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Analysis

Economic Growth Quality, Environmental Sustainability, and Social Welfare in China - Provincial Assessment Based on Genuine Progress Indicator (GPI)

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ABSTRACT

In order to devise scientific and sustainable development strategy, it is vital to assess the quality of economic growth. As a useful complement to traditional economic indicators, GPI's most reputed virtue is its great improvement in evaluating environmental and social costs. In this paper we estimate the GPI for all 31 provinces in mainland China from 1997 to 2016. GPI estimation is highly sensitive to income inequality, climate change damage, and depletion of non-renewables. We address contestable methodological assumptions associated with the three items which have been usually ignored in empirical studies. We use the Atkinson index in place of the Gini index as a measure of income inequality. We avoid the problematic duplicated counting of climate change damage and the unjustified cost escalation factor in depletion of non-renewables. Our results show that: first, GPI per capita has recently declined in some provinces, unveiling a threat to social welfare and sustainability; second, the "relative threshold effect"—the progress of social welfare promotion is slower than the expansion of economic scale—has been found in many provinces; third, resource consumption and environmental pollution, especially water pollution and carbon emissions, would generate substantial welfare losses.

1. Introduction

Economic growth emphasizes the expansion of economic scale indicated by the intensity of economic activities, while economic development focuses on the promotion of economic growth quality, environmental sustainability, and social welfare. We have witnessed a rise of environmental concerns since the Reforming and Opening-up Policy, as concerns about resource exhaustion, environmental degradation, public health, as well as growing awareness of income inequality, crime, and underemployment, have together triggered the shift of our attention from sheer economic growth to real economic development.

Moreover, China is placing more weight on the quality of economic growth by formalizing it in important government documents. Since 2015, there have been increasing discussions about the adjustment for China's expected economic growth. The 13th Five-Year Plan proposes that China's economic scale in 2020 is expected to be twice the size of that in 2010, that is, a 6.8% annual growth rate, the second time that the expected growth rate is lowered. Such adaptation demonstrates that China's government has abandoned blind pursuits of economic indicators, and has put more emphasis on the quality of economic growth and sustainability.

However, despite the broad consensus that sustainable development has become a problem to be reckoned with, there remains the main issue that the difficulties and ambiguities in measuring economic growth quality are still preventing governments from establishing scientific strategies. In 1994, China published "*China's Agenda 21*: *White Paper on China's Population, Environment and Development in the 21st Century*", which specified the goals and framework of a sustainable economic and social system while conserving resources and maintaining environmental foundations for sustainable usage. In 1996, "*Further Promoting the Implementation of the China Agenda for the 21st Century*" suggested that "when conditions permit, local departments may, in the light of local circumstances, design and apply a sustainable development index". Afterward, local and central governments have cooperated with research institutes and have established several such indices, including indices established by the Ministry of Science and Technology, State Scientific and Technological Commission, Chinese Academy of Sciences, and China

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Center for International Economic Exchanges.[1] These indices are comprehensive, but too difficult to estimate, and therefore infeasible for cross-sectional assessments at the provincial level.

GPI, on the other hand, is an ideal index with both excellent comprehensiveness and feasibility. Herman Daly and John Cobb proposed the Index of Sustainable Economic Welfare (ISEW) in 1989 (Cobb and Daly, 1989), which emphasizes the genuine progress of society, measuring sustainable welfare. The first calculation of ISEW was done by Daly and John Cobb, using data of the United States from the year 1950 to 1986 (Cobb and Daly, 1989). The result was, the sustainable economic welfare measured by ISEW had not revealed any upward trend, although the economic growth measured by GDP had been increasing. In 1994, Clifford Cobb and John Cobb responded to issues and problems associated with their original version of ISEW raised by a number of critics, and presented a revised version (Cobb and Cobb, 1994). Based on ISEW, GPI was then created by Clifford Cobb, Ted Halstead, and Jonathan Rowe in 1995 (Cobb et al., 1995). Since then, researchers and non-profit organizations have been attempting to calculate the GPI of many countries, including the United States, Austria, Canada, Chile, France, Italy, and the Netherlands, which serves as a positive motivation for the government to take actions. For instance, the state of Maryland, US, has selected GPI as its formal index to evaluate sustainable economic welfare, and has estimated the state's GPI from the year 1960 to 2013. Finland's government has also calculated its GPI from the year 1945 to 2011. As the data needed in estimating GPI have become more available in the recent years, the index has acquired a broader recognition as a relatively feasible approximation of economic welfare (Kubiszewski et al., 2013). Talberth and Weisdorf (2017) further devised the GPI 2.0 to resolve theoretical inconsistencies of the former GPI version. The GPI 2.0 directly ties social welfare function with the utility from positive components and disutility from negative components, which requires a specific functional form of utility.

However, there have been concerns and critiques about the use of ISEW and GPI. Neumayer (1999, 2000), Cracolici et al. (2010), and Dale et al. (2013) all criticized their arbitrary assumption and selection of the component variables. Neumayer (1999) proposed that ISEW and GPI neglects technological development and the increase in human capital, and that simple aggregation of different components depends on the oversimplified assumption that there is perfect substitution between natural and other forms of capital. Bleys and Whitby (2015) pointed out that no two studies use the same methodology, making the results incomparable. In response, Lawn (2003) provided a theoretical foundation to support ISEW and GPI, arguing that both indices serve as a good indicator of income and welfare because they are consistent with Fisher's concept of income and capital (Fisher, 1906). Furthermore, Lawn (2005) responded to the critiques regarding valuation methods, stating that many of the methods are legitimate, and only a small number are questionable and need refinement or replacement. Lawn, still, admits that ISEW and GPI need a more robust and consistent set of valuation method, yet some critiques are rather unreasonable. For example, ISEW and GPI are criticized for their being limited to the national scale (Dale et al., 2013), while in fact, subnational estimation has appeared in literature, and a GPI breakdown analysis has been seen in many studies.

We completely agree that ISEW and GPI are not perfect indicators for measuring sustainability or welfare, but they are good approximations. In addition, we do not believe that ISEW or GPI should replace GDP. Instead, we believe that GPI can be a vital supplementary index which can provide additional insights on the quality of economic growth. Furthermore, after decades' modification, both the ISEW's and GPI's calculation approach, precision, and comprehensiveness of components have all been improved substantially (Clifford Cobb et al., 1995, 2001; Talberth et al., 2007).

Initially, studies on ISEW and GPI mostly focus on developed countries at national level. Now literature gradually stretches its tentacles to a wider range of space and time, with developing countries slowly coming onto stage and an increasing number of studies gradually detailing down to smaller geographical areas such as states and cities. Table 1 is the summary of ISEW and GPI studies.

Some empirical studies have illustrated the "Threshold Hypothesis" proposed by Max-Neef (1995), where he postulated that:

> *There seems to be a period in which economic growth (as conventionally measured) brings about an improvement in life quality, but only up to a point - the threshold point - beyond which, if there is more economic growth, quality of life may begin to deteriorate.*

The threshold is a finite scale of macro-economy, beyond which the social welfare starts to diminish. We have summarized whether the empirical studies have proven the "Threshold Hypothesis" in the last column of Table 1. Among the studies cited in Table 1, about 1/3 have found an explicit threshold, and another 1/3 have presented a stagnant or slowing downward trend of welfare.

However, Neumayer (2000) believed that the "Threshold Hypothesis" is an artifact of highly controversial methodological assumptions. These concerns are addressed in Section 2 Method, where we try to improve the methodology of GPI valuation for more reliable results.

So far, there are few empirical studies on China's ISEW/GPI, nor are there any studies that evaluate social welfare at provincial level or explore the differences of social welfare and life quality between provinces. Therefore, we estimate the GPI of all 31 provinces, province-level municipalities, and autonomous regions in mainland China from year 1997 to 2016, to provide some insights on their economic growth quality, environmental sustainability, and social welfare.

In this paper, Section 2 presents the index system of GPI, and how we address the concerns about some of its controversial methodological assumptions with a detailed methodology for each item of GPI in Appendix A.2. Section 3 presents the results and analysis. Section 4 concludes and provides policy implications on sustainable development.

2. Method

GPI consists of three accounts: economy, environment, and society, and correspondingly covers three aspects: economic growth quality, environmental sustainability, and social welfare. Each account has a set of positive and negative items. Positive items are the welfare-relevant contributions, such as the value of domestic labor (housework and parenting) and services from public infrastructure. Negative items are the welfare-relevant losses, such as long-term environmental damage, depletion of non-renewables, and income inequality.

In this paper, the original GPI index system has been necessarily adjusted. The adjustments and their rationales are presented in Appendix A.1. Our modified GPI index system is shown in Table 2.

There are some highly controversial methodological assumptions related to the GPI index. The three mostly questioned assumptions are related to three GPI items respectively: income inequality, long-term environmental damage (or damage of climate change), and depletion of non-renewables. GPI valuation is highly sensitive to the estimations of the three items

[1] The index by the Ministry of Science and Technology has 196 qualitative items and 100 quantitative items, covering economy, society, population, resource, environment and education. The index by State Scientific and Technological Commission has goal layer, principle layer, and indicator layer, each with multiple items. The index by Chinese Academy of Sciences contains 57 variables and 415 elements, covering economic growth, urbanization, innovation, culture, public safety, natural resource and environment, etc. The most recent one is designed jointly by China Center for International Economic Exchanges and Columbia University, which was released in December 2017. The index system has three accounts: economic, social, and environmental. It further classifies environmental account into three subaccounts: ecological environment, pollution and depletion, and emission abatement. Each of the five (sub)accounts has 6 or 7 indicators. The provincial estimation shows that the growth rate of this sustainable development index is slower than the growth rate of economic index after GDP per capita reaches 50 thousand Yuan in China.

Table 1
A summary of ISEW and GPI studies.

	Scope	Period	Study	Threshold hypothesis?[a]
Globe	Global	1950–2003	Kubiszewski et al. (2013)	Yes
Selected countries	US, UK, Germany, Austria, Netherlands, Sweden	1950–1992	Jackson and Stymne-Airey (1996)	Yes
Asia-Pacific	Australia, New Zealand, Japan, China, Thailand, India, Vietname	1967–2006	Lawn and Clarke (2010)	Yes
China	Suzhou, Ningbo, Guangzhou, Yangzhou	1991–2001	Wen et al. (2007)	Weak
	Liaoning	1978–2011	Hou (2017)	Weak
US	National	1950–1997	Anielski and Rowe (1999)	Yes
	National	1950–2002	Venetoulis and Cobb (2004)	Weak
	National	1950–2005	Beça and Santos (2010)	Weak
	Baltimore City, Baltimore County, Maryland	1950–2010	Posner and Costanza (2011)	Yes
	Utah	1990–2007	Berik and Gaddis (2011)	No
	Vermont, Chittenden County, Burlington	1950–2000	Costanza et al. (2004)	No
	Northeast Ohio	1950–2005	Bagstad and Shammin (2012)	No
	Baltimore	1950–2005	Posner (2010)	Weak
	Hawaii	2000–2009	Ostergaard-Klem and Oleson (2014)	No
	Oregon	1960–2010	Kubiszewski et al. (2015)	Weak
	Fifty states	2011	Fox and Erickson (2018)	No
UK	National	1950–1996	Jackson et al. (1997)	Yes
Canada	Alberta	1961–1999	Anielski (2001)	Yes
	Edmonton	1981–2007	Anielski and Johannessen (2009)	Weak
Australia	National	1950–1996	Hamilton (1999)	Yes
	National	1950–2000	Hamilton and Denniss (2000)	Weak
	Victoria	1986–2003	Lawn and Clarke (2006)	Weak
Greece	National	2000–2012	Menegaki and Tsagarakis (2015)	No
Belgium	National	1970–2004	Bleys (2008)	Weak
Austria	National	1955–1992	Stockhammer et al. (1997)	Weak
Italy	National	1960–1990	Guenno and Tiezzi (1998)	No
	Siena	1999	Pulselli et al. (2006)	No
	Tuscany	1971–2006	Pulselli et al. (2012)	Weak
	North, center and south	1999–2009	Gigliarano et al. (2014)	No
Spain	National	1970–2012	O'Mahony et al. (2018)	Yes
Chile	National	1965–1995	Castaneda (1999)	Yes
Brazil	National	1970–2010	Andrade and Garcia (2015)	No
Poland	National	1980–1997	Gil and Sleszynski (2003)	No
Japan	National	1970–2003	Makino (2008)	No
	National (rural and urban)	1975–2008	Hayashi (2015)	No
Thailand	National	1975–1999	Clarke and Islam (2005)	Yes

[a] "Yes" means that the study has found a significant threshold. "Weak" means that the study does not find a significant threshold, but presents a stagnant or slowing down trend of ISEW/GPI. "No" means that the study does not find any signal of the threshold.

