İzmir İktisat Dergisi
İzmir Journal of Economics

E-ISSN: 1308-8505 **Year:** 2026 **Vol:** 41 **No:** 1 **Pages:** 230-263
Received: 21.01.2025 **Accepted:** 25.08.2025 **Published Online:** 06.03.2026 **Doi:** 10.24988/ije.1624210
RESEARCH ARTICLE

A New Approach to Purchasing Power: Discounted Gross Domestic Product Per Capita

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Abstract

This study presents a new approach to eliminate the large gap between GDP per capita calculated according to purchasing power parity and GDP per capita calculated by other methods. With this approach, inflation and exchange rate-driven changes in the purchasing power of countries are taken into account, and thus, the purchasing power losses in countries can be tracked through GDP per capita. In this way, the calculation based on purchasing power parity is discounted, and the potential differences between the real GDP per capita and the GDP per capita calculated according to PPP are reduced.

Keywords: *Purchasing Power Parity, GDP Per Capita, Discounted GDP Per Capita.*
Jel Codes: *E01*

Satın Alma Gücüne Yeni Bir Yaklaşım: İndirgenmiş Kişi Başı Gayri Safi Yurtiçi Hasıla

Özet

Bu çalışma, satın alma gücü paritesine göre hesaplanan kişi başı GSYH ile diğer yöntemlerle hesaplanan kişi başı GSYH arasındaki büyük farkı ortadan kaldırmak için yeni bir yaklaşım sunmaktadır. Bu yaklaşım ile ülkelerin satın alma gücündeki enflasyon ve döviz kuru kaynaklı değişimler dikkate alınmakta ve böylece ülkelerdeki satın alma gücü kayıpları kişi başı GSYH üzerinden takip edilebilmektedir. Bu sayede satın alma gücü paritesine göre yapılan hesaplama indirgenmekte ve kişi başı reel GSYH ile SAGP'ye göre hesaplanan kişi başı GSYH arasındaki olası farklar azaltılmaktadır.

Anahtar kelimeler: *Satın Alma Gücü Paritesi, Kişi Başı GSYH, İndirgenmiş Kişi Başı GSYH.*
Jel Kodu: *E01*

CITE (APA): Gerede, C. (2026). A New Approach to Purchasing Power: Discounted Gross Domestic Product Per Capita. *İzmir İktisat Dergisi*. 41(1). 230-263. Doi: 10.24988/ije.1624210

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1. INTRODUCTION

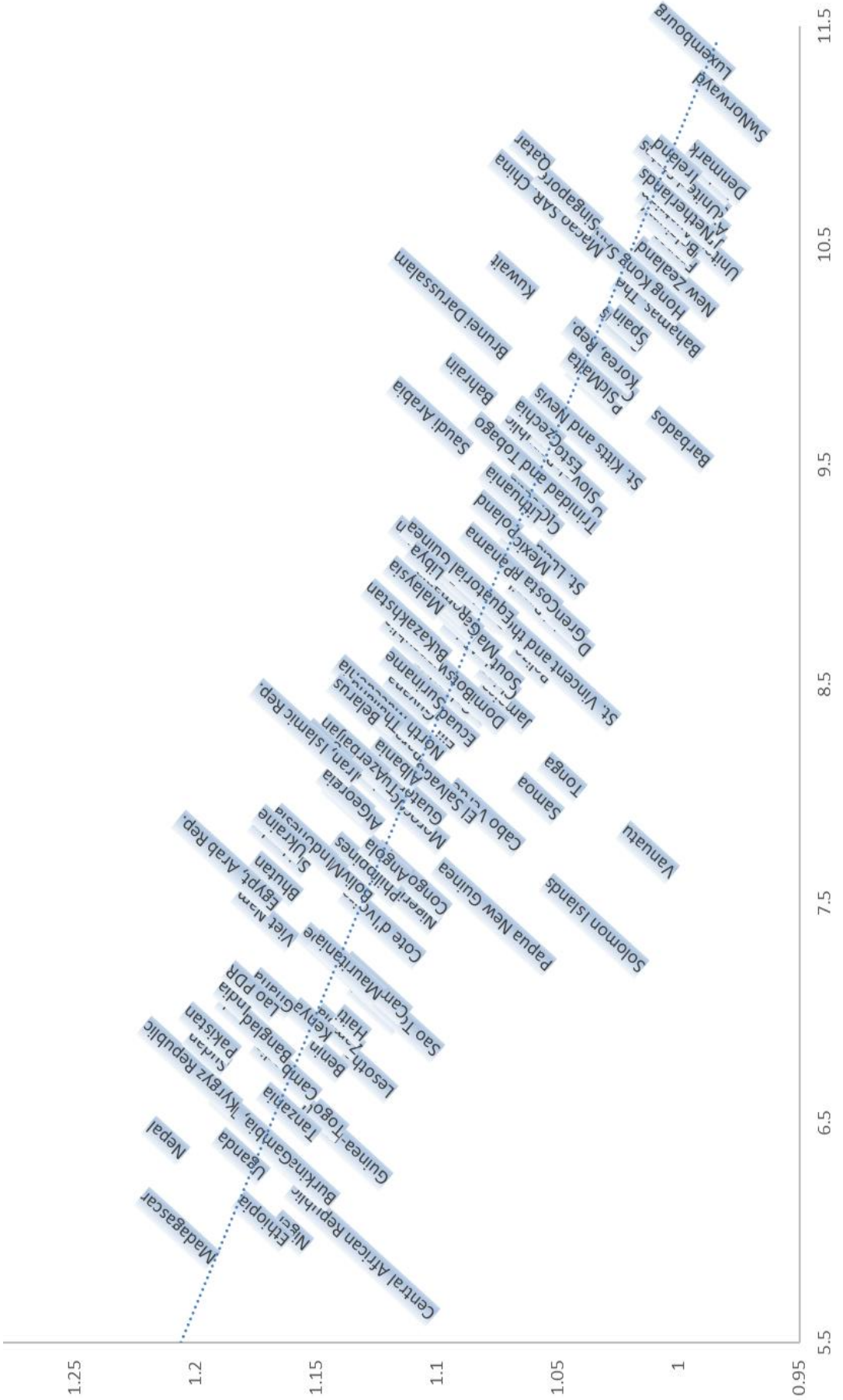
Many international organizations, such as the World Bank, calculate and publish the per capita national income of countries. The data published by these organizations present different results in terms of national income per capita. For example, Türkiye's GDP per capita in USD terms (hereafter referred to as GDPpc) for the year 2023 is USD 12985, while its GDP per capita in Purchasing Power Parity (PPP) terms (hereafter referred to as GDPpc PPP) is USD 44151, which is approximately 3.5 times higher. This huge difference is due to the difference in the way of calculation. Such a large difference suggests that one of the two types of calculation is far from reality.

An examination of the data for various countries reveals that the countries where the difference between GDPpc and GDPpc PPP is large are generally low-income countries. In other words, as the income of countries increases (decreases), the difference between GDPpc and GDPpc PPP decreases (increases). Graph 1 below shows the difference between the GDP per capita of low-income and high-income countries more clearly. The x-axis (horizontal) of the graph shows the logarithm of the average GDPpc of countries for the period 1995-2023, while the y-axis (vertical) shows the average GDPpc PPP value divided by the average GDPpc.

Graph 1 shows that the difference between GDPpc PPP and GDPpc is highest in poor countries such as Madagascar (average GDPpc $410), Ethiopia ($424), Nepal ($613), and Togo ($672) and lowest in rich countries such as Luxembourg ($91130), Qatar ($55196), USA ($48998), Australia ($42546). The main reason for this gap between rich and poor countries is not the problem in GDPpc calculation but the problem in GDPpc PPP calculation. The aim of this study is to develop an alternative calculation method to solve this problem and to weaken the illusion created by the GDPpc PPP indicator that makes poor countries look richer than they are.

In this paper, a new approach is presented to ensure that GDP per capita calculated according to PPP yields more accurate results and converges to GDP per capita in dollar terms. With this new approach, an empirical and practical correction tool for the deviations of the existing PPP-based per capita income indicator is presented. In this context, the second section briefly presents existing literature on alternative measures of GDP and per capita GDP, while the third section describes the Law of One Price (LOP) and Purchasing Power Parity (PPP). The fourth section provides the theoretical background of the new approach, and the fifth section presents the data about countries according to the new approach through graphs, tables, and some statistical methods. The sixth section gives robustness check, and the study is concluded with the final section, conclusions and recommendations.

Graph 1: The Relationship between GDPpc PPP to GDPpc Ratios of Countries and GDPpc Averages



Source: Calculated from World Bank data.

2. LITERATURE ON ALTERNATIVE MEASURES OF GDP AND PER CAPITA GDP

GDP per capita is generally used to indicate the welfare level of countries. In addition to that, economists employ many different measures to calculate the welfare level. These measures include life expectancy at birth, infant mortality rate, calorie intake, access to clean water, adult literacy rate, schooling rate, income distribution, number of beds per capita in hospitals, and many other concepts. A particularly popular approach to improve GDP measures of growth has been the use of a weighted average of various alternative measures of human well-being. Typical of this approach is the well-known Human Development Index (HDI), published annually by the United Nations Development Program (UNDP). HDI is a weighted average of real GDP per capita, a measure of health, and a measure of education (Van der Berg, 2002). The index defines human development as the "process of enlarging people's choices to live a long and healthy life, to be educated, to have access to resources needed for a decent standard of living, to have political freedom, guaranteed human rights, and personal self-respect", but in the end, these components cannot be easily quantified. That's why longevity, knowledge and decent living standards are chosen as proxies for human development (Costanza et al., 2009).

A better measure of individual human welfare would be the average annual GDP per capita multiplied by the average life expectancy that the country provides to its citizens. The same point applies to many alternative measures of well-being based on point-in-time aggregates or annual flows. Assuming that education is a better measure of well-being, the impact of education on human welfare depends on how long it is benefited from. If health or economic freedom are important for measuring human welfare, we should adjust these measures to a lifetime in which the average person experiences health or economic freedom. (Van der Berg, 2002). For this reason, Frank Lichtenberg (1998) introduced such a new measure, which he denotes as $Y_L = (Y_A)(E)$, where Y_L is expected per capita, Y_A is average annual GDP per capita, and E is life expectancy. According to this measure, lifetime expected per capita GDP is the multiplication of average annual GDP per capita with the life expectancy. In this way, lifelong expected GDP per capita can be calculated. However, this approach does not yield annual results. In other words, it is not possible to measure the GDP per capita or wealth of an average person in a country in a certain year. Although this measure is a good measure of the cumulative wealth of an average person, it is weak in terms of generating time series and computing the wealth in different periods.

Subasat and Uysal (2018) also presented a new approach to calculate GDP per capita. The new approach is called corrected gross national product and is calculated by dividing current GDP by a variable called Real Exchange Rate (RER). In other words,

$$\mathrm{GDP}_{\mathrm{ijCORRECTED}} = \frac{\mathrm{GDP}_{\mathrm{ijCURRENT}}}{\mathrm{RER}_{\mathrm{ij}}} \tag{1}$$

Where;

$$\mathrm{RER}_{\mathrm{ij}} = \frac{\mathrm{GDP}_{\mathrm{ij,CURRENT}}}{\mathrm{GDP}_{\mathrm{ij,CONSTANT}}} x \frac{\mathrm{GDP}_{1990\mathrm{j,CONSTANT}}}{\mathrm{GDP}_{1990\mathrm{j,CURRENT}}} x \frac{\mathrm{GDP}_{\mathrm{iUSA,CONSTANT}}}{\mathrm{GDP}_{\mathrm{iUSA,CURRENT}}} \tag{2}$$

An example formulation is shown here, where 1990 is chosen as the base year and the United States as the base country. The RER index is actually a kind of real exchange rate index, since it is calculated as the ratio of a country's dollar-denominated price level to the US price index. Assuming that the exchange rate is in equilibrium in the initial year with a value of one (1), a value of the index above one (1) would imply that average prices are rising faster for the country than prices in the United States; hence, the real exchange rate is overvalued. Conversely, a fall of the index below 1 would indicate that average prices have risen more slowly for the country than prices in the US, hence a depreciation of the real exchange rate. The exchange rate, which may be above or below 1 for a

certain period of time, will eventually tend to return to its equilibrium value of 1, as trade deficits cannot be sustained indefinitely (Subasat and Uysal, 2018). According to this method, the results will change as the base year and base country change. Therefore, this method is far from being reliable.

In addition to these methods, GDP adjustment can also be made through the Real Effective Exchange Rate (REER). Real Effective Exchange Rate is calculated such that we compile bilateral nominal exchange rates and price indices to calculate bilateral real exchange rates and then take the weighted average for each country, where the weight is calculated from bilateral trade data (Ahn et al., 2020: 2114). This calculation is carried out simply by the below-given formula:

$$REER_i = \prod_{j \neq i} \left(\frac{P_i S_{ij}}{P_j} \right)^{\lambda_{ij}} \quad (3)$$

In the equation, P is the price level of the country, S is the exchange rate between countries i and j, and λ is the share of country j in the trade of country i. Thus, an increase in the REER measure corresponds to appreciation in home currency (Ahn et al., 2020: 2114). In this case, the appreciated currency will increase the purchasing power of the country. However, this method also has problems, just like the method of Subaşat and Uysal (2018). If the REER of a country is overvalued, the GDP per capita of this country appears higher than it actually is. On the other hand, there are base year, base country, and weighting problems in the use of this method. In other words, the results of this method will vary according to the base year, base country, and weighting, which will impair the consistency and robustness of the method.

