original Balassa Index and the corresponding indices obtain the highest shares, while the multiplicative indices on general obtain higher shares compared to the additive indices. Furthermore the percentages of ρ values that are significant at high confidence levels are much higher for the multiplicative indices. Corresponding to the previous arguments on the construct of the individual RCA indices, $BRCA_a^i$ and $NRCA_a^i$ on average obtain higher shares in terms of the level of significance compared to $WRCA_a^i$ and $ARCA_a^i$, respectively.

Table 4 presents the summary percentages for rank correlations across countries. Similar to cross-industry analysis, when the shares of ρ values above the critical levels are calculated, the multiplicative RCA indices again obtain higher shares compared to the additive indices. Yet unlike cross-industry analysis, all the rank correlations calculated for both multiplicative indices as well as $ARCA_a^i$ are statistically significant at 1 per cent level, while the significance levels of ρ values for $NRCA_a^i$, on average, decreased. These outcomes can be explained by the previous arguments on the construct of the indices that; $WRCA_a^i$ is a normalised variant of $BRCA_a^i$, with its cross-

Table 3: Summary Percentages of Rank Correlations of Individual Years Across Industries

Percentages	$BRCA_a^i$	$WRCA_a^i$	$ARCA_a^i$	$NRCA_a^i$
$\rho > 0.95$	14.77	8.86	12.73	4.32
$\rho > 0.90$	45.23	39.32	34.55	30.68
$\rho > 0.85$	64.32	59.32	53.18	55.91
$\rho > 0.80$	77.73	72.95	64.55	72.73
$\rho > 0.75$	84.55	82.27	77.27	81.36
Significant at 0.01	96.36	93.87	89.54	91.82
Significant at 0.05	2.73	5.45	3.41	4.09
Significant at 0.10	0.23	0.00	1.14	0.91
Insignificant	0.68	0.68	5.91	3.18

Table 4: Summary Percentages of Rank Correlations of Individual Years Across Countries

Percentages	$BRCA_a^i$	$WRCA_a^i$	$ARCA_a^i$	$NRCA_a^i$
$\rho > 0.95$	3.17	1.76	0.35	1.41
$\rho > 0.90$	29.93	30.99	8.1	23.59
$\rho > 0.85$	65.49	65.14	27.46	52.11
$\rho > 0.80$	81.34	80.63	54.23	63.73
$\rho > 0.75$	91.55	91.9	74.3	72.89
Significant at 0.01	100.00	100.00	100.00	90.85
Significant at 0.05	0.00	0.00	0.00	3.52
Significant at 0.10	0.00	0.00	0.00	1.76
Insignificant	0.00	0.00	0.00	3.87

sectional mean, whereas the scaling factor employed in $ARCA_a^i$ was consistent across countries, while the scaling factor employed in $NRCA_a^i$ was consistent across industries. Nevertheless, apart from the level of significance, the associated biases and resulting differences in the shares of higher shares prevail themselves for rank correlations below 0.80 as indicated by the fifth row of table 4.

Similar to Yeats' (1985) findings, this analysis confirms that neither of the proposed RCA indices, including the original Balassa Index, provide a perfectly consistent ordering of industries and that the traditional approach to RCA analysis may fail to flag leading industries for countries. However unlike Yeats' analysis, the statistical significance of the calculated ρ values are quite high for both cross-industry and cross-country analysis as well as cross-temporal analysis, particularly for the multiplicative indices. Furthermore the correlations for the multiplicative indices, although not perfect, are higher compared to their additive counterparts. As the multiplicative indices, particularly the original Balassa Index and the corresponding indices, perform much better while being statistically more significant compared to their additive counterparts, they can be argued to be more consistent and hence more appropriate to be employed in RCA analysis.

5 Conclusion

Although the Balassa Index has vague theoretical foundations, its suggestive rather than deductive nature can be a useful tool in addressing policy options for industries or countries. Yet one has to be cautious on their implications as the employed reference industries, countries and the level of aggregation in the export flows may bias the results. Furthermore, those implications would not only depend on the employed data but would also depend on the employed measure itself, as RCA measures are volume-based indices.

Given such issues, the general use of such indices for drawing pedantic conclusions may not be rational. Yet this does not hinder their use in providing a benchmark with some inherent degree of oversight. This paper provides a critical assessment of the Balassa Index and the proposed alternative measures of RCA that have been widely used in empirical trade literature. Furthermore, unlike the foregoing literature, precedence among the alternative measures of RCA is investigated considering the indices' theoretical, statistical and empirical superiority in order to signify the ideal measure of RCA.

Considering theoretical precedence, the additive RCA indices are argued to violate relevant monotonicity conditions unless they reveal a comparative advantage, which makes their appropriateness and applicability to be more ambiguous. As for statistical precedence, none of the proposed indices including the Balassa Index meet the argued criteria. Furthermore the alterations for correcting certain biases in the original index generate further biases that still prevent robust comparison of the indices. Hence, statistical precedence among the proposed measures of RCA that is not conditional on the employed data may not be extrapolated.

As neither the theoretical nor the statistical precedence among the alternative measures of RCA provide strong arguments for an ideal index, an empirical approach for precedence is pursued considering a bias resulting from the informational content of the indices that is not directly related to the indices' structures. That is, Yeats' (1985) critique on the informational content of the Balassa

Index and hence the related bias in the ordinal measurement of comparative advantage is assessed for the proposed measures of RCA. The results suggest that the additive indices fail to flag the leading industries of countries at significant levels. On the other hand, the Balassa Index and the two corresponding multiplicative normalisations, performs much better while being statistically more significant compared to their additive counterparts and hence are argued to be more consistent and more appropriate to be employed in RCA analysis.

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