A Sustainable Metropolis: Perspectives of Population, Productivity and Parity

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Abstract: Research on countries' sustainable development has called for more complete assessments of sustainability. Indeed, integrated studies coupling human and natural systems reveal new and complex patterns and processes not evident when studied in isolation. In line with the need to construct an index that takes into account a more holistic notion of sustainability, this study investigates the overall sustainable development of a metropolis through three dimensions, population, productivity and parity, and takes Singapore as a case study. We incorporate these three dimensions in our construction of a total sustainability index. We find that the population dimension has remained relatively unchanged, while the productivity dimension has gradually moved towards sustainability. The parity dimension has moved towards sustainability before 2002, but it shows ups and downs until 2012 when an upward trend toward sustainability appeared again. Results from this study imply that the government should pay attention to controlling the size of the population of temporary residents, and increasing the government budget for the environment.

Keywords: population; parity; productivity; sustainability; index; Singapore

1. Introduction

Of late, given the world's severe depletion of resources, the topic of sustainable development has arrested both governments' and researchers' attention, and garnered keen scrutiny [1]. Although there is no universally agreed upon definition of sustainable development, many researchers have developed sustainability indices to investigate the notion of sustainability. In this paper, three main sustainability indices are discussed, and thereafter the paper is situated in the context of what has not been adequately explored.

Essentially, compared to existing sustainability index studies, the contributions of this inductive study are twofold: First, it is innovative in that it is at least a proof-of-concept of a sustainable metropolis index, and it focuses specifically on the non-environmental side of development (the 3Ps of this study). Second, this study takes Singapore as the case in question, because Singapore is a city state that has been directly caught within the crosshairs of globalization. An evaluation of its sustainability sheds light on sustainability research for not only a city but a country. Indeed, UNESCO notes that 'much has been written in academic terms about the meaning of sustainable development and the need to integrate ecological and economic principles into personal and public decision-making' [2]. At the same time, though, the definition of sustainable development is in itself not static, but is instead in a process of flux, and its meanings emerge and evolve according to local contexts [2]. We fill the research gap by expanding current understanding on the definition of sustainable development; firstly, by contextualizing it, and thus expanding the conceptualization of what sustainable development really

means (the 3Ps); and, secondly, by looking at a country state that has been caught up in the inexorable juggernaut of globalization. The dynamics of sustainability, especially within an evolving Asian context, are still rather poorly understood [3], and this is the gap which this study aims to address.

Three of the main sustainability indices in the literature are first reviewed: (1) Ecological Footprint (EF), (2) Environmental Sustainability Index (ESI) and (3) Emergy Performance Indices (EMPIs). Ecological Footprint was first proposed by Rees [4], and elaborated upon by Wackernagel and Rees [5]. This index measures the demand for natural resources and is usually compared with the productive biological capacity of available land and sea to the population [6]. Biocapacity is one of the characteristic terms, and it measures bioproductivity, which is the ability of a biome to produce biomass, including animals, plants and micro-organisms. For the EF method, a comparison between actual demand and potential supply is applied to estimate the ecological sustainability of countries. If a footprint is larger than biocapacity, it means that the demand for natural resource exceeds the supply, and an "ecological deficit" occurs [7].

The Environmental Sustainability Index (ESI) was developed by researchers from the Yale Center for Environmental Law and Policy, as well as the Earth Institute of Columbia University [8]. ESI treats environmental sustainability as a multi-dimensional concept. It has five dimensions: Environmental system (air, water), stresses, human vulnerability (illness related to environment), social and institutional capacity and global stewardship (global cooperation in environment issues). It includes 21 indicators and 76 elements. For each of these indicators, there is a set of elements which are used to reflect the environmental status for that indicator. Take the indicator of air quality as an example. For this indicator, concentration levels of elements such as nitrogen oxides, sulphur oxides, particulates and indoor air quality are collected. Overall, these specific indicators, along with their underlying set of elements, provide a comprehensive approach to analyzing sustainability issues. ESI could be used in comparisons of sustainability across different countries. In that case, a cluster analysis is applied to measure sustainability.

Emergy Performance Indices (EMPIs), on the other hand, were developed by Brown and Ulgiati [9]. Emergy indices include all energy used in making a product or service. In the emergy analysis, one needs to identify all the materials and energy flows in the working process, and thereafter calculate total "emergy" flows. EMPIs mainly contain renewability data (i.e., the ratio of emergy of the local renewable resources and the total emergy used in the system), as well as the emergy sustainability index, which is calculated from the emergy yield ratio and environmental loading ratio. The renewability index has been used in the sustainability evaluation of an economic system, and is also regarded as an indicator of the stress on ecosystems [10].