Recent contributions to the literature have questioned the accuracy of PPP-based GDP per capita indicators, especially in macroeconomically unstable countries. Ravallion (2020) and Deaton (2010) emphasize that global poverty and income comparisons based on PPP may overstate living standards in low-income countries. Inklaar and Rao (2017) highlight how methodological updates in PPP calculations have caused sudden upward shifts in the measured incomes of developing nations, which may not reflect true economic improvements. Additionally, institutional reports by the World Bank (2020) and IMF (2023) have drawn attention to the challenges of maintaining consistency and comparability in PPP estimates across time and countries. These critiques underscore the need for refined measures, such as the Discounted GDP per capita approach proposed in this study.

There are some other kinds of GDP measures like Index of Sustainable Economic Welfare (ISEW), Genuine Progress Indicator (GPI), Green GDP, Genuine Savings, etc. These and more measures are explained in detail in Lawn (2005), Costanza et al. (2009), Antal and van den Bergh (2014), Armiento (2018), and Cook and Davíðsdóttir (2021). These measures calculate GDP in a way that includes social and environmental dimensions of countries, but since the subject of the study is related to the depreciation of the currencies of countries, i.e. purchasing power, rather than social and environmental dimensions, these measures are not detailed in the study.

3. LAW OF ONE PRICE AND PURCHASING POWER PARITY

There may be many different reasons why the same good does have a different price in another country. Many factors such as transportation costs, customs and other taxes, cost differences (especially labor) that may arise when the same product is produced in different countries can affect this price difference. For example, according to the Big Mac Index, in June 2023, a Big Mac cost £4.19 in the UK and $5.58 in the US. Using the price difference between these two countries, it is possible to calculate the exchange rates between the two countries and decide whether the exchange rate is overvalued or undervalued according to the difference with the nominal exchange rate. This is where the concepts of law of one price (LOP) and purchasing power parity (PPP) come into play.

LOP is a law that asserts that the price of a good should be the same everywhere in the world in case of a common currency (Ardeni, 1989: 661) and therefore exchange rates can be adjusted by this price, assuming that there are no indirect and country-specific costs on the price of the good such as transportation, customs, taxes, etc. In other words, the PPP theory states that in the long run, the exchange rate between two countries is determined by their relative price levels (Lyon and Olmo, 2018: 79). Following this law, according to PPP, the nominal exchange rate between the currencies of two countries should be equal to the ratio of their aggregate price levels so that the currency of one country has the same purchasing power as the currency of the other (Taylor and Taylor, 2002: 135). These two concepts, despite their limitations, are theoretically and practically useful.

In the post-World War I period, the PPP concept was used to reconstruct the disrupted financial order. In the pre-war period, the currencies of countries were convertible at a certain parity according to the gold standard. The exchange rate between two countries was calculated by the value of their currencies in terms of gold. With the outbreak of the war, the use of the gold standard was immediately abandoned. By the end of the war, the problem of how to reach again the exchange rates of the pre-war period with the minimum deviation was faced. Because the countries involved in the war had experienced very different levels of inflation, it was impossible to return to the pre-war period in the same way. In such an environment, the works of Gustav Cassel (1921, 1922) demonstrated that PPP could be used to return to the parities of the gold standard era. Accordingly, the cumulative CPI would be calculated starting from 1914 and exchange rate differentials would be adjusted with the calculated CPI (Rogoff, 1996: 648-649). With this method, the exchange rates of the post-war period could be recalculated.

PPP is a concept that is still frequently used today. Especially organizations that publish data of GDP per capita use this concept. For example, the World Bank publishes both GDP per capita in dollar terms and GDP per capita calculated according to PPP for all countries. The difference between GDP per capita in dollar terms and GDP per capita calculated according to PPP is due to the exchange rate used in the calculation. In the calculation of GDP per capita in dollar terms, the value of the country's total annual production in the country's own currency is first divided by the country's population and then by the nominal dollar exchange rate of that year to calculate the data for the relevant year. For example, in 2023, let a country's per capita income in its own currency be 100 thousand units. At an exchange rate of 10 (1 USD = 10 units), the country's GDP per capita on dollar terms will be 10 thousand dollars. The PPP calculation is based on the prices of the same basket of goods in the two countries. Assuming that a basket of goods that cost 500 units in the country in the example costs 100 dollars in the US, the PPP exchange rate between the two countries is calculated as 5 (500/100) (1 USD = 5 units). Dividing this PPP-denominated exchange rate by the GDP per capita of 100 thousand units, also calculated in the country's own currency, yields a PPP-denominated GDP per capita of 20 thousand. This is how the difference between GDP per capita in dollars and GDP per capita calculated according to PPP is formed. The methods described here can be represented mathematically as:

GDP per capita in dollar: $$GDPpc_{DOLLAR} = \frac{GDPpc_{LOCAL}}{EXR_{NOMINAL}} \quad (4)$$

GDP per capita calculated according to PPP: $$GDPpc_{PPP} = \frac{GDPpc_{LOCAL}}{EXR_{PPP}} \quad (5)$$

Writing both equations given here together:

$$GDPpc_{LOCAL} = GDPpc_{DOLLAR} x EXR_{NOMINAL} = GDPpc_{PPP} x EXR_{PPP} \quad (6)$$

Here $GDPpc_{LOCAL}$ denotes GDP per capita in local currency, $GDPpc_{DOLLAR}$ denotes GDP per capita in dollars, $GDPpc_{PPP}$ denotes GDP per capita calculated according to PPP, $EXR_{NOMINAL}$ denotes the nominal exchange rate and EXR_{PPP} denotes the exchange rate calculated according to PPP. All

variables are calculated annually for the chosen country. Although Equation 4, one of the methods used in the calculation of GDP per capita, has its own problems, it is a robust indicator in terms of the calculation method and the result it produces in terms of understanding the welfare status of the country. Equation 5, however, fails to produce consistent results, especially for poor, underdeveloped or macroeconomically unstable countries.

Considering that Türkiye is a macroeconomically unstable country due to its high inflation and high exchange rate appreciation problems over the last few years, the data for this country constitutes an accurate example. Table 1 presents the data for Türkiye.

Table 1: ΔCPI, ΔEXR, GDPpc, GDPpc PPP and GDPpc PPP / GDPpc Data for Türkiye

Year	ΔCPI	ΔEXR	GDPpc	GDPpc PPP	GDPpc PPP / GDPpc
1995	89.11	54.84	2855.04	10249.16	3.59
1996	80.41	77.57	3009.67	10969.12	3.64
1997	85.67	86.56	3098.67	11785.24	3.80
1998	84.64	71.68	4433.36	8969.16	2.02
1999	64.87	60.62	4057.82	8649.61	2.13
2000	54.92	49.29	4278.26	9498.96	2.22
2001	54.40	96.03	3100.46	9157.48	2.95
2002	44.96	22.98	3640.76	9281.09	2.55
2003	21.60	-0.42	4704.77	9587.60	2.04
2004	8.60	-5.02	6031.79	10854.69	1.80
2005	8.18	-5.75	7369.43	11863.86	1.61
2006	9.60	6.32	8003.81	13581.52	1.70
2007	8.76	-8.79	9711.22	14866.43	1.53
2008	10.44	-0.11	10843.50	16038.30	1.48
2009	6.25	19.09	9013.00	15442.12	1.71
2010	8.57	-3.04	10622.70	17343.68	1.63
2011	6.47	11.45	11300.79	19590.95	1.73
2012	8.89	7.23	11713.28	20627.49	1.76
2013	7.49	6.00	12578.19	22373.25	1.78

2014	8.85	14.96	12165.22	24105.02	1.98
2015	7.67	24.28	11050.00	25855.77	2.34
2016	7.78	11.03	10970.05	26695.92	2.43
2017	11.14	20.79	10695.55	28193.17	2.64
2018	16.33	32.35	9568.84	28299.40	2.96
2019	15.18	17.51	9215.44	28461.18	3.09
2020	12.28	23.53	8638.74	28680.20	3.32
2021	19.60	26.28	9743.21	31637.53	3.25
2022	72.31	86.98	10674.50	38355.15	3.59
2023	53.86	43.45	12985.75	44151.02	3.40

Note: Δ stands for annual percentage change. Source: World Bank data and author's calculations.

According to the data in Table 1, Türkiye experienced single-digit annual inflation (ΔCPI) between 2004-2007 and 2009-2016, and double-digit annual inflation (ΔCPI) in the remaining years, sometimes above 50%. On the other hand, Türkiye experienced single-digit annual exchange rate changes (ΔEXR) between 2003-2008 and in 2010, 2012, 2013, and double-digit and sometimes close to 100% in the remaining years. In terms of these two indicators, Türkiye is a highly unstable country in macroeconomic perspective. In terms of the GDPpc PPP / GDPpc ratio, it is seen that the gap is at its lowest by 1.48 times and is 2-3 times in the pre-2003 and post-2015 periods. Therefore, Türkiye's GDPpc PPP value (Equation 5) is much higher than the GDPpc value (Equation 4). Therefore, it is once again evident that Equation 5 is a biased and erroneous approach in unstable countries like Türkiye in terms of macroeconomic variables. It is possible to find other countries with biased and erroneous results by looking at Graph 1, but since it would unnecessarily lengthen the study to include more tables for more countries, only Türkiye is given as an example.

4. NEW APPROACH: DISCOUNTED GDP PER CAPITA

There are two widely recognized facts in economic literature. First, inflation reduces the domestic purchasing power of the currency. Second, increases in exchange rates reduce the purchasing power of the currency abroad. When these two facts are evaluated together, the purchasing power of currency will decrease drastically in an economy where both the exchange rate and inflation rise. Therefore, factors that reduce the purchasing power of currency should be taken into account in purchasing power parity calculations. Especially inflation and exchange rate changes are among the main factors affecting the purchasing power of money. Therefore, inflation and exchange rate changes should be included in the calculation of GDP per capita. This is to say:

$$D\_GDPpc_{PPP} = \frac{GDPpc_{PPP}}{(1 + \%\Delta\text{CPI})(1 + \%\Delta\text{EXR})} \quad (7)$$

Here, D_GDPpc_{PPP} stands for discounted GDP per capita calculated according to PPP, $GDPpc_{PPP}$ stands for GDP per capita calculated according to PPP, ΔCPI stands for annual local inflation and ΔEXR stands for annual exchange rate change. According to this equation, a positive inflation rate will decrease the GDP per capita calculated according to PPP as it will reduce purchasing power. Likewise,

an increase in the exchange rate will mean a decrease in the GDP per capita calculated according to PPP because an increase in both variables means a decrease in purchasing power.

When speaking about inflation and exchange rate, it would not be correct to think about it only on the upward side. The general level of prices may increase in some years, but it may also decrease in others. Similarly, exchange rates do not tend to increase continuously. In some years, exchange rates may also decrease. Therefore, the currencies of the countries can appreciate or depreciate depending on the way of changing price levels and exchange rates. The appreciation of a country's currency means that its purchasing power will increase. In such a case, the discounted GDP per capita approach will diverge rather than converge to the dollar-based GDP per capita. For this reason, when using the discounted GDP per capita approach, it is necessary to determine the extent to which the national currency appreciates or depreciates in the domestic and foreign markets and to make the calculation accordingly. For example, in a country with 5% inflation, if the exchange rate is depreciated by 5%, the currency is depreciated by 10% (5% + 5%) in total. However, if the exchange rate is appreciated by 6% in an environment of 4% inflation, i.e. if the national currency is depreciated by 4% at home and appreciated by 6% abroad, the total appreciation would be 2% (6% - 4%). In this case, it can be said that the national currency has not depreciated, hence its purchasing power has not diminished but increased and GDP calculated according to purchasing power does not need to be discounted. Therefore, a prerequisite for the use and functioning of discounted purchasing power parity is that inflation and exchange rate changes must be in depreciation way in total. In other words:

$$\Delta\%CPI + \Delta\%EXR \geq 0 \quad (8)$$

Moreover, the further this value is from zero, the more consistent the reduction will be. Here, ΔCPI is the domestic depreciation of the national currency, i.e. inflation, and ΔEXR is the depreciation of the national currency in the foreign market. In other words, ΔCPI<0 implies that the general level of prices is falling and ΔEXR<0 implies that the exchange rate is falling, i.e. more foreign currency can be purchased per unit of national currency. In short, to discounted GDP per capita be functional, the currency must be depreciated in total considering domestic and foreign markets. The bigger the depreciation, the more accurate the new approach is.

5. EXAMPLES OF DISCOUNTED GDP PER CAPITA CALCULATION

Since the discounted GDP per capita calculation takes into account inflation and exchange rate driven increases or decreases in the purchasing power of countries, it provides more accurate results than the traditional PPP-based GDP per capita calculation. The convergence of the discounted GDP per capita calculated using this method to the dollar-based GDP per capita is presented in tables and graphs. In this section, different country examples from different development classes will be presented separately. Although the method can be applied to all countries in the world, it is limited to taking samples from developed, developing and least developed countries since including each country in the study may cause excessive length of the study. The important point here is to fulfil the condition given in Equation 8 and the conditions described in the fourth section.

In addition to tables and graphs, Root Mean Square Error (RMSE) and Mean Absolute Error (MAE) methods are also applied to the data for each country to test the statistical consistency and convergence power of the method. In order to statistically demonstrate the extent to which the proposed Discounted GDP Per Capita (D_GDPpcPPP) indicator provides more realistic results than the traditional Purchasing Power Parity (GDPpcPPP) based GDP per capita indicator, two error measures are used: Mean Absolute Error (MAE) and Root Mean Square Error (RMSE). While MAE gives the mean of the absolute values of the differences between the predicted value and the actual value, RMSE takes the square root of the mean of the square of these differences and gives more weight to larger deviations (Hyndman & Koehler, 2006; 682). Therefore, the RMSE value is more

sensitive and reflects the effect of extreme deviations more. The smaller the MAE and RMSE values, the closer the indicator used is considered to be to the reference value. In the analyses conducted in this context, it was observed that the D_GDPpcPPP indicator converged more to GDPpc than to GDPpcPPPP in terms of both MAE and RMSE.