(Neumayer, 2000), yet most studies have not addressed these assumptions carefully. The concerns are illustrated and addressed respectively as below:

(1) Income inequality

Consumption expenditures are adjusted by income inequalities, which, in previous literature, are measured by two indices: the Gini index and the Atkinson index.

The Gini index, which is the ratio between the area of inequality formed by the Lorenz curve to the area of complete inequality, has been applied by a large body of research as a measure of income inequality. Still, the index suffers from criticism. First, as Stymne and Jackson (2000) and Dietz and Neumayer (2006) pointed out, the Gini index is not tied to any social welfare function. Second, the society's aversion to income inequality is not explicitly reflected in the Gini index, which means the index does not "fully quantify the way inequality tracks with welfare" (Howarth and Kennedy, 2016). Third, the Gini index does not reflect the principle of diminishing transfers – "the effect of a transfer diminishes as the absolute level of income increases" (Stymne and Jackson, 2000). Fourth, in studies using the Gini index, the index of the first year of the studied period—the base year—is set as 100, and all subsequent years' are relative indices to the base year, which means the results can only reflect the improvement or deterioration in income inequality over time, rather than the actual level of income inequality (Makino, 2008). Hence, GPI results calculated with the application of the Gini index cannot be interpreted as the absolute level of GPI, making it hard to compare with the absolute level of GDP.

The Atkinson index, on the contrary, makes explicit the researchers' assumptions regarding society's aversion to income inequality (Jackson et al., 2008), and bases its assumptions on social welfare function.

Table 2
Modified GPI index system.

Account	Item	Contribution
Economic account	Personal consumption expenditures	+
	Income inequality	−
	Services of consumer durables	+
	Cost of consumer durables	−
	Cost of underemployment	−
	Net capital growth	±
Environmental account	Cost of water pollution	−
	Cost of air pollution (CO_2, SO_2, TSP)	−
	Cost of solid waste pollution[a]	−
	Change of wetlands	±
	Change of forest	±
	Long-term environmental damage (CO_2, CH_4, etc.)	−
	Depletion of non-renewables	−
	Cost of natural disaster[a]	−
Social account	Value of domestic labor	+
	Cost of family breakdown	−
	Cost of crime	−
	Value of volunteer work	+
	Change of leisure time	±
	Non-defensive public expenses on education and health	+
	Defensive private expenditure on education and health	−
	Services from public infrastructure	+
	Cost of commuting	−
	Cost of auto accidents	−

[a] Newly added items.

Stymne and Jackson (2000) and Howarth and Kennedy (2016) argued that the Atkinson index should be used in the GPI valuation to measure the welfare losses caused by economic inequality. Makino (2008), Jackson et al. (2008) and Hayashi (2015) adopt Atkinson index in their ISEW or GPI studies.

The adjusted average income $\widetilde{W}$ (reflecting income equality) is:

$$\widetilde{W} = \overline{W}\left[\sum_{i=1}^{n} (W_i/\overline{W})^{1-\varepsilon} P_i\right]^{1/(1-\varepsilon)}$$

where P_i represents the proportion of the population with income in the i^{th} range, W_i denotes the average income of group i, $\overline{W}$ denotes the average income of the whole population, and ε is the society's aversion to income inequality. ε equals to 0 for no aversion to inequality, and ε equals to ∞ for extreme aversion to inequality.

The Atkinson index is then defined as:

$$A = 1 - \frac{\widetilde{W}}{\overline{W}}$$

Equivalently,

$$A = 1 - \left[\sum_{i=1}^{n} (W_i/\overline{W})^{1-\varepsilon} P_i\right]^{1/(1-\varepsilon)}$$

The choice of the value for parameter ε is crucial in estimating income inequality. According to Latty (2011) of literature on the estimation of the parameter, the value 1.5 is consistent with a broad range of existing works.

In this paper we adopt the Atkinson approach (Results for Atkinson index are presented in Appendix A.3). Limited by data availability, we first estimate the Atkinson index for urban and rural population respectively, and then we calculate the overall Atkinson index through group weighting (Sundrum, 2003). The group weighting method is defined as:

$$A = P_u^2 \frac{W_u}{\overline{W}} A_u + P_r^2 \frac{W_r}{\overline{W}} A_r + P_u P_r \frac{W_u - W_r}{\overline{W}}$$

where A_u and A_r are the Atkinson index for urban and rural residents, P_u and P_r represents the proportion of urban and rural population, W_u and W_r represents average income in urban and rural areas, and $\overline{W}$ represents average income for the whole population.

Then, the private consumption expenditure is adjusted by the Atkinson index as:

$$E_{adj} = E(1 - A)$$

The above formula implies that a province with an Atkinson index of value A could achieve the same level of social welfare with only (1-A) percent of its current total income if total income is equally distributed.

(2) Long-term environmental damage

The long-term environmental damage, or the costs of climate change caused by greenhouse gas emissions, especially CO_2, is a crucial item in GPI valuation.

There are two ways to calculate the long-term environmental damage caused by greenhouse gas emissions. First, the product of social costs of carbon multiplied by carbon emissions can serve as a direct estimation of the climate change damage. The social cost of carbon is sensitive to modelling method, value judgment, stringency of controls, and society's willingness to tolerate catastrophic risks (Howarth et al., 2014). Second, since the long-term damage is proportional to the consumption of fossil fuels, we can begin with the fuel consumption, and multiply it with a tax or rent per barrel-equivalent fossil fuel. Cobb and Cobb (1994) justified the rationale behind using the second approach with the idea that the tax or rent represents the money to be set aside in order to compensate future generations for long-term environmental damage.

We should consider the cumulative impacts of carbon emissions (Jackson, 2004). The social cost of carbon or fuel rent serves as an indicator of the cumulative impacts, because it reflects the total present value of all future damages caused by the marginal amount of emission (Neumayer, 2000). However, many studies have mistakenly deducted the present value of total damage in the present year, as well as in all subsequent years, which results in duplicated counting of total future damage (Neumayer, 2000).[2] The duplicated counting largely affects the valuation of GPI, making the "threshold effect" found in those studies untenable. As Neumayer (2000) summarizes, about 33% of all deduction items in the US in 1990, 23% in the UK in 1996, and 30% in the Sweden in 1992 are the duplicated counting of long-term environmental damage, and "threshold effect" would not exist if eliminating such duplicated counting. Bleys (2008) applies a linear depreciation model of atmospheric stock of greenhouse gases to limit duplicated counting, yet the problem still seems to exist (O'Mahony et al., 2018).

Another problem is the ignorance of the variance of damages across time. The present value of future damages should be discounted to the present year at a discount rate, given a damage curve for a marginal ton of CO_2 emitted in each year. A few studies have avoided the problematic duplicated counting, but have failed to apply damage curve (O'Mahony et al., 2018). In this paper we choose a discount rate of 3% as suggested by Interagency Working Group in the US Department of Energy (2010). Following O'Mahony et al. (2018), we also adopt the damage curve detailed in Ackerman and Stanton (2012).

(3) Depletion of non-renewables

There are two ways to compute cost of depletion of non-renewable resources: the resource rents method by El Serafy (1989), and the replacement costs method by Cobb and Cobb (1994). The former was applied by Guenno and Tiezzi (1998) and Pulselli et al. (2006), while the latter by Costanza et al. (2004) and Bleys (2008). The replacement

[2] Please note that what we describe as "problematic" is the duplicated counting of cumulative impact, rather than the cumulative impact itself.

costs refer to the costs of future replacement of non-renewable fossil fuel with renewables. Neumayer (2000) criticized the rationale behind the replacement costs method because he believed that there is no reason why renewables have to replace non-renewables in the present when there are still abundant non-renewables. Lawn (2005) disagreed with Neumayer by arguing that the ISEW is an index focusing on sustainability. Despite the fact that our existing reserve of non-renewables can sustain for some time, this does not guarantee indefinite sustainability, so we should estimate them as if they were replaced currently. Since the resource rents method requires a larger database, including income arisen from resources or prices of resources, both of which are unavailable, the replacement costs method is employed here.

A debate about the replacement costs method concentrates on the cost escalation factor, which is based on the assumption that the replacement costs increase over time, with the rationale that exploration and drilling become increasingly difficult when approaching the limits of non-renewables. The cost escalation factor is estimated to be 6% for non-renewables (Cobb and Cobb, 1994). For renewables, it is 'not as dramatically as to oil and gas' (Neumayer, 2000), so the overall cost escalation factor is assumed to be 3% in some literature.

However, some argue that a declining replacement cost would be more logical (Neumayer, 2000). First, as technology develops, costs may fall over time (Lenssen and Flavin, 1996). Second, as the scale of renewables increase, the marginal cost of replacements from non-renewables to renewables tends to drop due to the economies of scale. Bleys (2008) has excluded the cost escalation factor in his study.

Considering the ideas of both parties, in this paper we assume that the replacement costs remain constant with no escalation. For comparison, we also conduct sensitivity analysis by employing a 3% escalation factor.

The detailed methodology for all items is presented in Appendix A.2. Each item is converted into year 1997 US dollars before adding up to final GPI. For simplicity, the following text uses USD instead of 1997 US dollars.

3. Results and Discussions

3.1. GPI Trends

GPI and GDP per capita of each province are depicted in Fig. 1. Detailed results are presented in Appendix A.5.

First, in most provinces of China, there exists an increasing trend of GPI per capita despite certain fluctuation, meaning that these provinces have been embracing a promotion of social welfare. However, in some provinces, including Hebei, Inner Mongolia, Liaoning, Jilin, Guangxi, Gansu, Qinghai, Ningxia and Xinjiang, a decreasing tendency of GPI per capita has emerged, possibly uncovering a decline in the quality of economic growth, implying the potential threat to environmental sustainability and social welfare in these provinces.

Second, most provincial GPI per capita are lower than their GDP per capita, indicating that in general, traditional national economic accounting overestimates real social welfare because it leaves out the negative contributors. However, for Tibet and Qinghai, in some years GPI is even higher than GDP, because their environmental damages and consumption of non-renewable resources are much lower. It is actually possible, though rare, for GPI to surpass GDP when welfare contributors ignored in GDP such as domestic and volunteer work are taken into the picture while welfare losses ignored in GDP are insignificant.

Third, although GPI and GDP are both rising, the gap between GPI and GDP is widening despite certain fluctuation in most provinces, such as Beijing, Tianjin, Hebei, Inner Mongolia, Jilin, Shanghai, Jiangsu, Zhejiang, Shandong, Fujian, Henan, Hubei, Hunan, Guangdong, Guangxi, Chongqing and Shaanxi. This widening gap illustrates the "relative threshold effect" - the promotion of social welfare lags behind the growth of economic scale.