Amongst the three indicators, the EF is the simplest index, and it does not have any sub-indicators. The ESI is the most complex index and is more arduous to calculate, and the EMPIs are widely used for solar emergy.

Besides these three, there are some other indices such as genuine progress indicator (GPI) and genuine saving (GS), which can also provide some useful insights. GPI considers not only the gross domestic product, but also the cost of the negative effects associated with economic activity. Therefore, it measures the net results of economic growth of a country. GS is another indicator of sustainable economic development at the country level, which is based on the idea of wealth accounting [11]. Other sustainability indices include the Sustainability Index for Urban Water Management that was used to explore the integrated urban water management in the African cities of Maputo and Hermanus [12]; the Human Development Index [13]; the human poverty index [14]; the water poverty index [15]; and the Falkenmark water stress indices [16]. These indices are often used as indicators of social welfare.

The problem with the aforementioned indicators is that they are too narrow in focus and do not incorporate holistic notions of sustainable development. However, as a guideline, the UNDP has set up indicators for sustainable development in terms of three dimensions—Environmental, Social and Economic. Review papers, such as those by Strezov, Evans and Evans [17] also note the problem

with commonly used indicators, acknowledging that these do not encompass the three dimensions of economic, environmental and social dimensions of sustainable development. The City Sustainability Index (CSI), on the other hand, as proposed by Mori and Yamashita (2015) [18], may in fact be the one closest to the aim of this study. This is because Mori and Yamashita (2015) [18] observed that adequate CSI needs to (1) be based on all three perspectives, i.e., economic, environmental and social, (2) use a set of constraint and maximization indicators, and (3) be constructed from a viewpoint of strong sustainability [18,19]. In that sense, therefore, CSI considers the fact that sustainability needs to be viewed holistically, and that it needs to be subject to environmental and socio-economic equity constraints [18].

Mori and Yamashita (2015) [18] also include maximization indicators, because these are an indicator of the kinds of benefits that cities generate in economic as well as social terms (Mori and Yamashita (2015) [18]). Mori and Yamashita (2015) [18] also suggest that maximization indicators should include indicators such as GDP per capita and the capital stock of infrastructure, whilst constraint indicators could be agglomeration costs, or even indicators of social amenities like the accessibility of public transportation and hospitals (Mori and Yamashita (2015) [18]: 12). As cities create more benefits, prosperity increases. This study also aims to examine sustainable development; but unlike Mori and Yamashita's (2015) [18] research which was a general review paper, this paper is application focused, and based on the context of Singapore's metropolis.

Besides CSI, other studies that are related to the measure of sustainable development in cities include Dempsey et al. (2009) [20], Berardi (2013) [21], Shmelev (2017) [22] and Lee and Huang (2007) [23]. Dempsey et al. (2009) [20] examined the social dimension of urban sustainable development. Berardi (2013) [21] discussed a few measures of sustainability for urban communities, and proposed some missing criteria within the social and economic dimensions. Shmelev (2017) [22] used multi-criteria decision tools to assess sustainability performance in a few world cities, including Singapore; and found that Singapore ranked top for most criteria. Using a different method and indicators of sustainable development, Lee and Huang (2007) [23] found that for places such as Taiwan, economic and institutional dimensions were performing relatively poorly. Basically, these studies try to answer the call by researchers for more indices that seek to consider human and natural systems in conjunction with each other (c.f. Liu et al., 2007 [24]; Pan, Deal, Destouni, Zhang, & Kalantari, 2018 [25]; Petrini & Pozzebon, 2009 [26]). Additionally, other studies that use alternative indicators to assess sustainable development include that proposed by Garcia-Ayllon and Miralles (2015) [27], which consider, amongst other things, management of cultural resources (for example, the number of museums and similar institutes). However, for smaller metropolises, absolute numbers of such institutes may not be applicable, and also, their methodology is more applicable for the European Mediterranean region. Our study, therefore, contributes to the line of research that seeks more holistic methods of assessing sustainable development; also, it focuses on the urban metropolis of Singapore, so as to develop a more inclusive measure that can be applied to smaller metropolises as well.