5.1. Examples of Developed Countries

Here, the examples of Canada and Australia is given to represent the case of developed countries. Table 2 presents the data for Canada.

Table 2: Discounted GDP Per Capita Data for Canada

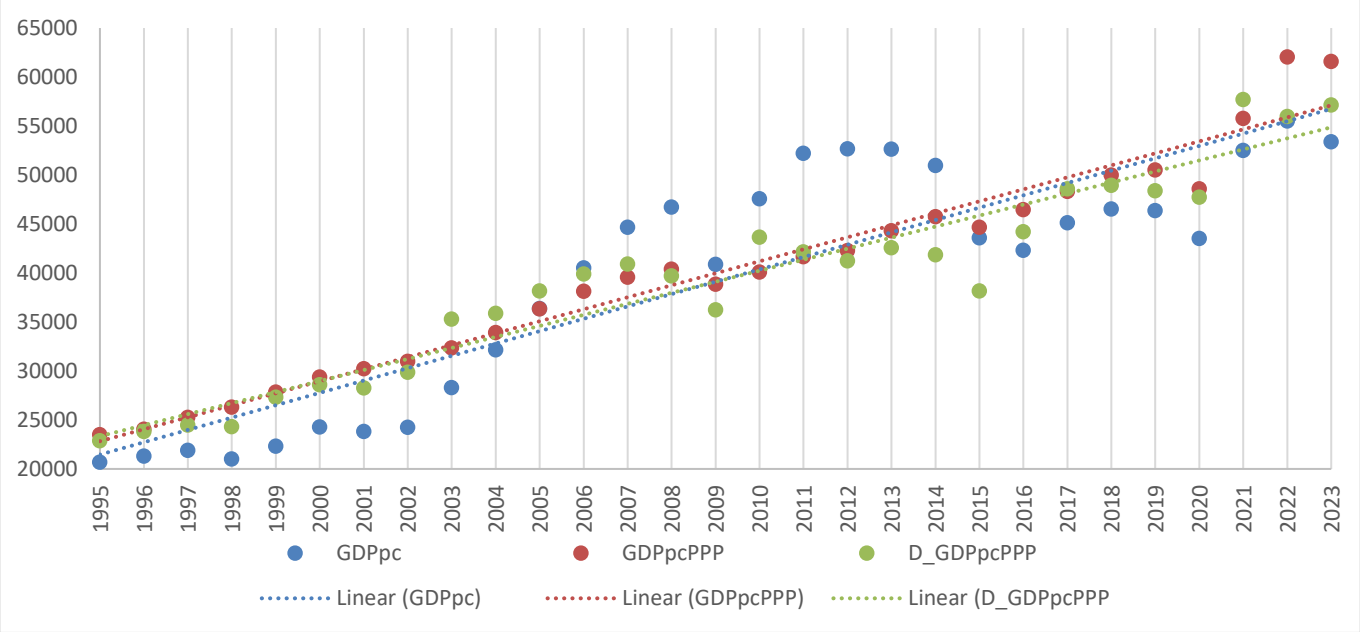
Year	CPI	ΔCPI	EXR	ΔEXR	GDPpc	GDPpcPPP	D_GDPpcPPP
1995	75.17172	2.14876	1.372445	0.49587	20679.63	23485.64	22878.16135
1996	76.35232	1.570531	1.363522	-0.65021	21296.97	24050.18	23833.26631
1997	77.59015	1.621216	1.384598	1.545732	21901.56	25258.86	24477.53561
1998	78.36291	0.995942	1.483505	7.143393	21024.59	26319.67	24322.66669
1999	79.72238	1.734843	1.485705	0.148265	22315.25	27841.35	27326.07109
2000	81.89038	2.71944	1.485394	-0.02091	24271	29362.08	28590.71888
2001	83.95821	2.52512	1.54884	4.271315	23822.1	30230.85	28278.4241
2002	85.85432	2.258394	1.570343	1.388322	24256.02	30963.92	29865.44981
2003*	88.22267	2.758563	1.401015	-10.7829	28301.86	32351.55	35288.14622
2004*	89.86119	1.857259	1.301282	-7.11862	32145.54	33927.67	35861.90907
2005*	91.85031	2.213552	1.211405	-6.90676	36383.66	36328.38	38178.54878
2006*	93.68918	2.002025	1.134345	-6.36124	40504.04	38119.39	39909.98014
2007*	95.69262	2.138384	1.074046	-5.31577	44660.08	39575.48	40922.24988
2008	97.96079	2.370271	1.067087	-0.6479	46710.25	40376.09	39698.42921
2009	98.25415	0.299467	1.141535	6.976797	40874.88	38864.06	36220.95664
2010*	100	1.776872	1.030113	-9.76077	47560.67	40098.25	43659.72461
2011*	102.9121	2.912135	0.989258	-3.96603	52223.86	41666.84	42159.85084
2012	104.472	1.515678	0.999365	1.021633	52670.34	42291.97	41239.21994
2013	105.4522	0.938292	1.030137	3.079218	52638.12	44301.06	42578.17222
2014	107.4628	1.906636	1.104747	7.242701	50960.84	45758.1	41869.50067
2015	108.672	1.125241	1.278786	15.75375	43594.19	44668.09	38159.50782
2016	110.2247	1.42876	1.325615	3.661985	42314.06	46470.65	44197.53825

2017*	111.9848	1.596884	1.297936	-2.08804	45129.63	48317.39	48572.14594
2018	114.5249	2.268226	1.295818	-0.16318	46539.18	49982.6	48953.90766
2019	116.7573	1.949269	1.326793	2.390416	46352.87	50498.97	48377.02135
2020	117.5944	0.717	1.341153	1.082257	43537.84	48590.68	47728.22649
2021*	121.587	3.395193	1.253877	-6.50752	52496.84	55781.7	57705.16752
2022	129.8583	6.802801	1.301555	3.802436	55509.39	62041.56	55961.91054
2023	134.8955	3.879002	1.349909	3.715085	53371.7	61582.35	57159.25544

Source: World Bank and author's own calculations. ΔCPI and ΔEXR are calculated as percentage change from the previous year. * indicates the years that the sum of ΔCPI and ΔEXR is negative, that is, the condition of Equation 8 is not met.

In the table, it is seen that inflation is highly steady around 2% and the exchange rate is not volatile. That's why Canada's currency doesn't depreciate remarkably. It can also be seen in Graph 2 that, for a developed country, GDPpc and GDPpcPPP are quite close to each other, which locates D_GDPpcPPP line near to them.

Graph 2: Canada's GDPpc, GDPpcPPP and D_GDPpcPPP Data



Source: World Bank and author's own calculations.

As seen in Graph 2, the trends of GDPpc, GDPpcPPP and D_GDPpcPPP series in the last 30 years are almost the same. Therefore, there is no major discrepancy between GDP calculated according to purchasing power parity and nominal GDP in developed countries without high inflation and high exchange rate increases.

Similar results are observed when the data for Australia are analyzed. Table 3 presents the data for Australia.

Table 3: Discounted GDP Per Capita Data for Australia

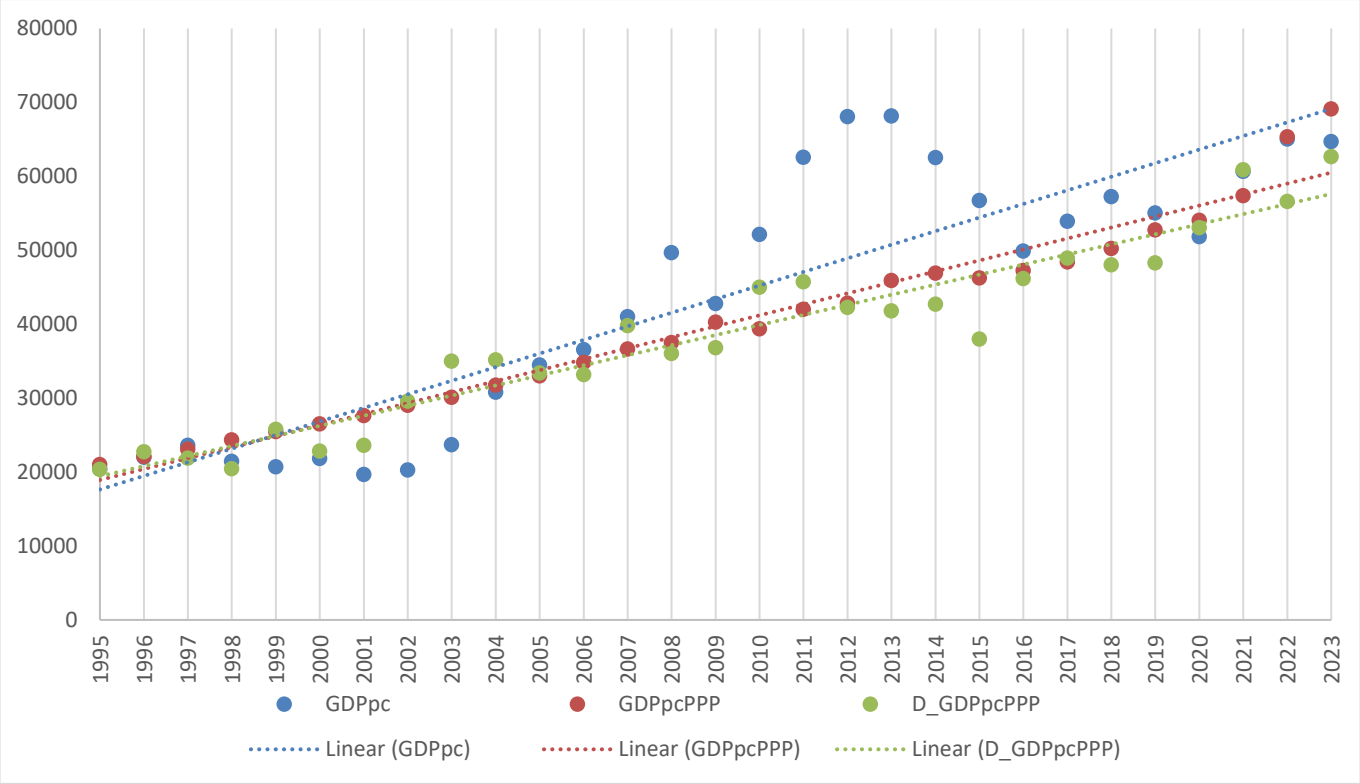
Year	CPI	ΔCPI	EXR	ΔEXR	GDPpc	GDPpcPPP	D_GDPpcPPP
1995	67.63788	4.627767	1.349033	-1.36855	20448.12	21038.67	20387.11796
1996*	69.40687	2.615385	1.277863	-5.27557	22021.78	22132.19	22769.31542
1997	69.56296	0.224888	1.34738	5.440071	23646.62	23124.96	21882.64416
1998	70.16129	0.860135	1.591828	18.14249	21479.11	24378.25	20458.64024
1999*	71.20187	1.483129	1.54995	-2.63083	20712.67	25485.39	25791.4643
2000	74.37565	4.457435	1.724827	11.28273	21870.42	26541.67	22832.89824
2001	77.65349	4.407135	1.933443	12.09489	19695.73	27645.81	23621.82236
2002*	79.96878	2.981575	1.840563	-4.80387	20301.84	29032.49	29614.57218
2003*	82.15401	2.732596	1.541914	-16.2259	23718.13	30121.82	34999.6172
2004*	84.07908	2.343255	1.359753	-11.814	30836.73	31763.8	35194.39513
2005*	86.34235	2.691832	1.309473	-3.69767	34479.77	33036.58	33405.84293
2006	89.41207	3.555288	1.327973	1.41279	36595.71	34846.72	33181.56313
2007*	91.49324	2.327611	1.195073	-10.0078	41051.61	36653.84	39803.54932
2008	95.47347	4.350299	1.192178	-0.24217	49701.28	37533	36055.58945
2009	97.16441	1.771117	1.282189	7.550085	42816.57	40312.4	36830.1343
2010*	100	2.91834	1.090159	-14.9767	52147.02	39374.63	44997.21969
2011*	103.3039	3.30385	0.969463	-11.0714	62609.66	42025.46	45746.16841
2012	105.1249	1.76278	0.965801	-0.37775	68078.04	42866.6	42283.77794
2013	107.7003	2.449889	1.035843	7.252225	68198.42	45936.05	41805.73268
2014	110.3798	2.487923	1.109363	7.097619	62558.24	46914.39	42741.87177
2015	112.0447	1.508367	1.33109	19.98687	56758.87	46292.1	38007.67336
2016	113.4755	1.276991	1.345214	1.061064	49918.79	47289.29	46202.77942
2017*	115.6868	1.948647	1.304758	-3.0074	53954.55	48418.56	48965.67701
2018	117.898	1.911401	1.338412	2.579334	57273.52	50251.34	48068.98586
2019	119.7971	1.610768	1.438507	7.478593	55049.57	52746.72	48298.51061
2020	120.8117	0.846906	1.453085	1.013452	51868.25	54064.08	53072.19174
2021*	124.2716	2.86391	1.331224	-8.38635	60697.25	57406.18	60916.56982

2022	132.4662	6.594097	1.441664	8.296138	65077.68	65365.95	56624.63886
2023	139.8803	5.597015	1.505191	4.406477	64711.77	69114.74	62689.03493

Source: World Bank and author's own calculations. ΔCPI and ΔEXR are calculated as percentage change from the previous year. * indicates the years that the sum of ΔCPI and ΔEXR is negative, that is, the condition of Equation 8 is not met.

According to the data in Table 3, Australia's inflation data fluctuates around 2% on average and the exchange rate level remains approximately the same. Therefore, as in Canada, Australia's currency is not subject to a large depreciation over the years. This situation can be seen more clearly in Graph 3.