Fourth, the adjustments made regarding the three methodological assumptions described in Section 2 have led to a significant difference in results. Fig. 2 presents the national GPI per capita over time under various assumptions. First, the 3% escalation factor in the replacement costs of non-renewables does not make a big difference. However, if we adopt a 6% escalation factor, as suggested in Cobb and Cobb (1994), GPI per capita is 13.7% lower than the case where there is no escalation factor in 2016 (see Appendix A.6). Second, if employing the Gini index to measure income inequality, GPI per capita is approximately 10% smaller than that when the Atkinson index is used. Third, according to Neumayer (2000), the duplicated counting of cumulative climate change costs raises the most severe problem, and in our estimations it would result in over 30% shrinkage of the GPI per capita. In total, the three problematic methodological assumptions can cut GPI by half.

3.2. GPI Between Provinces

The average GPI per capital over the studied period 1997–2016 is presented in Fig. 3 for a comparison analysis between provinces.

First, Shanghai, Beijing and Tianjin rank the first three, which are also the three most developed provinces with the highest GDP per capita. All three are direct-administered municipalities. Beijing and Shanghai are the centers of Jing-Jin-Ji urban agglomeration and Yangtze River Delta respectively, so both have benefited from economies of scale and network effects (Long et al., 2017). The high concentration of economic activity in Beijing and Shanghai is a critical contribution to their economic development, which improves life quality at these cities. Tianjin is geographically close to Beijing, so it can benefit from the spillovers of Beijing's technological innovation and human resource. Furthermore, the ongoing relocating of non-capital functions of Beijing to Tianjin and Hebei will further drive the coordinated development of Jing-Jin-Ji region.

Second, Shanxi and Hainan rank lowest. Shanxi serves as China's biggest coal producer—contributing about one quarter of China's national coal production. The cost of long-term environmental damages in Shanxi is estimated to be $14.8 billion in 2016, accounting for 18.5% of all its negative components. Hainan's net capital growths are negative from year 1997 to 2005, leading to more than 10% of welfare losses, which largely influences Hainan's GPI estimation.

Third, an east-west disparity in GPI exists, but is less severe than that in GDP. The eastern provinces' coastal locations and commercial infrastructure facilitate their international trade, while market mechanism further spurs the concentration of economic capacity along China's east coast. As a result, the GPIs of the eastern provinces are generally higher than those of the western provinces. However, western provinces suffer less from air and water pollution and depletion of non-renewables. Particularly, Qinghai and Tibet, two "poor" provinces in terms of GDP, are not "poor" in terms of GPI, due to less pollution, lower crime rate and lower family breakup rates.

Fourth, geographical disparity decreases over time. Fig. 4 presents the GPI per capita in 1997 and 2016 respectively. The relative standard deviation of provincial GPI per capita has been decreasing from 72.7% in 1997 to 34.1% in 2016,[3] a large portion of the reduction attributed to the decline in years 2001, 2002 and 2006. Such catch-up reflects that the geographical development has been converging in China. The rebalancing pattern is in part attributed to the convergence in manufacturing industry since the end of the 1990s (Lemoine et al., 2014), as the year 2000 witnessed the kick off of the "Western Development" plan, covering a whole span of the development of infrastructure, attraction of foreign investment, and better education. From 2000 to 2016, the Chinese government has invested 6.35 trillion Yuan in infrastructure and energy projects in western provinces. With the new "Belt and Road" policy since 2013, which aims partly at enhancing regional connectivity with Central Asia and South-East Asia, and

[3] The standard deviation is increasing from 1997 to 2016, as shown in the Fig. 3a and b; however, standard deviation is misleading when comparisons are made across dissimilar results. The average GPI per capita in 2016 is much higher than that in 1997; thus the deviation looks larger. Relative standard deviation ensures a more reliable comparison for variability.

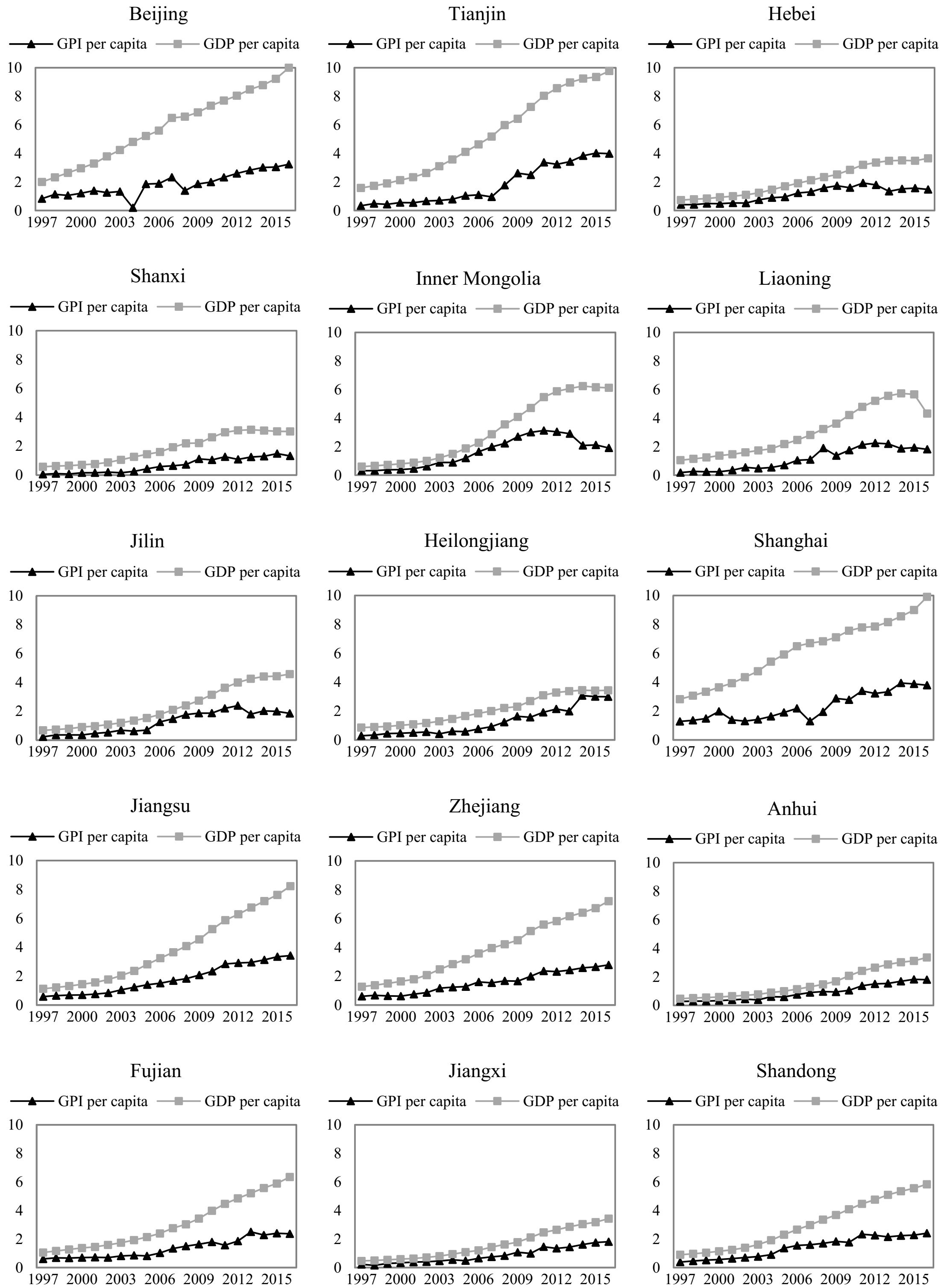


Fig. 1. GPI per capita and GDP per capita (thousand USD) by provinces, 1997–2016.

thereby boosting the economies of provinces adjoining those areas, we may expect to see the convergence to continue.

Fifth, economic and social disparity patterns are similar—the eastern regions performing better than the westerns, while environmental disparity pattern is opposite—the eastern worse than the westerns, as shown in Fig. 5. Economic activities, on one hand, generate revenue, incentivize development of infrastructure, improve education and health qualities, and therefore resulting in a similar social disparity pattern to the economic one. However, economic activities lead to more pollutant emissions and resource consumptions, indicating that the eastern regions might suffer more from environmental pollution and resource degradation.

3.3. GPI Breakdown

Breakdowns of GPI shown in Fig. 6 depict the trend of its economic, environmental and social components. Economic account is the biggest contributor to overall GPI. Our results have shown that provinces with good economic performance measured by GDP are all in the upper half

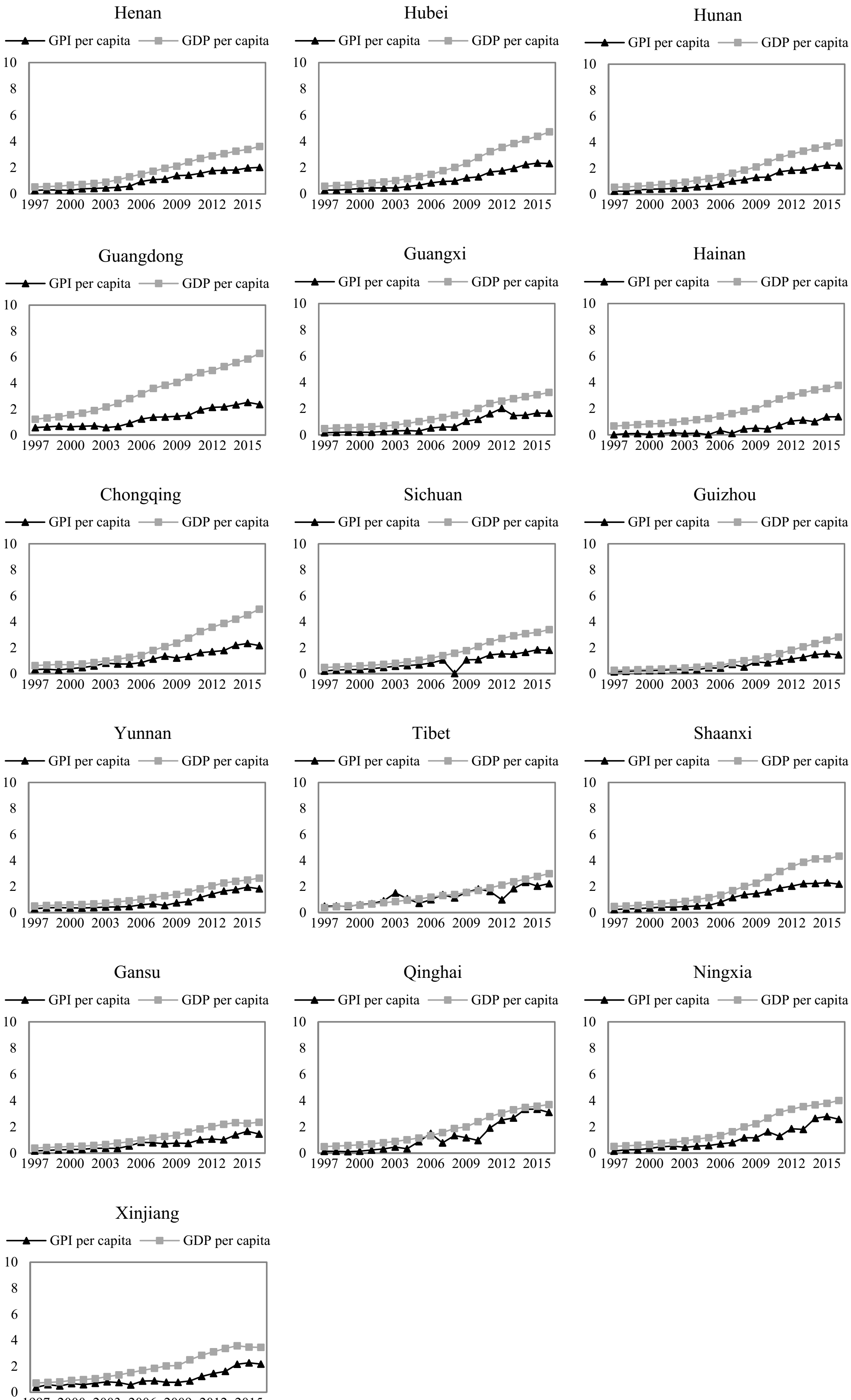


Fig. 1. (*continued*)