The Singapore government has exerted great effort in promoting sustainable development. The first Sustainable Singapore Blueprint (SSB) was released in 2009 to set out the national framework and strategy till 2030. A second edition of the blueprint SSB 2015 stretched these targets further. While laudable, these efforts at national sustainability mainly focused on issues relating to the environment, energy, and water management, or the hardware of a metropolis in general. The societal and economic side of a sustainable metropolis, though equally important, have not been as rigorously emphasized. This study aims to comprehensively examine the non-environmental side of sustainability in Singapore from the 3P perspective—namely, population, productivity and parity. The importance of the 3P perspective is explained, as follows.

First, population matters a great deal to sustainable development. As a city state and developed economy, Singapore faces the dual problems of declining fertility rate and an ever-changing population demographic due to its high inward immigration rates [28]. On the one hand, there is an urgent need to understand couples' baby decision-making processes and also conduct effective evaluations

of different incentive programs and policies targeted to improve total fertility rate, so as to sustain a preferred demographic balance. On the other hand, inflows of immigrants, despite being able to temporarily ease the shortage of labor supply in an aging society, put pressure on public resources and sustainable growth. Therefore, these inflows need to be carefully monitored and strategically managed.

Second, economic growth cannot be sustained without productivity improvements. To build a sustainable metropolis, maintaining sustainable economic growth is a precondition. Sustainable productivity takes a long-term view, being productive not only for today or tomorrow, but also twenty years from now and more. The Singapore government has launched many different incentives and schemes to support companies and industries so as to improve their productivity. However, their effectiveness, their impact on, and contribution toward improving sustainability remain to be investigated.

Finally, reducing economic disparity is a sustainable development challenge. The corrosive effects of economic inequality on health, education, crime, economic growth and social cohesion have been widely documented. To integrate the goal of reducing economic inequality into the blueprint of a sustainable Singapore is vital, because Singapore's income gap, as measured by the Gini coefficient, is found to be one of the widest among the developed countries.

The remainder of this study is organized as follows. Section 2 describes the method, including the data and indicators chosen with the rationale for the construction of the sustainability index. Section 3 presents the results, Section 4 the analysis of the results, and finally, Section 5 concludes with policy implications.

2. Method

2.1. Data and Indicators: Indicator Selection and Justification

This paper employs the *3P* concept (namely, population, productivity and parity) to construct the sustainable metropolis index. The indicators chosen for the construction of the index are as follows.

There are 24 indicators in total and eight indicators each for population, productivity and parity.

Population: Of the eight indicators, marriage rate, divorce rate, fertility rate, infant mortality rate, dependency ratio and temporary habitant population rate are indicators to measure population quantity sustainability. Primary school student ratio per teacher and ratio of population with a college level education are used to measure population quality sustainability. A holistic sustainability analysis requires both sustainability in population quantity and quality.

According to the Social Trends Institute [29], marriage and fertility play a key role in sustaining long-term economic growth, the size and quality of the workforce, and for sectors of the economy to maintain their profitability [29].

STI (2011) [29] also found that children raised in intact, married families are more likely to acquire the human and social capital they need to become well-adjusted, productive workers. In addition, men who get and stay married work harder, work smarter, and earn more money than their unmarried peers. Therefore, divorce ratio and mortality ratio are also included. Straughan (2012) [30] also studied such correlations between delayed marriages and low fertility rates in Singapore and found that this has a negative impact on Singapore's economy.

Dependency ratio which is closely related to the abovementioned indicators on marriage, birth and death, is also selected. A low dependency ratio means less burden on the resources of the metropolis. Since birth rates are down and medical advancements are up, there will be fewer young adults to support the retirees and elderly. Such strain on national resources can put a brake on the path to being a sustainable metropolis. Singapore, in particular, is feeling the pinch from an ageing population, which is partly attributable to its citizens' low birth rate [31]. Please refer to Table 1 for more information.

Table 1. Sustainable Metropolis Index of Singapore.