Graph 3: Australia's GDPpc, GDPpcPPP and D_GDPpcPPP Data



Source: World Bank and author's own calculations.

As can be seen in Graph 3, there is a similar situation with Canada, the other developed country. In other words, GDPpc, GDPpcPPP and D_GDPpcPPPP variables follow similar courses and move close to each other. This is because the currencies of developed countries do not experience large and serious depreciations in both domestic and foreign markets.

5.2. Examples of Developing Countries

Türkiye, Belarus and Brazil are taken as sample countries. Any other developing country who holds the condition in Equation 8 in most of the years may also be chosen as sample. Table 4 shows the data for Türkiye.

Table 4: Discounted GDP Per Capita Data for Türkiye

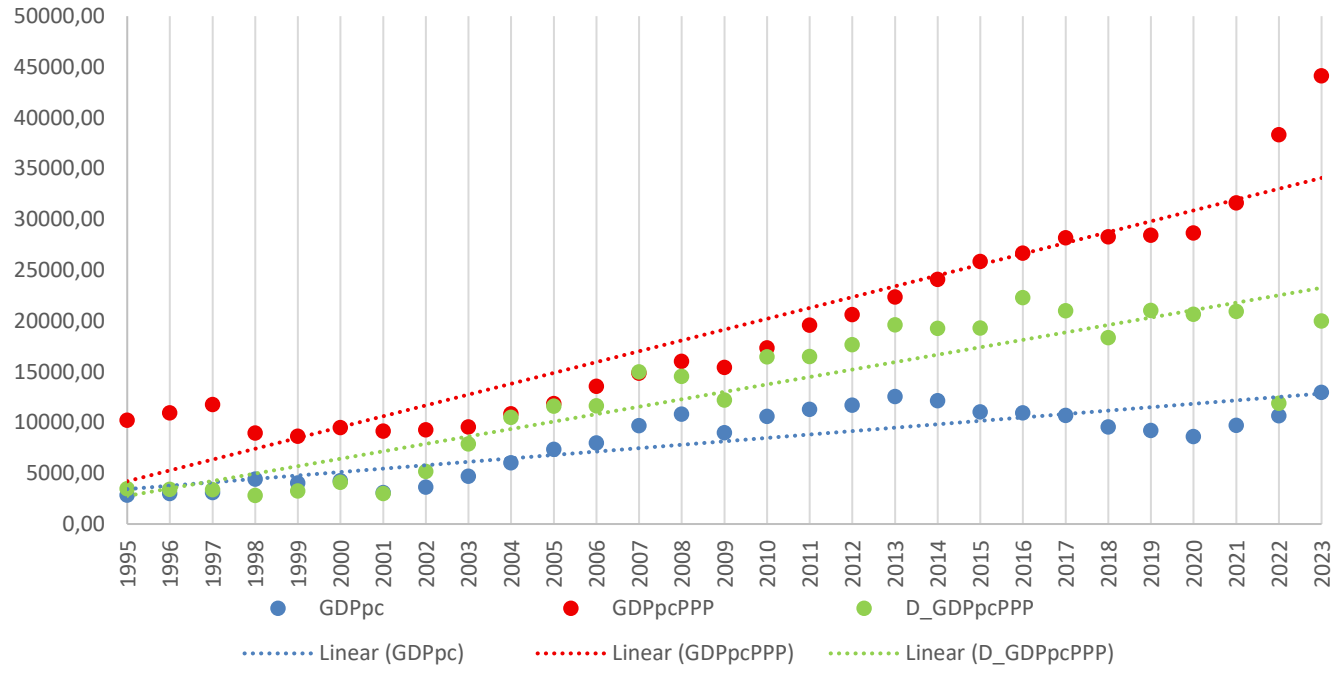
Year	CPI	ΔCPI	EXR	ΔEXR	GDPpc	GDPpcPPP	D_GDPpcPPP
1995	1.30	89.11	0.05	54.84	2855.04	10249.16	3500.20
1996	2.35	80.41	0.08	77.57	3009.67	10969.12	3424.11
1997	4.37	85.67	0.15	86.56	3098.67	11785.24	3402.44
1998	8.06	84.64	0.26	71.68	4433.36	8969.16	2829.43
1999	13.29	64.87	0.42	60.62	4057.82	8649.61	3266.29
2000	20.59	54.92	0.63	49.29	4278.26	9498.96	4107.13
2001	31.80	54.40	1.23	96.03	3100.46	9157.48	3025.63
2002	46.10	44.96	1.51	22.98	3640.76	9281.09	5206.00
2003	56.05	21.60	1.50	-0.42	4704.77	9587.60	7917.69
2004	60.87	8.60	1.43	-5.02	6031.79	10854.69	10523.58
2005	65.85	8.18	1.34	-5.75	7369.43	11863.86	11635.80
2006	72.17	9.60	1.43	6.32	8003.81	13581.52	11655.94
2007*	78.49	8.76	1.30	-8.79	9711.22	14866.43	14986.40
2008	86.69	10.44	1.30	-0.11	10843.50	16038.30	14537.36
2009	92.11	6.25	1.55	19.09	9013.00	15442.12	12204.08
2010	100.00	8.57	1.50	-3.04	10622.70	17343.68	16475.96
2011	106.47	6.47	1.67	11.45	11300.79	19590.95	16509.46
2012	115.94	8.89	1.80	7.23	11713.28	20627.49	17666.42
2013	124.63	7.49	1.90	6.00	12578.19	22373.25	19635.45
2014	135.66	8.85	2.19	14.96	12165.22	24105.02	19262.83
2015	146.07	7.67	2.72	24.28	11050.00	25855.77	19321.64
2016	157.42	7.78	3.02	11.03	10970.05	26695.92	22308.49
2017	174.97	11.14	3.65	20.79	10695.55	28193.17	20999.67
2018	203.55	16.33	4.83	32.35	9568.84	28299.40	18380.04
2019	234.44	15.18	5.67	17.51	9215.44	28461.18	21028.72
2020	263.22	12.28	7.01	23.53	8638.74	28680.20	20678.91
2021	314.81	19.60	8.85	26.28	9743.21	31637.53	20948.48

2022	542.44	72.31	16.55	86.98	10674.50	38355.15	11904.51
2023	834.59	53.86	23.74	43.45	12985.75	44151.02	20004.62

Source: World Bank and author's own calculations. ΔCPI and ΔEXR are calculated as percentage change from the previous year. * indicates the years that the sum of ΔCPI and ΔEXR is negative, that is, the condition of Equation 8 is not met.

Analyzing the data in Table 4, it is observed that the value of ΔCPI+ΔEXR is greater than 0 in Türkiye in all years except 2007. The high exchange rate depreciation that started in the post-2014 period combined with the high inflation that started in the post-2017 period led to a significant decline in purchasing power in the country. Finally, by 2023, GDPpcPPP is calculated as $44,000, while GDPpc is calculated as $13,000, but the value calculated according to the discounted GDP per capita approach is realized as $20,000. This large difference between GDPpcPPP and D_GDPpcPPP is an indication that the approach proposed by the study is accurate. This is because the purchasing power of the country has fallen significantly due to high inflation and high exchange rate depreciation. Moreover, the fact that ΔCPI+ΔEXR is less than 0 in the year shown with * symbol in the table indicates that there was an increase in the total purchasing power of the country in that year, hence the discounted GDP per capita value is larger than GDPpcPPP. This is also the case for Brazil and Sudan in Table 3 and Table 4 for the years in the respective tables.

Graph 4: Türkiye's GDPpc, GDPpcPPP and D_GDPpcPPP Data



Source: World Bank and author's own calculations.

Graph 4 shows that the discounted GDP per capita approach is closer to GDPpc values than GDPpcPPP. In general, the accuracy of the approximation can be observed by checking the trend lines as well as year-specific data. Indeed, the blue line at the bottom is GDPpc, the green line at the top is GDPpcPPP and the red line between them shows the discounted GDP per capita series. According to the graph, the discounted GDP per capita trend line is much closer to the GDPpc series than the GDPpcPPP series, which proves that the new approach, discounted GDP per capita, is valid.

Table 5: Discounted GDP Per Capita Data for Belarus

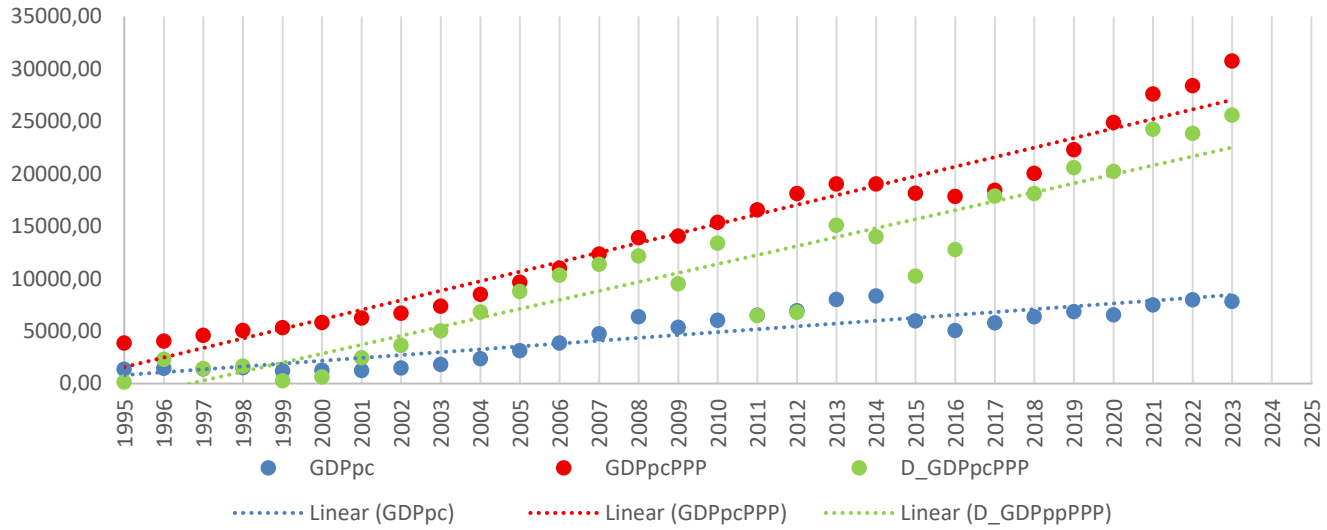
Year	CPI	ΔCPI	EXR	ΔEXR	GDPpc	GDPpcPPP	D_GDPpcPPP
1995	0.35	709.35	0.00	216.41	1370.48	3850.23	150.35
1996	0.54	52.71	0.00	14.83	1452.51	4044.09	2306.12
1997	0.88	63.94	0.00	96.68	1396.66	4601.90	1427.24
1998	1.52	72.87	0.00	77.27	1511.26	5067.29	1653.53
1999	5.98	293.68	0.02	440.45	1210.59	5337.69	250.88
2000	16.05	168.62	0.09	251.69	1276.28	5802.47	614.20
2001	25.86	61.13	0.14	58.54	1244.37	6245.44	2444.75
2002	36.86	42.54	0.18	28.84	1479.38	6705.04	3651.00
2003	47.33	28.40	0.21	14.54	1819.53	7370.39	5011.70
2004	55.90	18.11	0.22	5.31	2378.34	8492.90	6828.00
2005	61.68	10.34	0.22	-0.30	3126.07	9648.23	8770.32
2006	66.00	7.00	0.21	-0.43	3848.22	11007.54	10332.10
2007	71.56	8.43	0.21	0.07	4735.48	12334.52	11367.88
2008	82.18	14.84	0.21	-0.45	6376.18	13902.47	12161.03
2009	92.82	12.95	0.28	30.74	5352.49	14050.71	9515.51
2010	100.00	7.74	0.30	6.64	6034.68	15364.03	13372.88
2011	153.23	53.23	0.50	67.02	6527.66	16563.20	6472.05
2012	243.97	59.22	0.83	67.59	6953.22	18114.75	6788.78
2013	288.65	18.31	0.89	6.52	7998.08	19014.05	15088.08
2014	340.95	18.12	1.02	15.14	8341.29	19037.82	13998.64
2015	387.09	13.53	1.59	55.77	5967.07	18133.57	10253.55
2016	432.91	11.84	1.99	24.93	5039.78	17832.48	12763.70
2017	459.03	6.03	1.93	-2.88	5785.53	18413.71	17880.47
2018	481.39	4.87	2.04	5.45	6360.05	20026.03	18109.12
2019	508.34	5.60	2.09	2.66	6837.77	22301.58	20572.32
2020	536.54	5.55	2.44	16.63	6542.86	24872.34	20205.45
2021	587.30	9.46	2.54	4.06	7489.72	27611.18	24240.16

2022	676.63	15.21	2.63	3.44	7994.65	28406.07	23835.16
2023	710.46	5.00	3.01	14.52	7829.05	30751.50	25574.18

Source: World Bank and author's own calculations. ΔCPI and ΔEXR are calculated as percentage change from the previous year.

In Table 5, it is observed that the condition in Equation 8 holds for each and every year for Belarus, that is, the country loses its purchasing power in domestic and/or international manners.

Graph 5: Belarus's GDPpc, GDPpcPPP and D_GDPpcPPP Data



Source: World Bank and author's own calculations.

In Graph 5, the difference between GDPpc PPP and GDPpc is much higher than that of D_GDPpc PPP and GDP pc. That is, the new approach calculates the GDP per capita in terms of PPP better than the traditional approach.