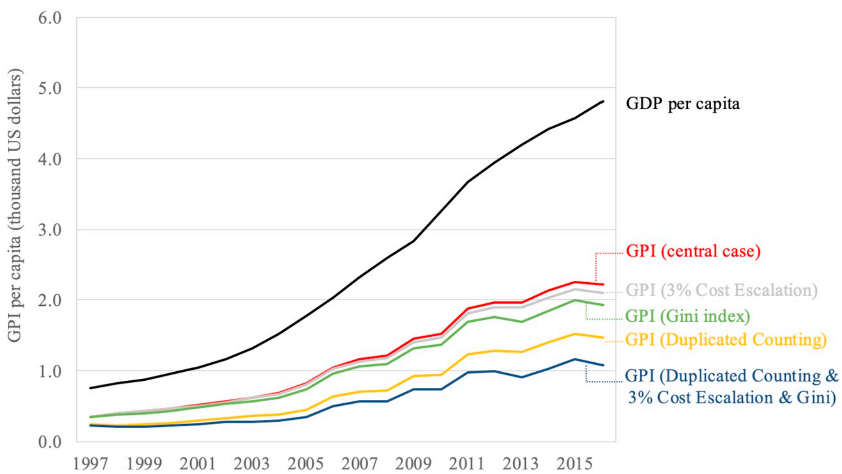


Fig. 2. National GPI per capita under various assumptions, 1997–2016.

Scenarios	Income inequality	Duplicated counting of cumulative climate change cost	Cost escalation factor in depletion of non-renewables
Central case	Atkinson	No	No
3% Cost escalation	Atkinson	No	3%
Gini index	Gini	No	No
Duplicated counting	Atkinson	Yes	No
Duplicated counting & 3% Cost escalation & Gini	Gini	Yes	3%

of the GPI list. Environmental costs and net social benefits are very close, to the extent that they often offset each other. Environmental costs even surpassed net social benefits since 2013, though the growth trend of environmental costs has slowed down since then. The trend of net economic benefits and environmental costs are smoother than net social benefits, and thereby the fluctuation pattern of overall GPI over 1997–2016 resembles the fluctuation pattern of social account, with a decrease trend in recent years.

A more detailed breakdown of China's national GPI in 2016 is presented in Fig. 7.

First, private consumption expenditure, capital growth and value of domestic labor are the three biggest contributors to GPI. As the starting point of GPI, private consumption expenditure accounts for 40.8% of all positive components combined. Capital growth is necessary to ensure an increasing or constant supply of capital per worker, and sustain the long-term economic welfare (Pulselli et al., 2006). As shown in Fig.1, there is a sharp decrease in GPI in Beijing in 2004 and Shanghai in 2007, both caused by a negative net capital growth, showing that the sustainability of capital investment can significantly influence the overall sustainability. Last but not least, the value of domestic labor contributes largely to social welfare, and leaving it out of the picture has long been one of the main critiques of the GDP.

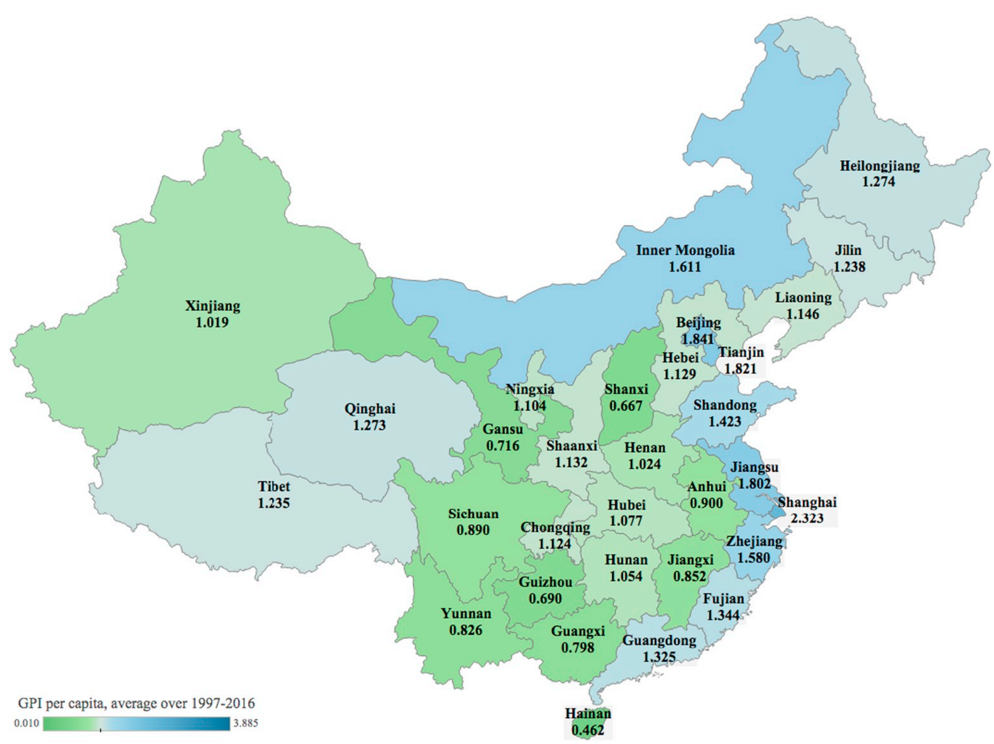
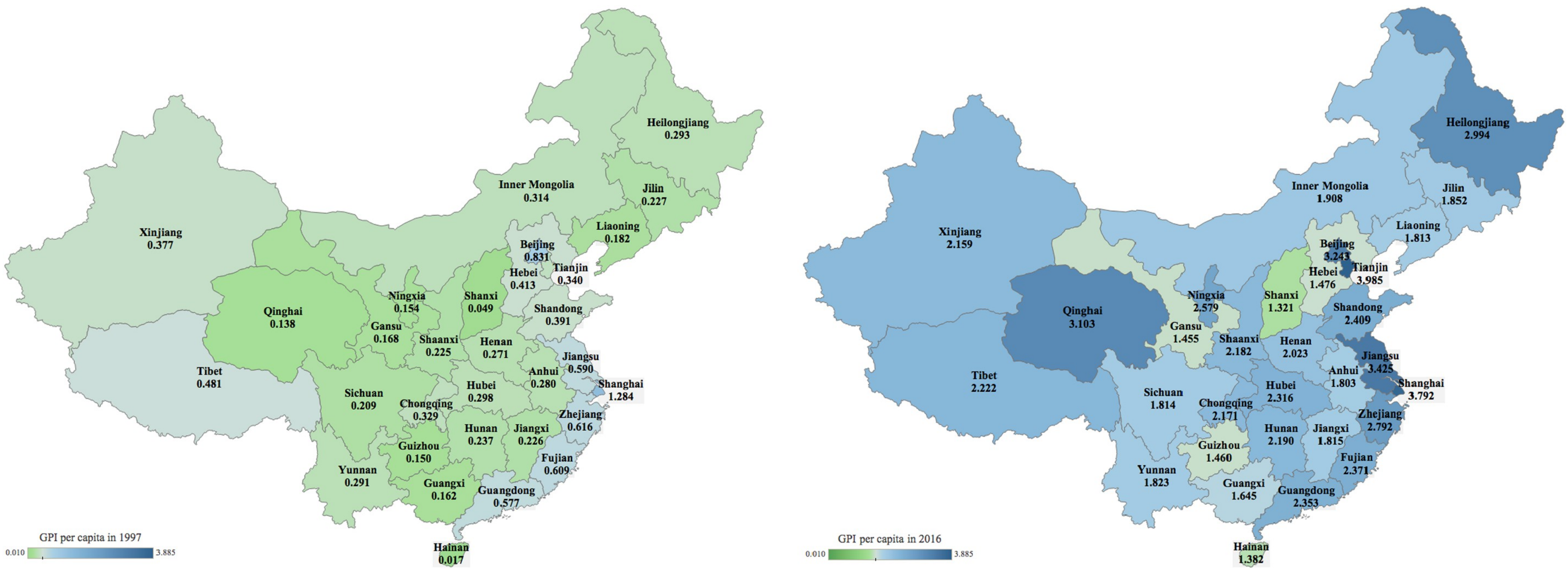


Fig. 3. Average GPI per capita over 1997–2016 (thousand USD).



(a) 1997 (b) 2016

Fig. 4. GPI per capita (thousand USD).

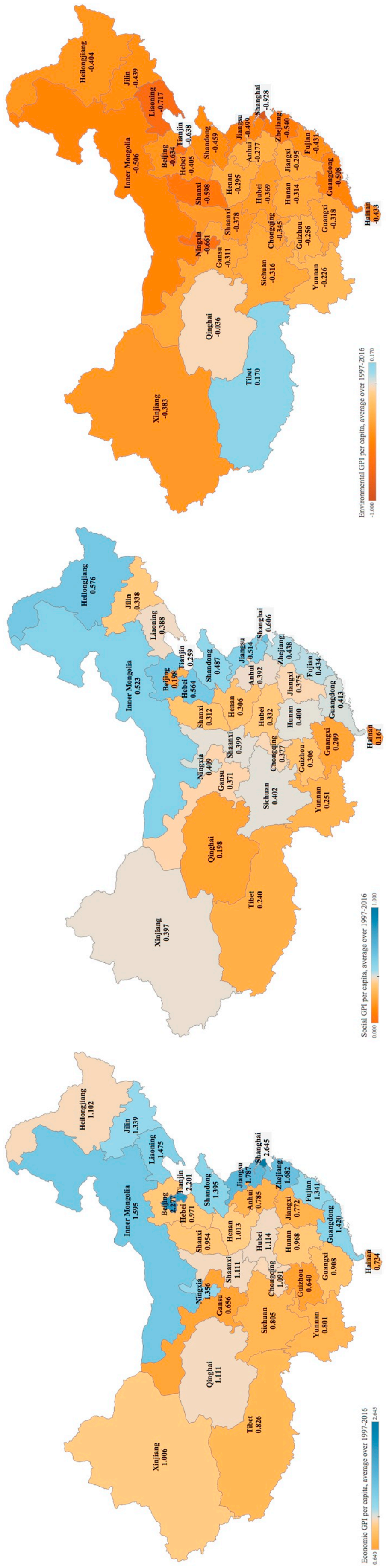


Fig. 5. Economic, social and environmental GPI per capita, average over 1997–2016 (thousand USD).