Population	Productivity	Parity
Quantity	**Efficiency**	**Income parity**
1. Crude marriage rate: Per 1000 residents	9. GDP per capita (current US$)	17. Gini coefficient after accounting for government transfers and taxes
2. Crude divorce rate: Per 1000 residents	10. Unemployment rate	18. Population in public versus private housing
3. Fertility rate: Per female	11. Vehicles per km of road	19. Number of months to buy a median priced house
4. Infant mortality rate: Per 1000 live births	12. Passenger cars per 1000 people	**Social parity**
5. Dependency ratio	13. Motor vehicles per 1000 people	20. Social welfare expenditure to total expenditure
6. Temporary inhabitant population rate	**Technology**	21. Environmental and ecological budget ratio to total government budget
Quality	14. Electric power consumption kWh per capita	22. Crime rate per 100,000 people
7. Primary school student ratio per teacher	15. Mobile cellular subscriptions per 100 people	23. Suicide rate per 100,000 people
8. Ratio of population with a college level education	16. Internet users per 100 people	24. Healthcare worker numbers per 10,000 people

Temporary inhabitant population is chosen because immigration and foreign population influx can have a negative effect on a metropolis' sustainability. Chamie (2013) [32] explored the controversial connection between immigration and overpopulation in the US. It showed that open immigration (temporary inhabitants) and sustainability are often inversely related [32]. It is true that immigration presents a dual opportunity-threat situation—on the one hand, agglomeration of individuals boosts productivity, connectivity and increasing returns, but on the other hand, problems such as congestion cost, higher rent, and cultural misunderstandings may be exacerbated. Certainly, more research should be done on how to manage these paradoxes in terms of sustainability. For example, Hämäläinen et al. (2011) [33], Lewis et al., (2014) [34] amongst others, advocate a strategy of reformulating governance models so as to better tackle the issues of paradox between contradictory objectives; they note that developing a country's strategic agility is essential, to separate financial and strategic efforts to focus on different aspects of the paradox so as to better cope with the tradeoffs and decision making under complexity. However, such considerations would be out of the scope of this paper—the objective is to come up with tentative propositions based on analysis of the data, and from there, policy makers can choose to develop their strategic plans further.

Other than sheer numbers, a workforce's *quality* also cannot be overlooked. Berger and Fisher [35] showed that countries can increase the strength of their economies and their ability to grow and attract high-wage employers by investing in education, as well as by increasing the number of well-educated workers. There is widespread consensus that children who attend schools with a low pupil-teacher ratio on average perform better and earn higher wages as adults, as compared to children who attend schools where the resources are limited (Card and Alan, 1996) [36]. Hence, two proxies of education: Student ratio per teacher, and educational attainment, are chosen.

Productivity: For Productivity, the eight indicators are roughly classified into two categories of efficiency and technology. GDP per capita and unemployment rate are directly related to productivity. Passenger cars and motor vehicles per 1000 people, and vehicles per km of road estimate Singapore's transportation efficiency. The remaining three indicators, i.e., electric power consumption per capita, mobile cellular subscriptions, and internet users per 100 people, are chosen so as to consider the rate of technological penetration.

A few points are noteworthy. Total factor productivity (TFP) is an ideal indicator to measure productivity; but the measures of TFP are controversial, since growth is estimated as a residual, and there are many unmeasured gains in product quality itself (Hulten, 2000) [37]. Commute time may be a better indicator for the measure of transport productivity; but the data is not available for most years. The selection of indicators on the number of vehicles could be debatable. One may argue that more vehicles do not necessarily improve transportation; if there are too many cars on the road, there will be traffic congestion, leading to not only a waste of time on the way but also increased stress that could further reduce people's productivity at work, let alone the air pollution associated with more vehicles. This is a valid concern. To avoid this issue, one may resort to improved indicators such as average commute time or advanced nonlinear methodologies which, however, may cause other concerns and complications. Recognizing the issue and trade-offs, we raise caution on the use of these indicators in the context of interpreting our results.

Transportation efficiency is essential to sustainability because at the macroeconomic level, transportation and the mobility it confers are related to output, income and profit within an economy. In many developed countries, transportation accounts for between 6% and 12% of the GDP (Rodrigue and Notteboom, 2017) [38]. At the microeconomic level, transportation is linked to producer, consumer and production costs. In an economy where transport is efficient and affordable, goods and services can be sold or exchanged easily. In the US, transportation accounts, on average, for 10 to 15% of household expenditures, and around 4% of the costs of each unit of output in manufacturing (Rodrigue and Notteboom, 2017) [38]. A study conducted by London consulting firm Credo in 2014 shows that Singapore has one of the most efficient public transport networks in the world (Sim, 2014) [39].

With better communication comes greater productivity. The relationship is straightforward: Since the advent of postage mail, to the current situation of internet and phone usage, economies have been able to be more productive. Therefore, mobile cellular subscriptions per 100 people and internet users per 100 people are used as proxies to measure technological penetration and the development of communication technologies within a metropolis. Having good technological penetration is also important for sustainability, because it allows for the Internet of Things (IoT) that creates a huge opportunity to increase the value of every connected thing [40]. Therefore, information prevalence can help to streamline the manufacturing process, user experience and scrap process. This in turn makes a metropolis more sustainable.