Table 6: Discounted GDP Per Capita Data for Suriname

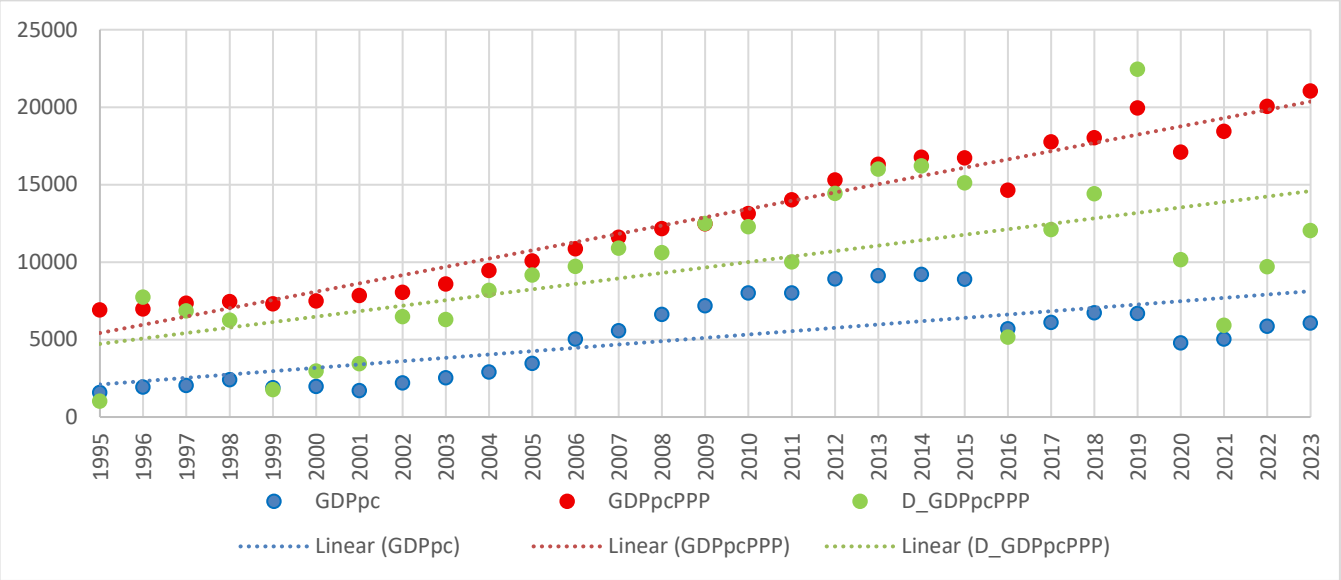
Year	**CPI**	**ΔCPI**	**EXR**	**ΔEXR**	**GDPpc**	**GDPpcPPP**	**D_GDPpcPPP**
1995	7.222016	235.5588	0.442772	99.03375	1591.729	6920.854	1036.249
1996*	7.171325	-0.70189	0.401018	-9.43005	1940.754	6968.179	7748.081
1997	7.683725	7.145112	0.401566	0.136602	2045.593	7342.607	6843.608
1998	9.14174	18.97537	0.401606	0.010029	2405.744	7450.124	6261.277
1999	18.17132	98.77309	0.834084	107.687	1883.889	7311.864	1771.174
2000	28.96539	59.40169	1.322491	58.55598	1978.447	7498.405	2966.835
2001	40.14206	38.58629	2.178182	64.70305	1711.714	7851.644	3439.844
2002	46.37507	15.5274	2.34675	7.738918	2206.273	8060.125	6475.662
2003	57.04238	23.00223	2.601333	10.84834	2529.259	8596.349	6304.808

2004	62.73881	9.986325	2.733583	5.083918	2906.725	9450.44	8176.681
2005	68.9487	9.898005	2.731667	-0.0701	3474.12	10073.92	9173.039
2006	76.72702	11.2813	2.74375	0.442343	5031.158	10864.09	9719.733
2007	81.65771	6.426279	2.745	0.045558	5562.334	11597.2	10891.97
2008	93.63456	14.66714	2.745	0	6616.815	12172.28	10615.31
2009*	93.50943	-0.13364	2.745	0	7176.858	12475.12	12491.81
2010	100	6.941082	2.745417	0.015179	7999.507	13131.21	12277.06
2011	117.7118	17.71178	3.268	19.03475	8009.252	14030.21	10013.15
2012	123.6054	5.006863	3.3	0.979192	8922.956	15307.96	14436.69
2013	125.9829	1.923436	3.3	0	9124.541	16318.18	16010.23
2014	130.2454	3.383413	3.3	0	9199.178	16763.39	16214.78
2015	139.2244	6.893904	3.416667	3.535354	8907.837	16720.43	15107.96
2016	216.372	55.41239	6.22863	82.30137	5705.399	14632.25	5164.585
2017	263.9673	21.99694	7.487661	20.21361	6112.883	17751.68	12104.22
2018	331.2641	25.49437	7.462511	-0.33588	6730.837	18029.85	14415.48
2019*	294.6822	-11.0431	7.458	-0.06045	6690.045	19951.61	22441.97
2020	397.4962	34.88978	9.309545	24.8263	4796.533	17093.51	10151.87
2021	632.4947	59.11966	18.23867	95.91361	5026.879	18447.34	5917.596
2022	964.213	52.44603	24.70917	35.47687	5858.825	20061.35	9713.572
2023	1133.119	17.51752	36.77587	48.83487	6069.029	21047.18	12033.35

Source: World Bank and author's own calculations. ΔCPI and ΔEXR are calculated as percentage change from the previous year.

As seen in Table 6, the country's currency depreciated in all years except 1996, 2009 and 2019 as a sum of domestic and foreign markets. This shows that Equation 7 is generally valid in Suriname. This suggests that this country is a suitable country to check the validity of the new approach proposed in this study.

Graph 6: Suriname's GDPpc, GDPpcPPP and D_GDPpcPPP Data



Source: World Bank and author's own calculations.

According to the data in Graph 6, it is clear that the D_GDPpcPPP series is generally closer to GDPpc.

Table 7: Discounted GDP Per Capita Data for Brazil

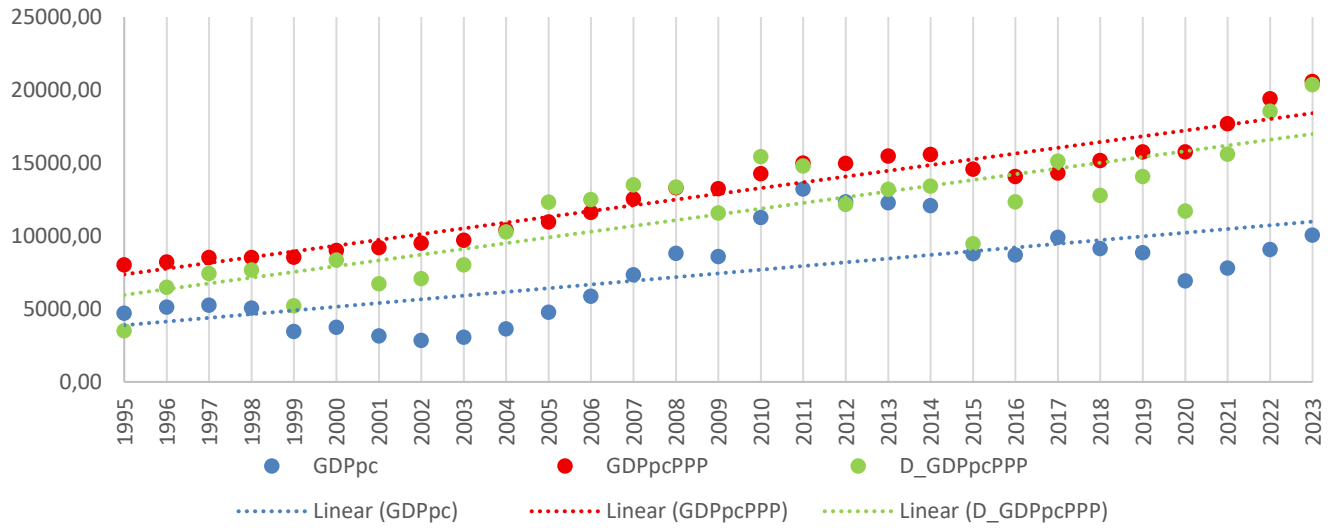
Year	CPI	ΔCPI	EXR	ΔEXR	GDPpc	GDPpcPPP	D_GDPpcPPP
1995	36.64	66.01	0.92	38.06	4704.96	8008.76	3494.37
1996	42.41	15.76	1.01	9.53	5121.91	8208.92	6474.58
1997	45.35	6.93	1.08	7.25	5240.13	8505.41	7416.56
1998	46.80	3.20	1.16	7.66	5049.76	8504.28	7654.96
1999	49.07	4.86	1.81	56.30	3456.42	8542.79	5212.27
2000	52.53	7.04	1.83	0.85	3726.81	8995.85	8332.71
2001	56.12	6.84	2.35	28.44	3142.24	9203.90	6707.35
2002	60.87	8.45	2.92	24.29	2824.72	9511.45	7056.34
2003	69.82	14.71	3.08	5.38	3056.65	9694.27	8019.32
2004	74.43	6.60	2.93	-4.95	3623.22	10409.08	10273.48
2005*	79.54	6.87	2.43	-16.78	4773.27	10956.12	12318.46
2006*	82.87	4.18	2.18	-10.64	5866.02	11615.64	12476.98
2007*	85.89	3.64	1.95	-10.49	7323.19	12524.57	13501.30
2008*	90.77	5.68	1.83	-5.82	8801.76	13284.39	13347.18
2009	95.20	4.89	2.00	9.03	8569.90	13222.88	11562.14
2010*	100.00	5.04	1.76	-12.01	11249.29	14256.56	15425.86

2011	106.64	6.64	1.67	-4.91	13200.56	14989.16	14782.30
2012	112.40	5.40	1.95	16.75	12327.51	14962.37	12158.48
2013	119.37	6.20	2.16	10.39	12258.57	15469.54	13194.29
2014	126.93	6.33	2.35	9.13	12071.40	15564.80	13413.60
2015	138.39	9.03	3.33	41.39	8783.22	14567.71	9449.71
2016	150.48	8.74	3.49	4.94	8680.74	14057.31	12318.79
2017*	155.67	3.45	3.19	-8.59	9896.72	14293.60	15115.95
2018	161.37	3.66	3.65	14.49	9121.02	15165.06	12777.47
2019	167.40	3.73	3.94	7.95	8845.32	15741.48	14056.84
2020	172.77	3.21	5.16	30.69	6923.70	15759.08	11682.79
2021	187.12	8.30	5.39	4.64	7794.88	17672.92	15594.58
2022	204.48	9.28	5.16	-4.27	9065.50	19398.59	18543.36
2023	213.88	4.59	4.99	-3.28	10043.62	20584.42	20348.66

Source: World Bank and author's own calculations. ΔCPI and ΔEXR are calculated as percentage change from the previous year. * indicates the years that the sum of ΔCPI and ΔEXR is negative, that is, the condition of Equation 8 is not met.

In the table, it is seen that the purchasing power of Brazil had risen between 2005-2008 and in 2010 and 2017. For the other years, discounted GDP per capita approach operates well.

Graph 7: Brazil's GDPpc, GDPpcPPP and D_GDPpcPPP Data



Source: World Bank and author's own calculations.

In Graph 7, Brazil shows a similar pattern with Belarus. The new approach is a better way of calculating PPP based per capita GDP. All in all, in these countries namely Türkiye, Belarus and Brazil, the discounted GDP per capita trend line is closer to the GDPpc line than the GDPpcPPP line. Especially in periods of high inflation and exchange rate depreciation, the discounted GDP per capita

values move away from the GDP per capita value calculated according to purchasing power parity and converge to the dollar-based GDP per capita value. Therefore, in periods of high inflation and exchange rate depreciation, it would be more accurate to use the discounted GDP per capita approach proposed in this study instead of purchasing power parity in comparing the purchasing power of countries.

5.3. Example of Least Developed Countries

Sudan and Angola are taken as sample least developed countries. Any other least developed country who holds the condition in Equation 8 in most of the years may also be chosen as sample.