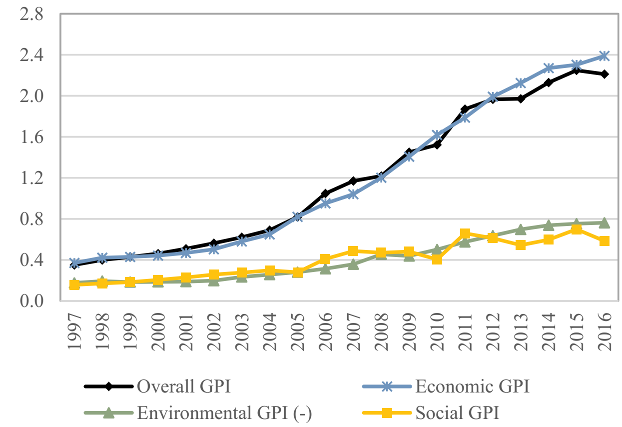
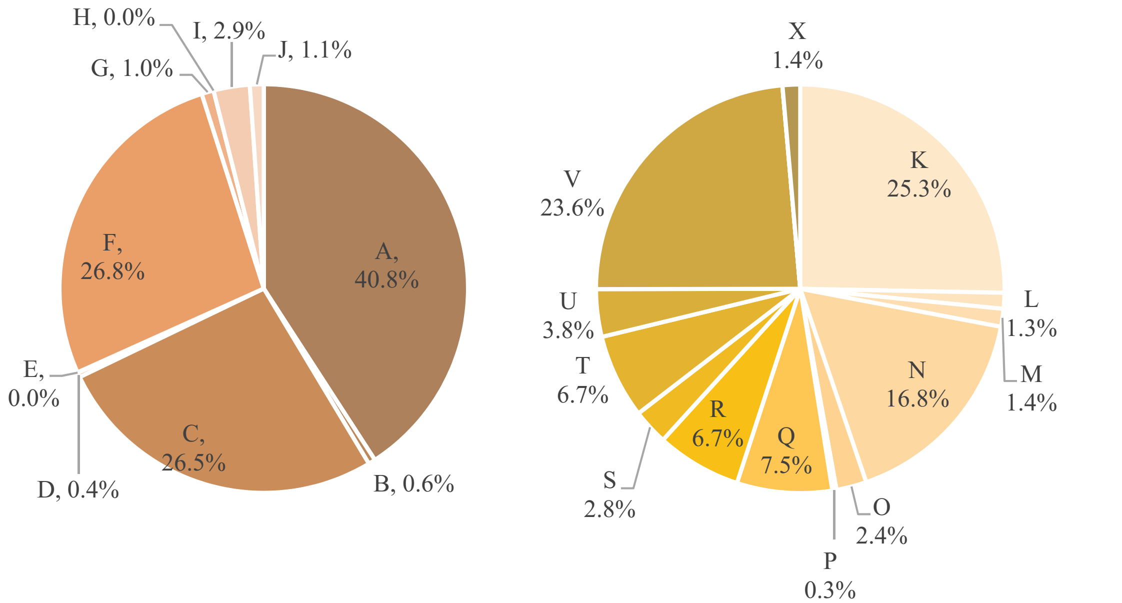


Fig. 6. GPI breakdown (per capita, thousand USD).

Second, regarding the negative contributors, income inequality and commuting both severely affect social welfare, accounting for 25.3% ($774 billion) and 23.6% ($723 billion) of all negative contributions in 2016 respectively. Income inequality is linked to economic instability, crime, mental stress and financial crisis, all resulting in substantial impact on social welfare. Meanwhile, the portion of commuting costs has been constantly rising from 8.9% in 1997 to 23.6% in 2016. In a study in 2006 (Pulselli et al., 2006), commuting cost ranked the third among all negative items, and is responsible for 23% of all welfare-relevant losses. The last decade has witnessed an alarming growth of the number of China's overcrowded roads, and the value of time has also been rising, owing to the continual increase in labor productivity. The two combined, it is not surprising that commuting cost became the second most negative component of economic welfare in 2016.

Third, environmental and ecological damages are responsible for more than 33.8% of total negative value contributing to GPI. (1) Water pollution, a pressing environmental problem burdening many regions in China, accounts for 16.8% ($514 billion) of all negative components combined in 2016. Water pollution directly affects human health, one vivid example being the infamous "cancer villages" along the Huai River, where mortality from gastrointestinal cancer are much higher than the national average (Yang and Zhuang, 2013). As shown in Fig. 8, water pollution has always been the most severe environmental damage. However, the portion of water pollution in all environmental costs has been decreasing with fluctuation, from 60.2% in 1997 to 49.7% in 2016, with a minimum of 41.5% at 2007. (2) On the contrary, carbon emissions from fossil fuel combustion has soared in China. The portion of climate change cost from carbon emissions in all environmental costs has dramatically increased from 1.9% in 1997 to 20.3% in 2016, as the only component in environmental account that has increased, as presented in Fig. 8. Also, climate change cost has exceeded cost of non-renewables depletion and ranks as the second most severe environmental problem in 2016. (3) Air pollution accounts for around 2.4% of welfare loss and 7.1% of all environmental costs in 2016. In this paper, the cost of air pollution covers the costs of SO_2, TPS, CO_2.[4] Since there is no sufficient data to estimate the welfare loss caused by $PM_{2.5}$, which has become one of the major air pollutants in China, the cost of air pollution has without doubt been underestimated. (4) Depletion of non-renewables used to be the second costly environmental item for most of the past years, responsible for 6.7% ($205 billion) of all deduction items and 19.2% of environmental costs (with no cost escalation factor) in 2016. For comparison, if including a 3% cost escalation factor, as many studies did, depletion of non-renewables will account for 11.2% ($360 billion) of all deduction items, and 30.3% of total

[4] In addition to climate change, carbon emissions also cause short-term environmental damages (acid rain, etc.), which is included in air pollution.



Positive:
A: Private consumption expenditures
B: Services of Durables
C: Net capital growth
D: Wetlands
E: Forests
F: Domestic labor
G: Volunteer work
H: Change of leisure time
I: Non-defensive public expenditure on education and health
J: Value of public infrastructure

Negative:
K: Income inequality
L: Cost of durables
M: Underemployment
N: Water pollution
O: Air pollution
P: Solid waste
Q: Long-term environmental damage
R: Depletion of non-renewables
S: Family breakdown
T: Crime
U: Defensive private expenditure on education and health
V: Commuting
W: Auto accidents
X: Natural disasters

Fig. 7. Detailed GPI breakdown (left: positive items; right: negative items).

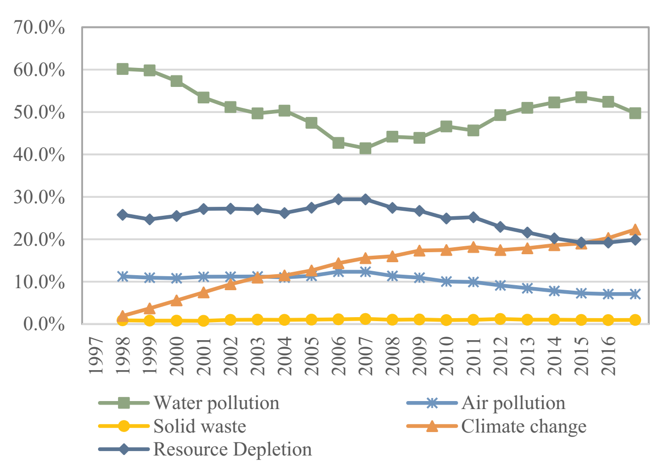


Fig. 8. Environmental cost breakdown.

environmental costs in 2016.

In sum, GDP is an overestimation of social welfare. The widening gap between GPI and GDP illustrates that, although social welfare is still gradually increasing alongside with the expansion of economic scale, the growth rate of benefits has been slowing down, while that of costs has been speeding up. Welfare losses brought by economic expansion include commuting cost, environmental and ecological damages, and income inequality. These costs are unnecessarily inevitable consequences of economic expansion, but illustrate the problem associated with economic structure and growth quality (Jackson and Victor, 2016; Jackson, 2019). The widening gap is the herald of threat, warning us to lay more emphasis on the quality of economic growth, environmental sustainability, and social welfare.

4. Conclusion

4.1. Main Results

In this paper, the GPI of all 31 provinces in mainland China from year 1997 to 2016 are estimated, with the three highly controversial methodological assumptions associated with income inequality, long-term environmental damage and depletion of non-renewables having all been addressed. Specifically, we have replaced the Gini index which is not tied to any social welfare function with the Atkinson index. We have also avoided the incorrect duplicated counting of long-term environmental damage, as well as the unjustified cost escalation factor used in the calculation of the depletion of non-renewables.

In most provinces, GPI is climbing despite certain fluctuation, but some provinces exhibit a declining tendency in recent years, unveiling a threat to social welfare and economic sustainability. Resource consumption and environmental pollution both cause substantial welfare losses. Limited by the availability of data, we are unable to take the costs of $PM_{2.5}$ into consideration, which is the most severe air pollutant and therefore non-negligible in most provinces, especially for the estimation of the recent years (Ji et al., 2018). Without doubt, adding the costs of $PM_{2.5}$ into our framework will lower down the GPI results greatly for the more recent years, hence a more significant declining trend will probably appear in more provinces.

Furthermore, the “relative threshold hypothesis” has been supported by the results in some provinces, even in the absence of the cost escalation factor in the calculation of the depletion of non-renewables, and after leaving out the problematic double counting of long-term environmental damages. From the results we can see that a rapid expanding economy is companied however by a relatively slow GPI progress. The existence of the “relative threshold effect” illustrates that the traditional national economic accounting system overestimates real social welfare, and can be biased and misguiding. What's more, the “relative threshold effect” is expected to be more significant if quantifying the costs of $PM_{2.5}$.

4.2. Policy Implications

So far, China has witnessed the “growth-mania”, yet a GDP-oriented, high mass consumption economy cannot last forever. Policy-makers, who rely on the GDP as the measurement of economic growth, are likely to have biased perception of the real social welfare and sustainability (Cobb, 1995; Cobb et al., 1999; Victor, 2010; Costanza et al., 2014; Coulter, 2017). The “relative threshold effect”, which is found in our study, justifies the danger of overusing the GDP. The GDP should be extended to take in the value of ecosystem services, the loss of natural capital, and other changes associated with social welfare (Howarth and Farber, 2002). With its various shortcomings, GPI is clearly not a perfect index for sustainability (Van den Bergh and Antal, 2014), whereas the GPI can be a good complement, offering further insights into social welfare with its considerable improvements in accounting environmental and social costs.

As a part of the finite natural ecosystem, the aggregate economy is thus facing biophysical constraints and its growth is accompanied by opportunity cost (Daly, 1972, 1974a, 1974b). Unlike growth that puts weight on the expansion of scale, development stresses more on bettering the economic structure, human intelligence, technology and so on, which does not further spur the expansion of macroeconomic scale, but instead prompts the increase of social welfare, and eventually alleviate the conflicts between mankind and nature. Emphasizing the quality instead of the quantity of economic growth is a strategy to prevent our earth dying at an early age from the cancer of our growth-mania (Daly, 2014).

For provinces that have shown the signal of threats to environmental sustainability and social welfare, it is time to abandon blind scale expansion and to emphasize the quality of economic growth. Even though it might just be a signal, we should take actions immediately, because the effect of our actions at the macroeconomic level are always lagged. If we do not take action to “rein in at the brink of the precipice”, we are at the risk of ending up with an improper scale of a macro-economy that brings more severe environmental and social costs (Daly, 1973, 1987, 1991, 1993, 1996). Specifically, for provinces that suffer from huge environmental and ecological costs, such as Beijing, Shanghai, Liaoning, Shanxi and Guangdong, properly designed environmental regulations, which can account for the external costs of pollution, including tradable water pollution rights and carbon pricing, can be employed for reducing pollution-intensive output and promoting technological innovation. Also, proper energy management strategies should be seriously considered to prevent energy consumption soaring (Ji and Long, 2016). For provinces that are economically disadvantaged, such as Sichuan, Yunnan, Guizhou, Gansu and Tibet in the western China, policies such as “Western Development” and “Belt and Road” should be strictly implemented to boost the economies of these provinces. For provinces that have high income inequality, efficient welfare redistribution concerning social fairness should be considered, painting a healthier and more sustainable society.