On the other hand, electric power consumption per capita is a proxy for production activities. It is related to the productivity dimension, as studies find a bi-directional causality between energy use per capita and total factor productivity [41]. Energy sustainability advocates may emphasize energy use efficiency or energy intensity as a better indicator and question the choice of this indicator. While this may be so, due to the data unavailability of those other indicators, electric power consumption, although imperfect, at least enriches the productivity measure in this study and is relevant, especially for many Asian cities.

Parity: For Parity, the indicators include the Gini coefficient, the proportion of population in public housing, the number of years required to buy a median priced house, social welfare expenditure, environmental and ecological budget ratio to total government budget, crime rate, suicide rate, and the number of healthcare workers. The first three can be categorized as income parity measures, and the last five can be considered measures of social parity.

Housing is also selected as an important income parity measure because housing is a significant monetary cost spread over long periods of time. Basic housing is a necessity and its cost is rather indivisible compared to other necessities, such as food and utility, which involve smaller payments per transaction. Researchers have shown that housing subsidies can increase social equality, bridging the gap between the haves and the have-nots [42]. Chen (2015) [43] postulates that housing speculation and ownership has implications on social inequality in Taiwan. As such, a society in which people have less financial pressure to own a house is therefore considered more sustainable.

In Singapore, about 82% of population lived in Housing Development Board (HDB) housing over the last decade. Although the percentage of the population in public housing remained relatively stable across the years, the composition of housing seems to be skewed towards higher-end housing; suggesting increasing income disparity in Singapore. The number of months to buy a median priced house is calculated from median income and median house price with the assumption of a 20% down-payment for purchase.

Government expenditure on social welfare and the environment are also selected as indicators, as such public good expenditures could be equally utilized by residents. Similar to environmental and social expenditure, law and order is also a public good that can be equally utilized by residents. Fajnzylber et al. [44] showed that crime rates and inequality are positively correlated within countries and between countries, and this correlation reflects causation from inequality to crime rates, even after controlling for other crime determinants. Hicks and Hicks [45] also found a significant association between violent crimes and the inequality of visible consumption. Hence, including crime rate figures can better show the social parity of a sustainable metropolis.

Much like government social expenditure and crime rate, suicide rate is also positively related with social disorder and inequality. Suicide is mainly caused by mental disorders, or stress from financial difficulties and relationships. It affects the overall well-being of the population and makes society less sustainable. High suicide rates among the young will affect otherwise healthy production capacity, while high suicide rates among the old will affect the overall level of well-being or happiness that is a counter-force of sustainability. This justifies why suicide rate should be an indicator of metropolis sustainability. Beyond the personal, family and community anguish of such events poses great costs via the loss of human capital and efficient community functioning [46]. Therefore, suicide

rate is seen as one of the proxies of social exclusion and is included in the UN Commission on Sustainable Development's Indicators of Sustainable Development [47].

The health care system in Singapore is a two-tiered one, where the rich can opt for private and expensive health service, and the general populace can go for subsidized, and "quality and affordable basic medical service" that is ensured by the Ministry of Health, Singapore. Both the poor and the rich benefit from more healthcare personnel, especially in a time when there is a global shortage of healthcare professionals [48,49] illustrated the importance of equity in healthcare as a vital social indicator amongst citizens of the Philippines. Healthcare personnel is a quintessential component in contributing towards healthcare quality. Consequently, better healthcare will make social parity more equal and bridge the gap between the upper and lower classes.

2.2. Data Sources and Descriptive Statistics

Yearly data for the period of 2000 to 2014 were obtained from various sources such as the CEIC database, the World Bank and government statistical reports. The descriptive statistics for these indicators are shown in Table 2.

Table 2. Descriptive Statistics.