Table 8: Discounted GDP Per Capita Data for Sudan

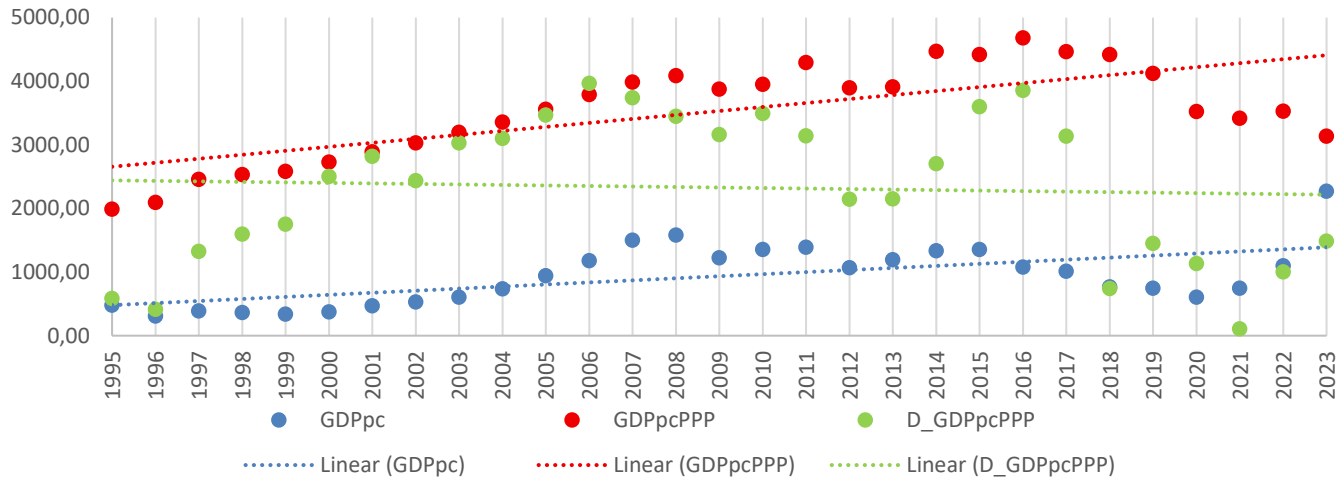
Year	CPI	ΔCPI	EXR	ΔEXR	GDPpc	GDPpcPPP	D_GDPpcPPP
1995	6.69	68.38	0.58	100.57	483.70	1989.28	589.04
1996	15.57	132.82	1.25	115.33	307.82	2094.01	417.68
1997	22.92	47.17	1.58	25.98	388.81	2457.57	1325.53
1998	28.56	24.62	2.01	27.43	366.12	2534.49	1595.93
1999	33.46	17.17	2.53	25.77	339.28	2586.53	1755.23
2000	35.84	7.12	2.57	1.81	378.16	2732.37	2505.37
2001	36.54	1.94	2.59	0.61	471.37	2892.64	2820.40
2002	44.66	22.22	2.63	1.78	529.45	3030.89	2436.41
2003	47.55	6.49	2.61	-0.88	607.01	3198.73	3030.53
2004	52.15	9.66	2.58	-1.18	737.12	3361.20	3101.76
2005	56.58	8.51	2.44	-5.54	945.69	3558.41	3471.96
2006*	60.66	7.20	2.17	-10.86	1179.90	3789.64	3965.78
2007	69.61	14.75	2.02	-7.16	1500.67	3986.03	3741.33
2008	79.56	14.30	2.09	3.67	1585.58	4087.03	3449.09
2009	88.51	11.26	2.30	10.11	1223.90	3876.30	3164.12
2010	100.00	12.98	2.31	0.19	1356.89	3955.03	3493.94
2011	118.10	18.10	2.67	15.64	1391.43	4293.56	3143.97
2012	160.09	35.56	3.57	33.99	1070.34	3896.47	2145.24
2013	218.56	36.52	4.76	33.13	1195.42	3910.75	2151.66
2014	299.22	36.91	5.74	20.60	1338.17	4470.14	2707.28
2015	349.82	16.91	6.03	5.04	1355.13	4421.75	3600.88

2016	411.91	17.75	6.21	3.09	1082.62	4684.09	3858.89
2017	545.17	32.35	6.68	7.59	1014.84	4465.09	3135.58
2018	890.23	63.29	24.33	264.02	769.87	4422.37	743.98
2019	1344.19	50.99	45.77	88.12	748.01	4123.92	1451.85
2020	3538.69	163.26	54.00	17.98	608.33	3525.56	1135.11
2021	16245.89	359.09	370.79	586.70	749.71	3420.45	108.50
2022	38796.56	138.81	546.76	47.46	1102.25	3532.07	1003.03
2023	54784.91	41.21	816.61	49.35	2272.49	3137.16	1487.47

Source: World Bank and author's own calculations. ΔCPI and ΔEXR are calculated as percentage change from the previous year. * indicates the years that the sum of ΔCPI and ΔEXR is negative, that is, the condition of Equation 8 is not met.

According to Table 8, Sudan's purchasing power increases only in 2006. In other years, the country loses its purchasing power, holding the condition in Equation 8.

Graph 8: Sudan's GDPpc, GDPpcPPP and D_GDPpcPPP Data



Source: World Bank and author's own calculations.

As it is seen in Graph 8, Sudan's GDPpc PPP is much higher than GDPpc and both are in upward trend. However, according to new approach, the D_GDPpc PPP line is not increasing, but slightly decreasing. Therefore, it is possible to state that Sudan is not getting better in terms of per capita GDP. Table 9 presents data for Angola.

Table 9: Discounted GDP Per Capita Data for Angola

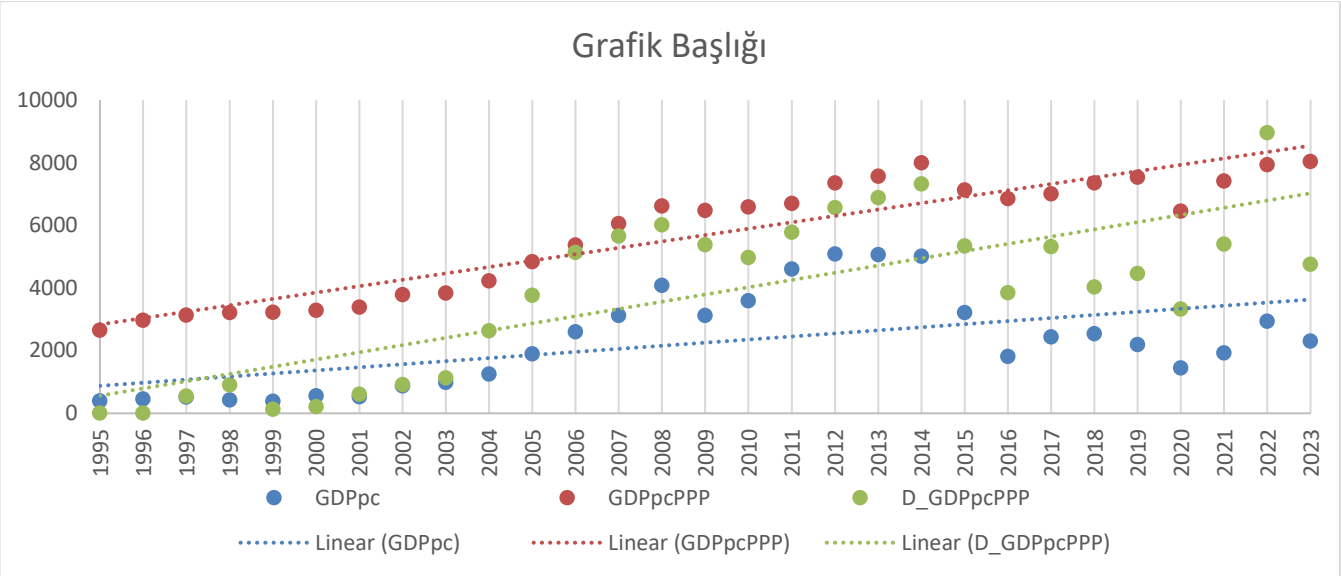
Year	CPI	ΔCPI	EXR	ΔEXR	GDPpc	GDPpcPPP	D_GDPpcPPP
1995	0.0007	2666.451	0.00275	4521.07	398.1136	2654.634	2.076535051
1996	0.029713	4145.106	0.128029	4555.217	454.3766	2968.84	1.502305358

1997	0.094837	219.1767	0.22904	78.8968	516.1286	3133.454	548.7688987
1998	0.196583	107.2848	0.392824	71.50863	423.4037	3210.303	903.0100679
1999	0.684495	248.1959	2.790706	610.4224	387.6894	3221.133	130.2172003
2000	2.909082	324.9969	10.04054	259.7851	556.8843	3286.358	214.9245691
2001	7.347208	152.561	22.05786	119.6879	527.4641	3388.525	610.7143835
2002	15.34813	108.8974	43.53021	97.34554	872.6576	3783.143	917.6822048
2003	30.4237	98.22414	74.6063	71.38972	982.8056	3839.854	1130.247095
2004	43.67082	43.54211	83.54136	11.97628	1254.696	4224.14	2628.045704
2005	53.69481	22.95351	87.15914	4.330524	1900.724	4836.227	3770.112686
2006	60.83901	13.30521	80.36807	-7.79157	2597.964	5364.965	5135.070541
2007	68.2927	12.2515	76.70614	-4.55645	3121.349	6057.772	5654.239065
2008	76.81278	12.47583	75.03335	-2.18078	4081.718	6616.769	6013.987745
2009	87.3594	13.73028	79.32817	5.723871	3123.699	6471.348	5382.023251
2010	100	14.46966	91.90572	15.85509	3586.664	6587.408	4967.1706
2011	113.4825	13.48247	93.93475	2.207729	4608.155	6700.114	5776.565287
2012	125.1461	10.2779	95.46796	1.632203	5083.827	7351.761	6559.511862
2013	136.1312	8.777814	96.51828	1.100185	5061.349	7566.423	6880.156889
2014	146.0421	7.280387	98.30242	1.848497	5011.984	7999.827	7321.593799
2015	159.7057	9.355972	120.0607	22.13403	3217.339	7127.34	5336.398622
2016	208.7264	30.69442	163.6564	36.31141	1809.709	6850.385	3845.260085
2017	271.0198	29.84448	165.916	1.380646	2439.374	6998.796	5316.732371
2018	324.2181	19.62894	252.8557	52.3999	2540.509	7353.35	4033.335042
2019	379.5976	17.08095	364.8258	44.28219	2191.348	7533.512	4459.626667
2020	464.1398	22.27154	578.2588	58.50271	1450.905	6455.12	3330.751661
2021	583.6758	25.75429	631.442	9.197124	1927.474	7414.279	5399.268148
2022*	708.3214	21.35529	460.5675	-27.061	2933.485	7928.641	8957.363597
2023	804.9655	13.6441	685.0202	48.73395	2309.522	8040.544	4756.948047

Source: World Bank and author's own calculations. ΔCPI and ΔEXR are calculated as percentage change from the previous year. * indicates the years that the sum of ΔCPI and ΔEXR is negative, that is, the condition of Equation 8 is not met.

According to the data in Table 9, Angola's currency depreciated significantly in all years except 2022, both in the domestic and foreign markets. In this case, the D_GDPpcPPP series is expected to produce a more consistent result than the GDPpcPPP series. As a matter of fact, this situation can be clearly seen in Graph 4.

Graph 9: Angola's GDPpc, GDPpcPPP and D_GDPpcPPP Data



Source: World Bank and author's own calculations.

When the data in Graph 9 are analysed, it is clearly seen that the D_GDPpcPPP series is closer to the GDPpc series in all years except 2022. This is again an indication of the consistency of the method described in this study. In other words, as the country's currency depreciates in the domestic and foreign markets, the GDP per capita value calculated according to purchasing power parity loses its meaning and consistency.

5.4. RMSE ve MAE Uygulaması

RMSE and MAE methods were applied to the countries in the study, so that it can be determined which of the GDPpcPPP and D_GDPpcPPP series is closer to the real GDPpc series. Before presenting the application results, it is necessary to present the operating ways of the methods. As shown in Hodson (2022), these methods are as follows:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2} \tag{9}$$

$$MAE = \frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i) \tag{10}$$

Mean Absolute Error (MAE) gives the mean of the absolute values of the differences between the predicted values and the actual values. Root Mean Square Error (RMSE) is the square root of the mean of the squares of these differences. RMSE reflects the effect of outliers more strongly by giving greater weight to large deviations, while MAE is a more balanced measure of error. Both measures

are frequently used statistical criteria to assess how close the predicted variable is to the true value. Both methods are widely used for model performance comparisons (Chai and Draxler, 2014: 1247). The values for RMSE and MAE calculations for each country in the study are given in Table 10.

Table 10: RMSE and MAE Values

	RMSE of (GDP-PPP)	RMSE of (GDP-D_GDP)	% Diff	MAE of (GDP-PPP)	MAE of (GDP-D_GDP)	% Diff
Canada	5471.05	5317.46	%2	4850.78	4547.79	%6
Australia	9493.02	10511.08	-%9	6705.14	7420.96	-%9
Türkiye	13220.28	6321.05	%109	11003.11	5053.66	%117
Belarus	11150.55	8155.03	%36	9676.68	6120.13	%58
Suriname	8330.82	5489.82	%51	7867.51	4765.20	%65
Brazil	5899.52	4879.98	%20	5452.68	4135.41	%31
Sudan	2662.08	1728.11	%54	2597.70	1501.38	%73
Angola	3608.10	2068.78	%74	3434.26	1638.23	%109

Note: GDP, PPP and D_GDP denote GDPpc, GDPpcPPP and D_GDPpcPPP, respectively. Source: Own calculations.

When the values in the table are analyzed, it is seen that the differences are very small in Canada and Australia, which are developed countries, because the currencies of these countries do not depreciate at high rates both in the domestic market (inflation) and in the foreign market (exchange rate). Therefore, it can be said that these countries are macroeconomically stable countries. When other countries are analyzed, it is clearly seen that this is not the case. For example, in Angola, there is a 109% divergence according to the RMSE value and a 74% divergence according to the MAE value. This shows that the D_GDPpcPPP variable presented in the study produces a result much closer to the real GDPpc value when inflation and exchange rate values are taken into account. In other words, the methodology presented in this study reveals that in macroeconomically unstable countries (countries with high inflation and exchange rate appreciation), purchasing power parity should be updated according to the D_GDPpcPPPP variable.

6. RELIABILITY CHECK

6.1. Checking by Weighting

It is important to test the reliability of the new method applied in the study. Testing how the results will change if the parameters in the new approach presented in Equation 6 are changed will provide a test of the reliability of this new approach. In this context, Equation 6 is modified as follows to produce new results.