Acknowledgement

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Appendix A.1. Modification on the GPI Accounting System

(1) Adding the cost of solid waste pollution

Improper storage or disposal of solid waste can cause severe environmental pollution, and such pollution is a non-negligible problem in many provinces of China.

(2) Adding the cost of natural disasters

Floods, earthquakes and other natural catastrophes not only cause huge economic loss, but also irreparable spiritual damage. It is suggested to be add as an item in GPI 2.0 by Bagstad et al. (2014). In recent years, some places in China were struck by natural catastrophes, significantly reducing local social welfare. For example, the 2008 Sichuan earthquake caused over 87,000 deaths, as well as a direct economic loss of 845 billion Yuan.

(3) Removing net international debt

First, Bleys (2008) has argued that this item does not comply with the theoretical foundation of ISEW. Second, data on international debt at provincial level are not fully available. Referring to the solution to the same problem by Costanza et al. (2004), we remove net international debt from the index system. Third, net international debt is used to reflect the dependency on foreign economies as well as the net variation of international position (Beça and Santos, 2010), so it is more commonly used in GPI valuation at national scale; as for provincial GPI, international position is less important. Studies find that the influence of net international debt on social welfare is insignificant (Wen et al., 2007).

(4) Removing the cost of noise pollution

Data on noise pollution are incomplete, and studies have proved that it does not significantly affect results.

(5) Removing the cost of farmland loss

The statistical method on China's farmland area has been considerably adjusted twice from 1997 to 2014, and there is no detailed elaboration on the adjustments. Besides, studies have proved that it does not significantly affect results.

(6) Remove the cost of ozone loss

First, there is no available data on ozone. Though theoretically, we can estimate each province's emission of carbon chlorine fluoride from the level of social economic activity and ozone emission factor, such estimation requires detailed data on consumption in refrigeration, automobile air conditioning, which are barely available. Besides, studies find that the cost of ozone loss is insignificant (Wen et al., 2007).

Appendix A.2. Description of Indicators and Methodologies of GPI

Account	Item	Method	Data source
Economics accounts	Personal consumption expenditures	Personal consumption expenditure is the starting point of GPI calculation. An increase in personal consumption expenditures brings an improvement in welfare.	Statistics yearbook of China
	Income inequality	We apply Atkinson index to measure the income inequality. Following Latty (2011), we choose the value of society's aversion to inequality to be 1.5. Detailed calculation is stated in the main text.	Statistics yearbook of China, provincial statistics yearbook
	Services of consumer durables	We assume that the average service life of consumer durables is eight years, so the depreciation rate is 12.5% per year. *Services of Consumer Durables = Cost of Consumer Durables × Depreciation rate*	Statistics yearbook of China
	Cost of consumer durables	Since services of consumer durables is included, its cost should be deducted to avoid double counting.	Statistics yearbook of China
	Cost of underemployment	Cost of underemployment is measured with wage rate (Costanza et al., 2004). *Cost of Underemployment = Number of underemployed × Unprovided hours per worker × Hourly wage* China's statistical yearbooks contain only registered urban unemployment. Data on rural and unregistered unemployment are not collected. The cost of underemployment is therefore underestimated.	China population and employment statistics yearbook, China labor statistical yearbook
	Net capital growth	Net capital growth is the difference between newly-added capital investment and the human capital required in such increment. The calculation formula is: $NCI = (K - K_{-1}) - \frac{L - L_{-1}}{L} \times K_{-1}$ where K is the capital stock of the current period, K_{-1} the stock of the previous period, L human capital in the current period, L_{-1} the human capital period in the previous period. Capital stock is not reported in any official statistical yearbooks, so the Perpetual Inventory Method based on each year's capital investment is employed to estimate the capital stock. The calculation formula is: $NK_t = (1 - \delta)^t \times NK_0 + \Sigma_{k=1}{}^t (1 - \delta)^{t-k} \Delta_k$ where NK_t represents the capital stock of period t, δ the consumption rate (depreciation rate) of fixed capital, NK_{t-1} capital stock of period t − 1, NK_0 capital stock of the base period, Δ_k the fixed capital formation of period k adjusted by price index of investment in fixed asset. According to Shan (2008), the average depreciation rate of fixed-asset is 10.96%. Capital stock at the base year is calculated from the formula below: $NK_t = I_t/(\delta + g_t)$ where I_t represents fixed capital formation in period t, g_t the average capital growth rate or output growth rate including period t. Here the average growth rate of capital investment between year 1996 and 1998 is chosen as average capital growth rate. The results of capital stock estimations are shown in Appendix A.4.	Statistics yearbook of China, provincial statistics yearbook
Environmental accounts	Cost of water pollution	Data on the amount of waste water are obtained from statistical yearbooks. The unit cost of waste water is estimated by Yang and Tong (2014).	Statistics yearbook of China, China's environmental yearbook
	Cost of air pollution	Cost of air pollution includes the environmental cost of SO_2, NO_X, Total Suspended Particles (TSP) and CO_2. Emission: Emissions of SO_2 and TSP are directly obtained from statistical yearbooks, but the emission of CO_2 is not reported in any official statistics. We calculate CO_2 emissions based on emission factor of CO_2 and energy use, where the emission factor is estimated by Liu et al. (2015). Data on nitrogen oxides are unavailable. Although it can be estimated using emission factors and energy use, the calculation requires energy use by industry and by energy, which is also unavailable. We have to ignore the cost of nitrogen oxide Unit cost: Unit environmental cost of SO_2 and TSP is 1250/t CNY and 109/t CNY, respectively. The unit environmental cost of CO_2 estimated by Liang et al. (2015) is applied (the average cost between year 1992 and 2012 is $7.28/t).	Statistics Yearbook of China, China's environmental yearbook, China Energy Statistical Yearbook

	Cost of solid waste pollution	Solid waste includes household solid waste and industrial solid waste. The latter includes general industrial solid waste disposal, general industrial solid waste storage, hazardous industrial solid waste disposal and hazardous industrial solid waste storage. Unit cost of general industrial solid waste disposal: 75/t CNY, general industrial solid waste storage: 15/t CNY, hazardous industrial solid waste disposal: 1500/t CNY, hazardous industrial solid waste storage: 300/t CNY. Unit cost of household solid waste is 27/t CNY.	China's environmental yearbook, China's environmental statistics yearbook, China urban construction statistical yearbook, statistics yearbook of China
	Change of wetlands	The unit cost of wetland loss estimated by Costanza et al. (1997) ($14,785/ha) is used.	China forestry statistical yearbook
	Change of forest	The unit cost of forest loss estimated by Costanza et al. (1997) ($969/ha) is used.	China forestry statistical yearbook
	Long-term Environmental damage	Following Cobb and Cobb (1994) and due to a lack of data on carbon emissions at provincial level in China, we employ the fuel tax approach. We estimate the long-term environmental damage caused by greenhouse gas emissions using fuel tax as a proxy for environmental damage and multiplying it by fuel consumption. We convert the consumptions of all fossil fuels (coal, oil and natural gas) into equivalent oil consumption. To avoid the problematic multiply counting of the environmental damages, we annualize the present value of total future damages to each year at discount rate 3% (Interagency Working Group, 2010), giving the damage curve from Ackerman and Stanton (2012). Following O'Mahony et al. (2018) which is applying the same damage curve in Ackerman and Stanton (2012), the annual damage is assumed to increase at a compound growth rate of 1.9837% per year.	China energy statistical yearbook
	Depletion of non-renewables	Replacement costs method is employed. We use the price of non-renewable resources as the replacement costs. Since the historical price of non-renewable resources in China is unavailable, we refer to the historical price in the US. The replacement costs of each nonrenewable in the base year are: oil, $17.23/barrel; coal, $18.14/t; natural gas, $3.66/kCF.	China energy statistical yearbook
	Cost of natural disasters	Data are obtained from statistical yearbooks.	Statistics yearbook of China, China civil affairs' statistical yearbook
Social accounts	Value of domestic work	Average time spent on housework and parenting are obtained from statistical yearbooks. The unit value of domestic work is measured by the wage rate of domestic service. Only the population in age 15–64 are considered.	Data compilation on time use in 2008, statistics yearbook of China
	Cost of family breakdown	Cost of family breakdown is the unit cost of each divorce multiplied by the number of divorces. According to Costanza et al. (2004), the unit cost of each divorce is $8922/divorce plus $13,380/child. According to Wen et al. (2007), about 0.8599 child is involved in each divorce in China, so the unit cost of divorce in China is $20,427.	Statistics yearbook of China
	Cost of crime	Chen and Liu (2013) estimated the total social cost of all crimes in China from year 1997 to 2010, which is approximately increasing by 100 billion CNY per year, so we assume that it continues to increase by 100 billion CNY between year 2011 and 2014. Cost of crime by province is the national crime cost by Chen and Liu (2013) multiplied by the share of crime by province. $Cost\ of\ Crime = National\ crime\ cost \times \frac{Provincial\ number\ of\ crimes}{National\ number\ of\ crimes}$	Statistics yearbook of China
	Value of volunteer work	The calculation is similar to that of value of domestic work.	Data compilation on time use in 2008, statistics yearbook of China
	Change of leisure time	The welfare change of leisure time is the change of leisure time multiplied by the unit value of leisure. Wage rate is used as a proxy for unit value of leisure.	China labor statistical yearbook, international statistical yearbook, statistics yearbook of China
	Non-defensive public expenses on education and health	Public expense on education and health can improve welfare. It is the bill the government pays for its residents, as a supplement to personal consumption expenditures. A part of the public expense on education and health, which is defensive, does not promote public welfare, so it should be excluded (Guenno and Tiezzi, 1998). Referring to Pulselli et al. (2006) and Bleys (2008), 50% of the expense is considered as non-defensive. Public expense includes central government expenditure and local government expenditure. Since there is no data on the distribution of central government expenditure across provinces, we estimate the non-defensive public expenses on education and health as: $Non\ defensive\ Public\ Expenses\ on\ education\ and\ health$ $= \left(E_P + H_P + \frac{E_P}{\sum_{P=1}^{31} E_P} \times E_C + \frac{H_P}{\sum_{P=1}^{31} H_P} \times H_C\right) \times 50\%$ where E_P represents provincial government expenditure on education, H_P provincial government expenditure on health, E_C central government expenditure on education and H_C central government expenditure on health.	Statistics yearbook of China, finance yearbook of China

Defensive private expenditure on health and education	Part of personal expenditure on education and health that is defensive should be excluded from personal consumption expenditure. The share of defensive private expenditure on education and health in all private expenditure on education and health is also estimated to be 50%.	Statistics yearbook of China
Services from public infrastructure	The value of public infrastructure is mainly about transportation. Like public educational/health expense, the welfare improvement brought by public infrastructure is government's payment for its residents, which is not included in personal consumption expenditure but should be considered. The value of public infrastructure is annualized public expenditure on public infrastructure during its service life (Costanza et al., 2004). Since data on service life are unavailable, and there is little difference of the expenditure on public infrastructure over time, we can approximate the value simply using each year's expenditure. Expenditure on public infrastructure includes local government expenditure and central government expenditure. Since there is no data on the distribution of central government expenditure across provinces, we estimate the public expenses on public infrastructure as: $\textit{Services from Public Infrastructure} = \left(PI_P + \frac{PI_P}{\sum_{P=1}^{31} PI_P} \times PI_C\right)$ where PI_P represents provincial government expenditure on public infrastructure, and PI_C represents central government expenditure on public infrastructure.	Statistics yearbook of China, finance yearbook of China
Cost of commuting	Cost of commuting includes the economic cost (non-recreational expenditure on transportation) and the cost of time. The economic cost, which is included in personal consumption expenditure, should be deducted, because it does not contribute to welfare. Following Cobb and Cobb (1994), the economic cost of commuting is calculated as: $\textit{Direct cost of commuting} = 0.3(A - 0.3A) + 0.3B$ where A denotes the private expenditure on transportation. 0.3A denotes the estimated cost of depreciation of private cars. 0.3A is deducted to avoid double counting because it has already been included in the cost of consumer durables. 0.3 is the portion of total non-commercial private vehicle miles used in commuting. B is private expenditure on local public transportation. 0.3 is the portion of passenger miles on local public transportation used for commuting. The cost of time should be deducted as well since it negatively affects welfare. The cost of time is commuting time multiplied by wage rate (Costanza et al., 2004).	Statistics yearbook of China, data compilation on time use in 2008
Cost of auto accidents	Costs of auto accidents are obtained from statistical yearbooks. Since only economic costs are considered, this item is underestimated.	Statistics yearbook of China