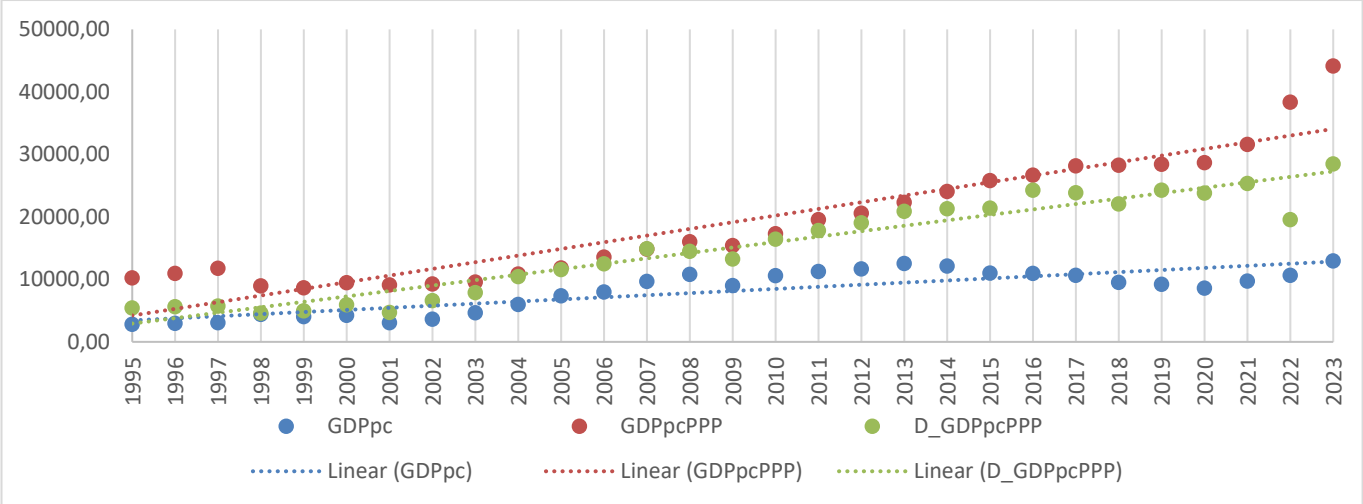
$$D\_GDPpc_{PPP} = \frac{GDPpc_{PPP}}{(1 + (\alpha)\%\Delta\mathrm{CPI})(1 + (1 - \alpha)\%\Delta\mathrm{EXR})} \quad (11)$$

Here, α represents the weight of the ΔCPI, i.e. the inflation term, in the total change. In other words, given that the sum of the weights of inflation (ΔCPI) and exchange rate change (ΔEXR) is 1in a given year, α indicates the percentage weight of inflation. In the study, first, the α rate for each year is calculated as a reliability check;

$$\alpha = \frac{|\Delta CPI|}{|\Delta CPI| + |\Delta EXR|} \tag{12}$$

In this way, the weight of inflation in total change is obtained. Calculations are made according to these α values and the results are presented again for some countries. And second, some random α values, i.e. 50% for inflation and 50% for exchange rate, are tested. By this way, impact of different weights is demonstrated via graphs. The graphs for other values of α (i.e. %30 inflation-%70 exchange rate and %70 inflation-%30 exchange rate for Türkiye, Sudan, Belarus and Brazil) is given at Appendix 1.

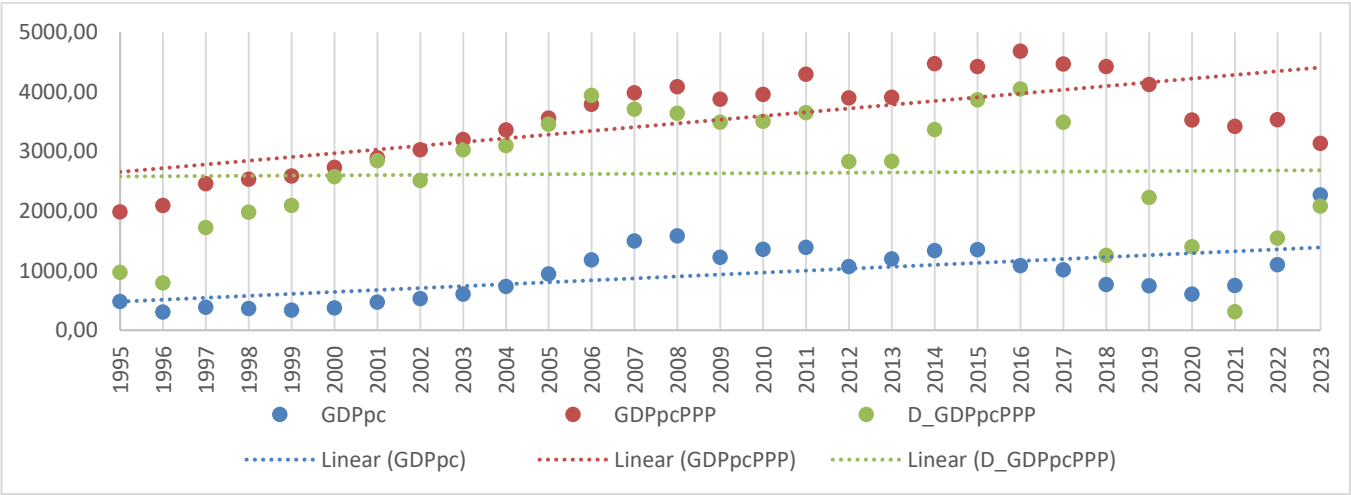
Graph 10: Türkiye's GDPpc, GDPpcPPP and α-Weighted D_GDPpcPPP Data



Source: World Bank and author's own calculations.

It is seen that on Graph 10 that Türkiye's weighted D_GDPpcPPP line (green line) converges slightly to the original GDPpcPPP line (red line) since the weighted average method computes the data in a different and more robust way.

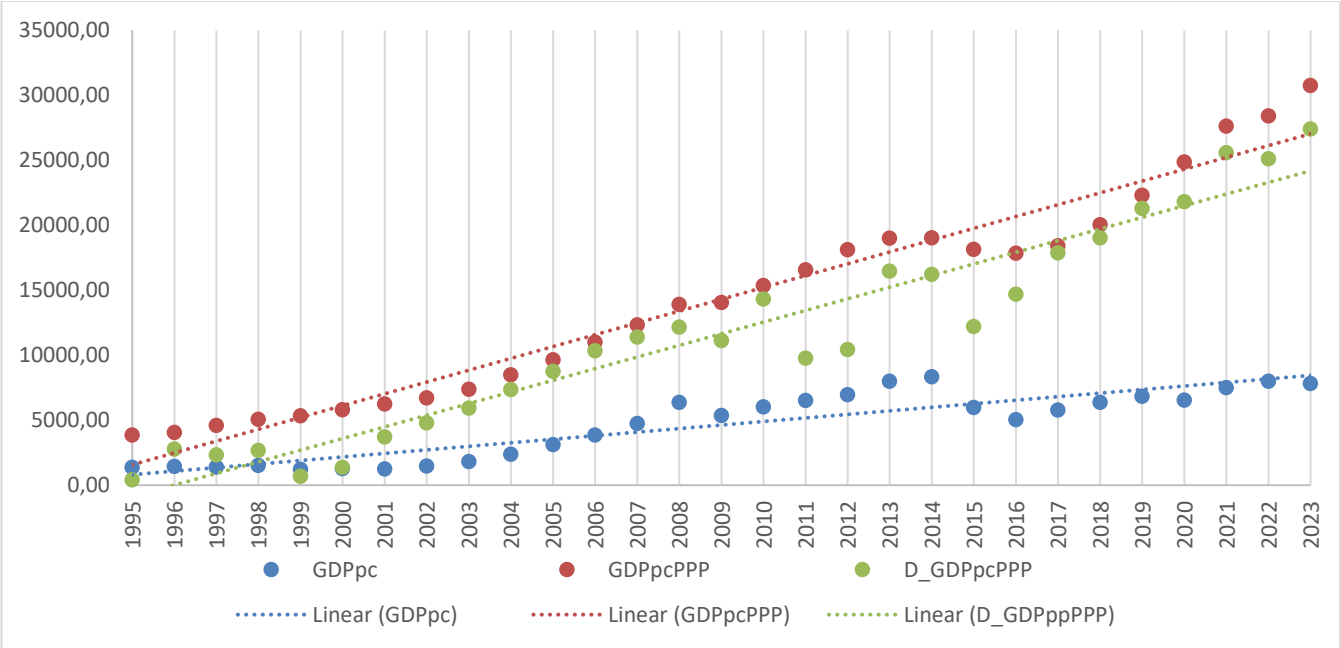
Graph 11: Sudan's GDPpc, GDPpcPPP and Weighted D_GDPpcPPP Data



Source: World Bank and author's own calculations.

Graph 11 shows that weighted D_GDPpcPPP points (green points) converges to the GDPpc points (blue points) when the sum of inflation and exchange rate changes are greater and to the GDPpcPPP points (red points) when the sum is lower.

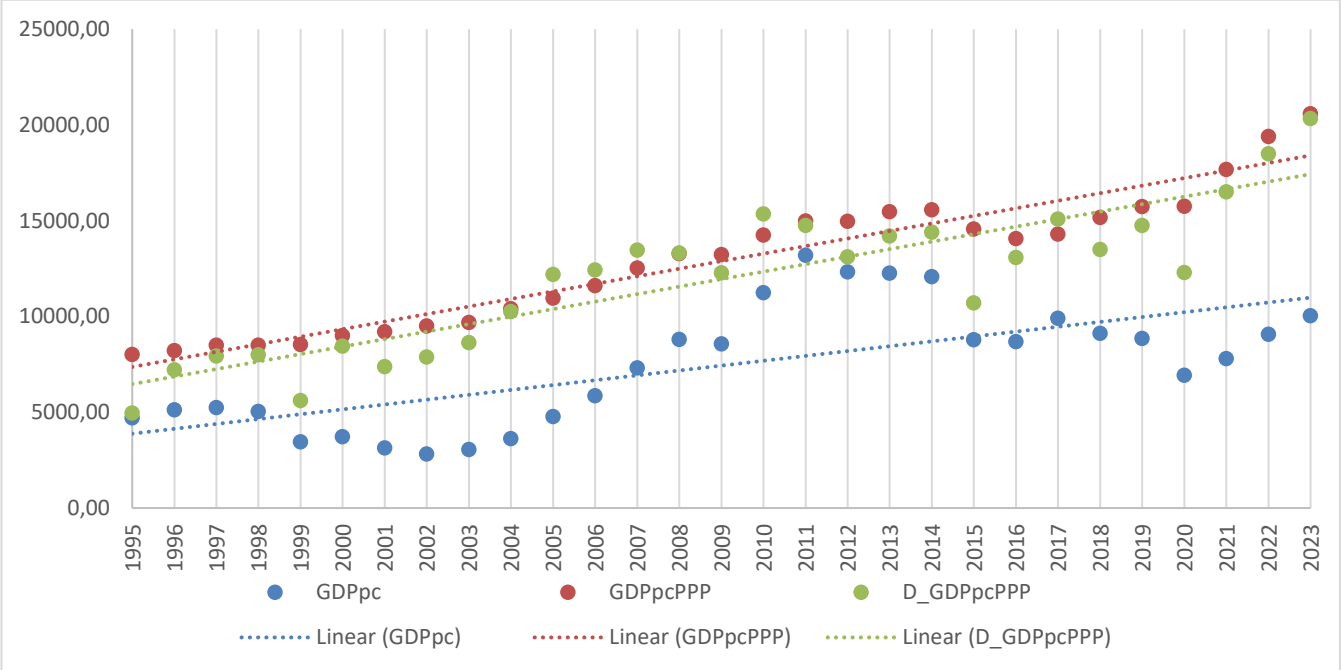
Graph 12: Belarus's GDPpc, GDPpcPPP and Weighted D_GDPpcPPP Data



Source: World Bank and author's own calculations.

It is indicated in Graph 12 that in some years (1995 and 1999) weighted D_GDPpcPPP points (green points) are lower than GDPpc points (blue points) and in some years like 2011 and 2012 weighted D_GDPpcPPP converges to GDPpc since the sum of inflation and exchange rate changes are high.

Graph 13: Brazil's GDPpc, GDPpcPPP and Weighted D_GDPpcPPP Data



Source: World Bank and author's own calculations.

Graph 13 show that weighted D_GDPpcPPP line (green line) follows a close path to GDPpcPPP line (red line) since Brazil is a relatively stable country in terms of macroeconomic indicators such as inflation, exchange rate change and the sum of these two.

6.2. Checking by Regression

In this section, robustness of the method is controlled by regression analysis. In order to do this, GDPpc is set as dependent variable and GDPpcPPP and D_GDPpcPPP variables are set as independent variables in two different models. That is to say that:

Model 1: $\text{GDPpc} = \alpha_0 + \alpha_1 GDPpcPPP + \varepsilon$ (13)

Model 2: $\text{GDPpc} = \beta_0 + \beta_1 D\_GDPpcPPP + \epsilon$ (14)

The rationale behind constructing these two models is as follows: if the explanatory power, R^2, of Model 2 is higher than the R^2 of Model 1, then the D_GDPpcPPP indicator developed in this study is more accurate than the traditional purchasing power parity-based GDP per capita (GDPpcPPPP). Table 9 presents country-based results for both models.

Table 11: Results of the Models

	Model 1 R^2	Model 2 R^2
Canada	0.77	0.94
Australia	0.85	0.93
Türkiye	0.67	0.79
Belarus*	0.83	0.86
Suriname	0.54	0.83
Brazil	0.82	0.91
Sudan*	0.72	0.79
Angola	0.66	0.78

Note: Dynamic OLS (DOLS) is chosen as the regression method. * indicates that a linear trend is used.

According to the regression analysis results in Table 11, the R^2 results of Model 2, which includes the D_GDPpcPPP variable, are higher in all countries. This shows that the GDPpc variable is explained by the D_GDPpcPPP variable more than GDPpcPPP, which means that the method described in the study is consistent and accurate.

7. CONCLUSION AND RECOMMENDATIONS

Many different macroeconomic indicators can be used as a baseline for comparisons between countries. One of the most commonly used indicators for comparing welfare levels is national income per capita. National income per capita can be calculated in constant prices based on a specific year or in current prices based on the current year, as well as according to purchasing power parity. These

three different calculations yield different values and the welfare status of countries can be seen in different ways. While calculations based on constant and current prices are generally consistent and produce similar results, calculations based on purchasing power parity can produce highly biased and erroneous results. Therefore, there is a need to update the per capita national income calculation based on purchasing power parity.