Appendix A.3. Atkinson Index

	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Beijing	0.273	0.258	0.256	0.257	0.250	0.255	0.263	0.259	0.252	0.248
Tianjin	0.295	0.258	0.267	0.267	0.268	0.269	0.275	0.270	0.266	0.265
Hebei	0.348	0.272	0.281	0.291	0.299	0.330	0.340	0.333	0.345	0.352
Shanxi	0.382	0.290	0.315	0.318	0.343	0.364	0.381	0.377	0.380	0.383
Inner Mongolia	0.379	0.292	0.310	0.322	0.346	0.363	0.378	0.372	0.367	0.366
Liaoning	0.318	0.242	0.262	0.293	0.290	0.309	0.321	0.314	0.314	0.317
Jilin	0.324	0.240	0.266	0.306	0.310	0.339	0.345	0.330	0.333	0.333
Heilongjiang	0.300	0.256	0.281	0.296	0.305	0.325	0.338	0.320	0.327	0.327
Shanghai	0.232	0.212	0.229	0.230	0.236	0.233	0.240	0.236	0.231	0.230
Jiangsu	0.304	0.240	0.253	0.257	0.264	0.291	0.308	0.304	0.317	0.321
Zhejiang	0.319	0.276	0.284	0.288	0.295	0.316	0.325	0.321	0.320	0.320
Anhui	0.389	0.317	0.328	0.334	0.343	0.358	0.390	0.375	0.395	0.398
Fujian	0.362	0.292	0.294	0.302	0.317	0.343	0.354	0.353	0.355	0.360
Jiangxi	0.326	0.271	0.286	0.303	0.314	0.347	0.359	0.348	0.355	0.354
Shandong	0.364	0.291	0.300	0.316	0.324	0.343	0.354	0.351	0.354	0.357
Henan	0.368	0.284	0.290	0.297	0.309	0.347	0.378	0.369	0.375	0.374
Hubei	0.368	0.294	0.307	0.315	0.320	0.355	0.365	0.355	0.362	0.363
Hunan	0.400	0.326	0.336	0.345	0.355	0.366	0.381	0.378	0.380	0.381
Guangdong	0.353	0.311	0.311	0.323	0.334	0.340	0.353	0.351	0.350	0.342
Guangxi	0.392	0.335	0.336	0.366	0.386	0.414	0.425	0.425	0.425	0.414
Hainan	0.375	0.312	0.326	0.317	0.332	0.357	0.359	0.349	0.350	0.361
Chongqing	0.364	0.371	0.387	0.383	0.386	0.402	0.417	0.411	0.409	0.421
Sichuan	0.423	0.340	0.350	0.361	0.372	0.380	0.389	0.379	0.378	0.387
Guizhou	0.418	0.378	0.391	0.396	0.405	0.420	0.437	0.436	0.445	0.457
Yunnan	0.475	0.425	0.425	0.426	0.438	0.456	0.464	0.472	0.465	0.461
Tibet	0.431	0.446	0.455	0.469	0.491	0.500	0.499	0.489	0.473	0.417
Shaanxi	0.430	0.359	0.374	0.397	0.405	0.435	0.445	0.437	0.438	0.437
Gansu	0.415	0.338	0.368	0.379	0.395	0.425	0.439	0.437	0.444	0.447
Qinghai	0.417	0.360	0.376	0.393	0.410	0.417	0.425	0.419	0.424	0.427

Ningxia	0.415	0.309	0.324	0.349	0.365	0.384	0.392	0.382	0.390	0.396
Xinjiang	0.436	0.370	0.402	0.394	0.409	0.423	0.413	0.403	0.396	0.396

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Beijing	0.244	0.237	0.229	0.221	0.216	0.202	0.196	0.207	0.248	0.250
Tianjin	0.265	0.263	0.254	0.247	0.231	0.213	0.184	0.192	0.229	0.232
Hebei	0.351	0.355	0.360	0.345	0.335	0.323	0.295	0.297	0.318	0.319
Shanxi	0.382	0.378	0.383	0.379	0.371	0.358	0.314	0.315	0.338	0.338
Inner Mongolia	0.365	0.359	0.360	0.353	0.342	0.329	0.303	0.306	0.332	0.333
Liaoning	0.320	0.317	0.319	0.310	0.294	0.281	0.266	0.271	0.300	0.302
Jilin	0.332	0.327	0.331	0.315	0.307	0.296	0.264	0.269	0.298	0.300
Heilongjiang	0.318	0.307	0.310	0.291	0.278	0.269	0.262	0.264	0.291	0.293
Shanghai	0.230	0.226	0.216	0.211	0.206	0.192	0.178	0.190	0.237	0.239
Jiangsu	0.324	0.323	0.322	0.312	0.296	0.283	0.255	0.258	0.285	0.285
Zhejiang	0.319	0.314	0.310	0.303	0.291	0.280	0.239	0.244	0.270	0.271
Anhui	0.394	0.384	0.388	0.372	0.373	0.361	0.308	0.308	0.329	0.331
Fujian	0.358	0.358	0.356	0.350	0.329	0.316	0.272	0.275	0.301	0.302
Jiangxi	0.358	0.350	0.354	0.341	0.331	0.322	0.295	0.298	0.319	0.319
Shandong	0.359	0.359	0.358	0.350	0.340	0.328	0.292	0.293	0.314	0.314
Henan	0.372	0.371	0.376	0.364	0.356	0.345	0.302	0.304	0.324	0.324
Hubei	0.363	0.358	0.360	0.348	0.335	0.323	0.277	0.279	0.302	0.306
Hunan	0.382	0.374	0.374	0.359	0.356	0.347	0.317	0.318	0.338	0.339
Guangdong	0.341	0.333	0.332	0.323	0.307	0.294	0.264	0.270	0.298	0.300
Guangxi	0.426	0.428	0.431	0.417	0.411	0.396	0.338	0.339	0.357	0.356
Hainan	0.360	0.357	0.355	0.353	0.349	0.337	0.296	0.297	0.316	0.315
Chongqing	0.395	0.384	0.381	0.365	0.350	0.336	0.294	0.295	0.316	0.314
Sichuan	0.388	0.384	0.389	0.379	0.371	0.361	0.319	0.320	0.339	0.339
Guizhou	0.454	0.441	0.453	0.438	0.434	0.426	0.384	0.383	0.399	0.399
Yunnan	0.455	0.450	0.454	0.438	0.434	0.422	0.372	0.373	0.389	0.389
Tibet	0.436	0.430	0.433	0.413	0.402	0.390	0.362	0.366	0.396	0.401
Shaanxi	0.432	0.432	0.428	0.409	0.398	0.381	0.337	0.338	0.358	0.358
Gansu	0.455	0.438	0.441	0.429	0.427	0.417	0.385	0.385	0.402	0.405
Qinghai	0.430	0.425	0.423	0.409	0.396	0.378	0.344	0.345	0.370	0.370
Ningxia	0.398	0.401	0.397	0.387	0.376	0.363	0.317	0.318	0.339	0.340
Xinjiang	0.396	0.396	0.392	0.376	0.370	0.358	0.322	0.326	0.356	0.359

Appendix A.4. Capital Stock Estimation (100 Million in 1997 CNY)

	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Beijing	2970	3832	4666	5540	6567	7760	9073	10,488	12,261	14,108
Tianjin	1824	2273	2666	3073	3543	4081	4789	5604	6589	7774
Hebei	3549	4847	6169	7468	8742	10,003	11,503	13,440	15,833	18,674
Shanxi	1283	1711	2139	2566	3009	3535	4237	5119	6288	7706
Inner Mongolia	1534	1721	1922	2144	2408	2859	3729	4996	6897	9154
Liaoning	6251	6649	7055	7584	8199	8928	10,006	11,712	13,807	16,567
Jilin	2021	2247	2535	2889	3273	3738	4305	4928	5978	7842
Heilongjiang	2225	2857	3418	3975	4593	5248	5912	6670	7570	8745
Shanghai	5865	7050	8109	9165	10,264	11,493	12,824	14,426	16,258	18,315
Jiangsu	7465	9323	11,192	13,109	15,122	17,458	20,906	25,075	30,296	35,978
Zhejiang	5693	6940	8184	9567	11,169	13,199	16,111	19,500	23,079	26,897
Anhui	2740	3273	3768	4288	4833	5436	6173	7236	8471	9953
Fujian	2807	3659	4463	5240	5988	6775	7747	8945	10,386	12,221
Jiangxi	1409	1782	2149	2522	2944	3553	4438	5502	6652	7973
Shandong	6178	7878	9722	11,876	14,152	16,862	20,175	24,479	29,820	35,902
Henan	3416	4475	5482	6550	7642	8835	10,279	12,186	14,960	18,717
Hubei	2971	3900	4815	5748	6732	7693	8685	9879	11,353	13,292
Hunan	2139	2762	3432	4144	4925	5766	6712	7792	9281	11,071
Guangdong	9550	11,189	12,987	14,758	16,639	18,707	21,485	24,633	28,687	33,148
Guangxi	2162	2506	2871	3231	3614	4060	4584	5283	6253	7545
Hainan	3618	3397	3216	3061	2933	2835	2782	2762	2791	2866
Chongqing	890	1315	1739	2186	2708	3343	4194	5173	6305	7535
Sichuan	5224	5852	6461	7111	7910	8862	10,019	11,318	12,977	15,139
Guizhou	702	969	1268	1591	1997	2447	2936	3429	3961	4563
Yunnan	1552	2080	2585	3007	3427	3881	4465	5229	6256	7508
Tibet	114	132	156	177	200	246	318	439	570	716
Shaanxi	1471	1891	2346	2890	3462	4099	5010	5989	7188	8790
Gansu	567	747	954	1187	1422	1733	2062	2429	2960	3559
Qinghai	218	312	411	524	669	839	1032	1214	1413	1628
Ningxia	307	383	474	584	716	868	1085	1318	1579	1869
Xinjiang	2018	2348	2651	3013	3404	3887	4517	5170	5958	6945
	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Beijing	16,091	17,309	19,020	21,130	23,200	25,781	28,473	31,104	33,698	37,200
Tianjin	9240	11,202	14,106	17,639	21,650	26,064	30,791	35,611	39,434	42,601
Hebei	21,998	26,255	31,016	36,091	42,219	48,585	55,004	61,310	67,324	73,715
Shanxi	9378	11,198	13,922	17,086	20,559	23,889	27,586	30,937	34,039	36,506

Inner Mongolia	11,918	15,055	19,446	24,333	29,649	35,838	43,015	48,026	52,952	56,397
Liaoning	19,966	25,703	30,131	35,486	41,522	47,937	54,654	60,899	63,130	63,003
Jilin	10,444	13,752	17,354	21,434	25,240	29,202	33,086	36,957	41,004	44,053
Heilongjiang	10,275	12,051	14,794	17,421	20,373	23,841	27,877	31,535	35,192	38,112
Shanghai	20,667	22,705	25,461	27,681	29,657	31,516	33,595	35,712	38,423	42,084
Jiangsu	42,060	48,899	57,481	67,443	78,115	88,800	99,198	109,140	119,216	130,035
Zhejiang	31,041	35,078	39,547	44,715	49,997	55,160	60,839	66,460	72,582	79,939
Anhui	11,755	13,873	16,274	19,250	22,734	26,568	30,731	35,114	39,440	44,259
Fujian	14,638	17,481	20,803	24,288	28,300	32,681	37,583	42,888	48,596	54,804
Jiangxi	9424	10,934	13,057	15,348	17,928	20,554	23,223	25,648	28,509	32,071
Shandong	42,157	48,765	57,847	67,841	78,291	89,244	100,710	112,547	124,671	135,850
Henan	23,620	29,317	36,676	44,988	53,920	63,798	74,513	85,613	96,636	107,960
Hubei	15,614	18,166	21,554	25,631	30,629	36,062	42,063	48,616	55,622	63,237
Hunan	13,269	16,167	19,818	24,375	29,428	34,940	40,971	47,424	53,329	59,686
Guangdong	38,093	42,974	49,674	57,431	65,451	74,332	84,344	95,289	106,375	119,360
Guangxi	9167	10,989	14,286	18,833	23,948	29,008	32,894	36,852	41,104	45,570
Hainan	2980	3242	3615	4145	4767	5664	6665	7777	8636	9555
Chongqing	8946	10,836	12,604	14,661	17,114	19,640	22,268	25,163	28,325	31,970
Sichuan	17,807	21,080	24,842	29,116	33,801	38,909	44,148	49,422	54,616	60,330
Guizhou	5240	6007	7014	8216	9634	11,542	14,012	16,762	20,014	23,726
Yunnan	8948	10,045	11,793	14,594	17,914	21,743	26,123	31,153	36,630	42,480
Tibet	873	1026	1222	1529	1764	2088	2512	2996	3423	3901
Shaanxi	10,552	13,023	15,883	19,523	23,416	27,917	32,688	37,623	42,084	46,791
Gansu	4225	5139	6030	7080	8282	9654	11,247	12,990	14,814	16,814
Qinghai	1865	2124	2535	3088	3759	4728	5966	7447	9063	10,700
Ningxia	2201	2642	3317	4123	4889	5787	6767	8185	9877	11,576
Xinjiang	7918	8819	9864	11,322	12,990	15,557	18,896	22,825	26,769	30,244

Appendix A.5. GPI per capita (in 1997 Thousand US Dollars)

	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Beijing	0.831	1.139	1.060	1.213	1.392	1.260	1.331	0.197	1.856	1.889
Tianjin	0.340	0.488	0.437	0.558	0.549	0.670	0.708	0.791	1.046	1.100
Hebei	0.413	0.419	0.493	0.484	0.532	0.523	0.752	0.902	0.949	1.231
Shanxi	0.049	0.094	0.067	0.154	0.156	0.199	0.154	0.253	0.428	0.582
Inner Mongolia	0.314	0.320	0.378	0.394	0.457	0.621	0.891	0.890	1.200	1.648
Liaoning	0.182	0.266	0.243	0.242	0.357	0.549	0.477	0.543	0.705	1.046
Jilin	0.227	0.352	0.359	0.353	0.466	0.529	0.684	0.622	0.693	1.257
Heilongjiang	0.293	0.346	0.448	0.472	0.505	0.559	0.422	0.606	0.581	0.765
Shanghai	1.284	1.361	1.487	1.981	1.399	1.304	1.421	1.634	1.907	2.189
Jiangsu	0.590	0.657	0.691	0.704	0.763	0.844	1.056	1.239	1.409	1.516
Zhejiang	0.616	0.686	0.645	0.625	0.763	0.872	1.180	1.247	1.283	1.613
Anhui	0.280	0.299	0.300	0.335	0.384	0.443	0.387	0.610	0.593	0.761
Fujian	0.609	0.686	0.672	0.704	0.722	0.702	0.816	0.860	0.820	1.027
Jiangxi	0.226	0.161	0.286	0.334	0.385	0.408	0.464	0.550	0.486	0.654
Shandong	0.391	0.465	0.524	0.568	0.635	0.704	0.773	0.906	1.365	1.553
Henan	0.271	0.309	0.297	0.272	0.393	0.418	0.455	0.501	0.583	0.950
Hubei	0.298	0.296	0.349	0.409	0.461	0.454	0.460	0.562	0.666	0.844
Hunan	0.237	0.227	0.332	0.380	0.400	0.437	0.459	0.569	0.616	0.787
Guangdong	0.577	0.629	0.690	0.644	0.680	0.715	0.577	0.661	0.908	1.238
Guangxi	0.162	0.189	0.211	0.199	0.195	0.260	0.301	0.323	0.288	0.527
Hainan	0.017	0.088	0.098	0.040	0.101	0.158	0.106	0.129	0.016	0.334
Chongqing	0.329	0.356	0.292	0.394	0.477	0.599	0.816	0.753	0.752	0.858
Sichuan	0.209	0.286	0.318	0.331	0.390	0.486	0.579	0.633	0.694	0.825
Guizhou	0.150	0.188	0.234	0.247	0.266	0.342	0.294	0.315	0.457	0.434
Yunnan	0.291	0.359	0.378	0.352	0.343	0.375	0.421	0.426	0.453	0.589
Tibet	0.481	0.495	0.469	0.601	0.680	0.894	1.502	1.055	0.705	0.981
Shaanxi	0.225	0.274	0.289	0.350	0.413	0.416	0.458	0.505	0.545	0.791
Gansu	0.168	0.207	0.253	0.270	0.290	0.363	0.377	0.361	0.551	0.828
Qinghai	0.138	0.144	0.116	0.151	0.239	0.321	0.465	0.332	0.881	1.505
Ningxia	0.154	0.261	0.255	0.363	0.486	0.542	0.444	0.538	0.578	0.709
Xinjiang	0.377	0.575	0.480	0.659	0.576	0.687	0.797	0.741	0.556	0.856

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Beijing	2.332	1.390	1.863	1.995	2.326	2.598	2.827	3.020	3.050	3.243
Tianjin	0.959	1.772	2.618	2.496	3.377	3.241	3.425	3.839	4.023	3.985
Hebei	1.311	1.589	1.740	1.601	1.933	1.797	1.347	1.524	1.573	1.476
Shanxi	0.637	0.724	1.115	1.047	1.263	1.080	1.246	1.295	1.484	1.321
Inner Mongolia	1.985	2.227	2.698	3.005	3.130	3.043	2.908	2.085	2.121	1.908
Liaoning	1.092	1.901	1.368	1.750	2.135	2.254	2.198	1.870	1.936	1.813
Jilin	1.473	1.763	1.865	1.868	2.195	2.389	1.792	2.026	1.992	1.852
Heilongjiang	0.920	1.233	1.641	1.571	1.914	2.147	1.988	3.072	3.002	2.994
Shanghai	1.298	1.947	2.880	2.784	3.397	3.222	3.338	3.944	3.881	3.792
Jiangsu	1.689	1.833	2.079	2.339	2.848	2.919	2.955	3.130	3.348	3.425
Zhejiang	1.549	1.684	1.666	2.001	2.371	2.327	2.432	2.587	2.654	2.792

Anhui	0.902	0.969	0.943	1.055	1.374	1.506	1.541	1.690	1.824	1.803
Fujian	1.339	1.504	1.638	1.796	1.568	1.861	2.505	2.282	2.405	2.371
Jiangxi	0.753	0.833	1.077	0.992	1.461	1.351	1.439	1.615	1.758	1.815
Shandong	1.601	1.699	1.836	1.770	2.337	2.264	2.152	2.238	2.279	2.409
Henan	1.095	1.130	1.396	1.428	1.569	1.772	1.805	1.826	1.979	2.023
Hubei	0.953	0.978	1.224	1.304	1.676	1.760	1.947	2.235	2.349	2.316
Hunan	1.006	1.106	1.289	1.313	1.725	1.838	1.860	2.073	2.235	2.190
Guangdong	1.375	1.395	1.447	1.526	1.942	2.135	2.168	2.331	2.516	2.353
Guangxi	0.602	0.586	1.037	1.187	1.609	2.016	1.466	1.496	1.664	1.645
Hainan	0.110	0.442	0.510	0.451	0.707	1.050	1.127	1.000	1.368	1.382
Chongqing	1.131	1.359	1.212	1.343	1.621	1.703	1.785	2.198	2.332	2.171
Sichuan	1.065	0.019	1.072	1.090	1.451	1.534	1.504	1.656	1.847	1.814
Guizhou	0.723	0.520	0.910	0.847	0.988	1.136	1.264	1.480	1.551	1.460
Yunnan	0.670	0.536	0.744	0.831	1.153	1.411	1.648	1.760	1.950	1.823
Tibet	1.369	1.122	1.551	1.806	1.619	0.971	1.835	2.321	2.023	2.222
Shaanxi	1.144	1.371	1.451	1.591	1.873	2.026	2.217	2.234	2.288	2.182
Gansu	0.794	0.715	0.768	0.743	1.030	1.074	1.012	1.392	1.669	1.455
Qinghai	0.782	1.342	1.177	0.964	1.913	2.517	2.680	3.345	3.348	3.103
Ningxia	0.803	1.173	1.170	1.626	1.285	1.858	1.808	2.652	2.790	2.579
Xinjiang	0.874	0.764	0.760	0.864	1.213	1.440	1.602	2.151	2.258	2.159

Appendix A.6. GPI Under Different Methodological Assumptions

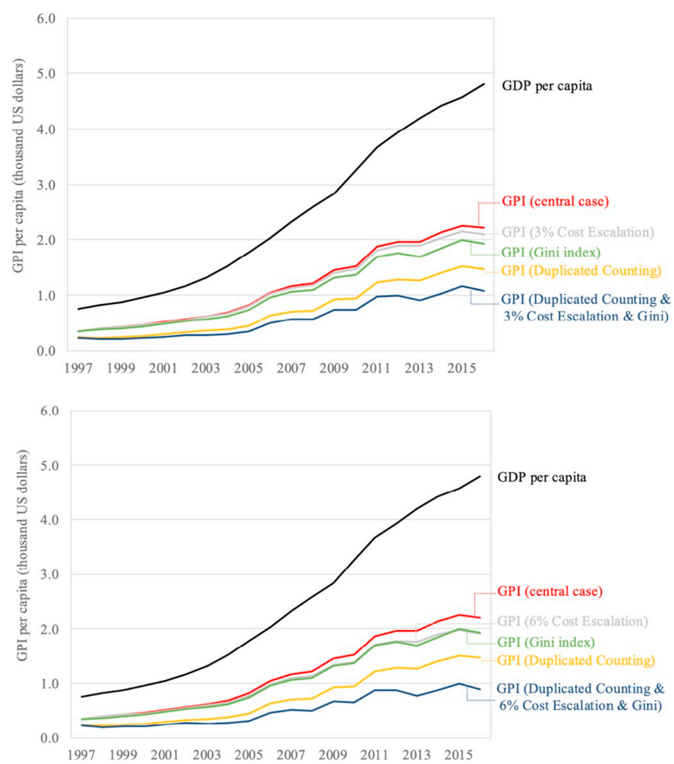

Fig. A6. National GPI per capita under various assumptions, 1997–2016.

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