In this study, a new GDP per capita approach is introduced to reduce the excessive gap between GDP per capita calculated according to purchasing power parity (PPP) and dollar-based GDP per capita in some countries. This approach is based on a new national income calculation by updating the purchasing power of a country's currency with inflation and exchange rates. In line with the method proposed by the approach, GDP per capita calculated according to purchasing power parity is discounted with the inflation and exchange rate changes of the relevant year and increases or decreases in the purchasing power of the country's currency can be seen on GDP per capita. The applications of this new discounted GDP per capita approach proposed by the study are also given in the study and the results produced by the approach are evaluated in terms of sample countries.

Thanks to the new approach proposed in this paper, changes in purchasing power of countries are tracked together with national income per capita. In other words, the methodology, which is calculated through purchasing power parity and usually yields biased results in poor, underdeveloped or macroeconomically unstable countries, is updated and become more accurate. The newly introduced discounted GDP per capita approach provides a clearer and more consistent understanding of countries' purchasing power.

The proposed Discounted GDP Per Capita (D_GDPpcPPP) indicator provides a practical tool that can be used not only in academic discussions but also in the implementation of development policies. Traditional PPP-based per capita income indicators may overestimate the real welfare level, especially in countries experiencing macroeconomic imbalances such as high inflation and floating exchange rates. This may lead to artificial imbalances, especially in the indicators used by multilateral development organisations such as the World Bank, IMF and OECD in cross-country comparisons. For example, a country whose per capita income appears to be in the middle-income group according to PPP may be found to be closer to the low-income group as a result of the measurement made with D_GDPpcPPPP. Such deviations can lead to serious distortions in the distribution of development assistance, credit assessments or criteria for participation in international programmes.

In this context, the D_GDPpcPPP indicator can be a complementary measure that these organizations can use as an income indicator that reflects more dynamic and up-to-date macroeconomic conditions. Moreover, in the prioritization of development assistance, regional inequality analyses or the design of income distribution policies, such an indicator can offer sensitivity that nominal or PPP-based indicators cannot.

This new approach is expected to guide future studies. This study uses only inflation and exchange rates as discount factors. In future studies, other factors that affect the purchasing power of the currency, such as money supply and interest rate, can also be used as a discount factor. In this way, large deviations in GDP per capita calculated according to purchasing power parity can be eliminated and GDP per capita can be calculated according to real purchasing power.

DECLARATIONS

ACKNOWLEDGEMENTS

The author thanks the referees for their helpful advices.

FUNDING / SUPPORT INFORMATION

No financial support was received

CONTRIBUTIONS OF AUTHORS

The whole study is completed by single (corresponding) author.

CONFLICT OF INTEREST

The author declares that there is no conflict of interest.

DATA AVAILABILITY

The data are publicly available.

ETHICAL STATEMENT

No approval is required for this study.

ARTIFICIAL INTELLIGENCE (AI) USAGE STATEMENT

No AI-based tools were used in this study.

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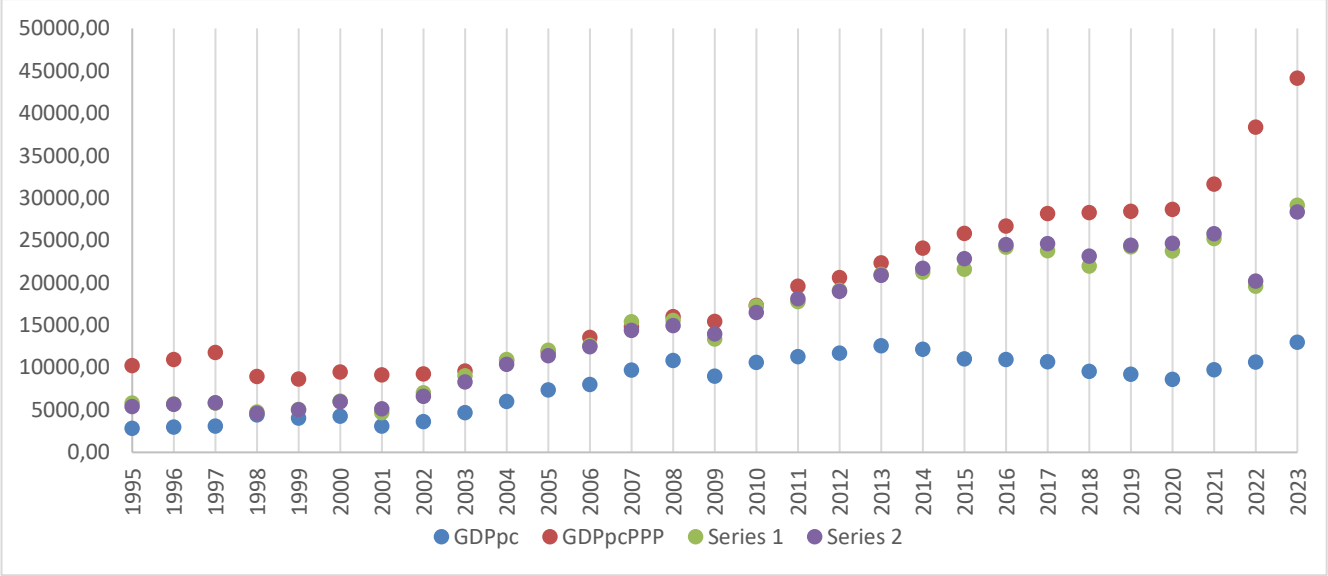
APPENDIX 1: Graphs for Other Values of α

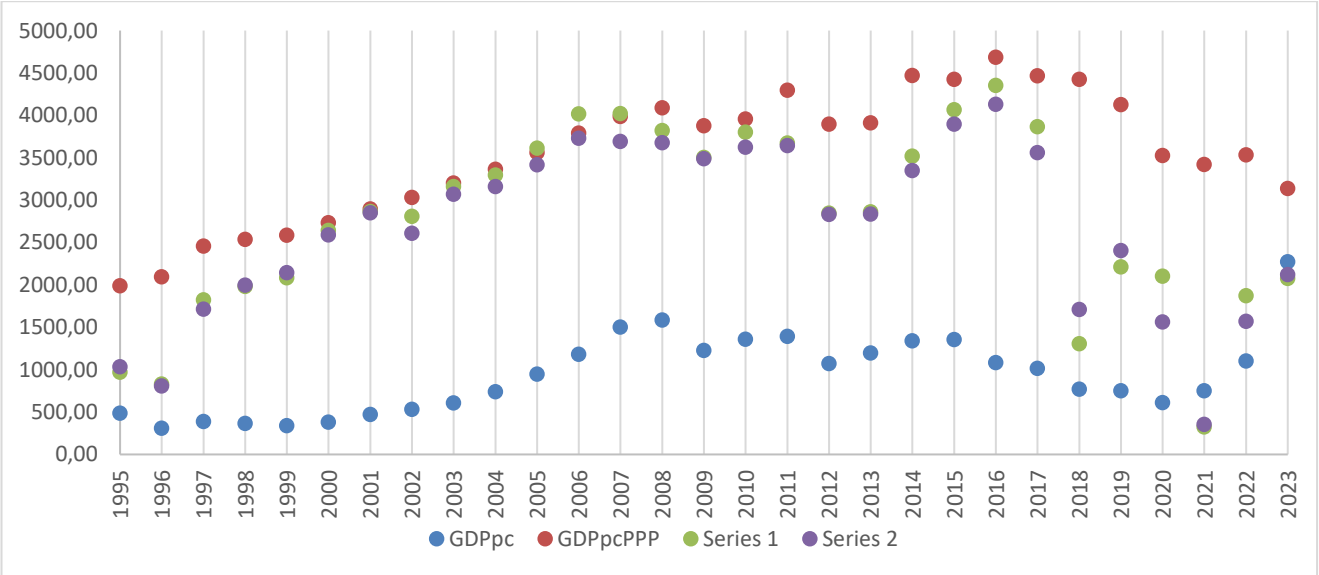
In the graphs, Series 1 (which is weighted by %30 inflation and %70 exchange rate) and Series 2 (which is weighted by %30 exchange rate and %70 inflation) is shown for Türkiye, Sudan, Belarus and Brazil. Especially in the years with greater inflation and/or exchange rate increases, Series 1 and Series 2 converge more to the GDPpc series. It can be seen by checking the values of each year for each country. For example, 2022 for Türkiye and Sudan, 2000 for Belarus and 2015 for Brazil is such years.

Graph14: Alternative Weightings for Türkiye



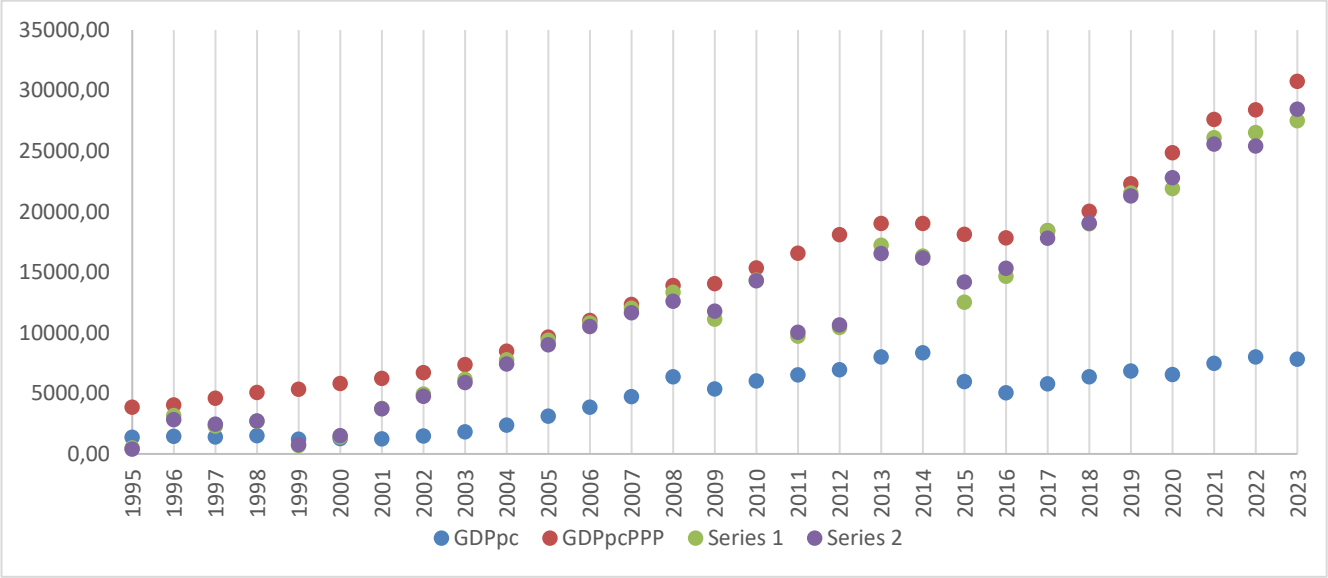
Source: World Bank and author's own calculations.

Graph15: Alternative Weightings for Sudan



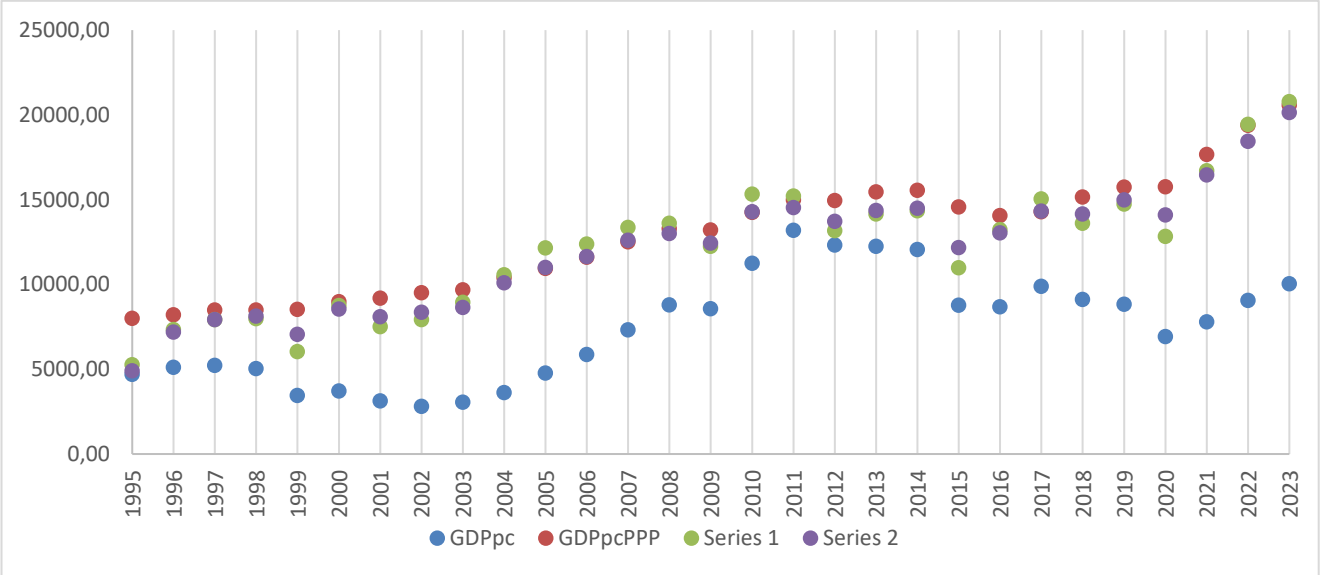
Source: World Bank and author's own calculations.

Graph16: Alternative Weightings for Belarus



Source: World Bank and author's own calculations.

Graph17: Alternative Weightings for Brazil



Source: World Bank and author's own calculations.