Indicators	Min	Max	Mean	Std
Population				
Crude marriage rate: Per 1000 residents	6.1	6.8	6.49	0.19
Crude divorce rate: Per 1000 residents	1.5	2	1.85	0.14
Fertility rate: Per female	1.15	1.6	1.29	0.11
Infant mortality rate: Per 1000 live births	1.8	2.9	2.19	0.31
Dependency ratio	35.78	40.45	37.49	1.42
Temporary habitant population rate	0.18	0.29	0.23	0.04
Primary school student per teacher	16.35	25.2	21.47	3.27
Ratio of population with a college level education	0.08	0.2	0.14	0.04
Productivity				
GDP per capita (current US$)	21,577	56,287	37,725	13,015
Unemployment rate	1.9	3.95	2.62	0.65
Vehicles: Per km of road	166.43	229.51	197.96	23.12
Passenger cars: per 1000 people	96.81	119.26	108.82	9
Motor vehicles: per 1000 people	126.89	154.68	142.86	9.9
Electric power consumption (kWh per capita)	7516.19	8689.67	8242.9	410.43
Mobile cellular subscriptions (per 100 people)	70.12	158.13	117.27	32.51
Internet users (per 100 people)	36	82	63.03	13.52
Parity				
Gini coefficient after accounting for government transfers and taxes	0.41	0.44	0.42	0.01
Proportion of population in public housing	0.81	0.87	0.84	0.02
Number of months to buy a median priced house	21.61	32.18	26.97	3.28
Social welfare expenditure to total expenditure	0.24	0.34	0.29	0.03
Environmental and ecological budget ratio to total government budget	0.02	0.05	0.03	0.01
Crime rate (per 100,000 people)	555	870	735	124
Suicide rate (per 100,000 people)	7.85	10.31	9.30	0.69
Number of healthcare workers (per 10,000 people)	55	90	69	12

Note: Indicators in Population and Productivity are retrieved from the CEIC or the World Bank. Suicide rate is obtained from the World Bank; number of healthcare workers (per 10,000 people) is obtained from Ministry of Health Singapore; number of months to buy a median priced house is calculated by the authors; other parity indicators are obtained from the Department of Statistics, Singapore.

It is noteworthy that Table 2 only describes the standard statistics of the indicators chosen for the period from 2000 to 2014 in Singapore. Obviously, the statistics would vary if a different time period had been chosen. In fact, the descriptive statistics would be more meaningful if compared across cities rather than over time when the 3P index analysis is expanded to other municipalities. As a result, caution should be raised in the result interpretation, and the implications of this are discussed in the concluding section.

2.3. Transformation of Raw Data

The main idea behind the use of the methodology is to standardize different indicator values and use simple numbers to directly measure sustainability and make comparisons over time.

2.4. Standardization

Following the formula stated below, this study calculates the standardized values of each indicator over a time period (range is from 0 to 1). A value closer to 1 means more contribution to sustainable development.

The first step is to standardize the data collected for each indicator using *Standardized value* $P_i = (X_i - \mu)/\sigma$, where P_i denotes the standardized value, or z-score of the *i*-th observation in the indicator, X_i represents the *i*-th observation, μ is the mean, and σ denotes the standard deviation.

The second step is to get the transformed series $\{Y\}$. For most standardized values, the following indicator transformation method can be applied (refer to (1) as follows).

$$Y = (P_i - d)/(u - d) \tag{1}$$

where u and d denote the maximum and minimum values of P_i. Therefore, the range of Y is between 0 and 1.

For some indicators, a lower number indicates progress towards sustainable development. Therefore, the values of such indicators should be adjusted by $(Y^* = 1 - Y)$, so that values approaching 1 indicate progress towards sustainability for all indicators. Amongst the productivity indicators, unemployment rate is the only indicator that needs to be reversed since a lower unemployment rate indicates progress towards sustainable productivity development. Among parity indicators, the Gini coefficient, after accounting for government transfers and taxes, has a negative correlation with sustainable development, so the reverse calculation is used.

2.5. Index Construction

A large number of methods are available for calculating the composite index weighting, and different methods yield different results. While some authors apply unequal weights [50], this study applies the equal weight and simple arithmetic average method, following Barrera-Roldán and Saldívar-Valdés (2002) [51], for an initial investigation on the overall sustainability trend. Specifically,

$$SustainabilityIndexforPopulation = \frac{1}{8} \begin{pmatrix} marriagerate \\ +divorcerate \\ +fertilityrate \\ +mortalityrate \\ +dependencyrate \\ +temporaryhabitantpopulationrate \\ +primaryschoolstudentrateperteacher \\ +ratioofpopulationwithacollegeleveleducation \end{pmatrix} \tag{2}$$

$$SustainabilityIndexforProductivity = \frac{1}{8} \begin{pmatrix} GDPperrate \\ +unemploymentrate \\ +vehiclesperkmofroad \\ +passengercarsper1000people \\ +motorvehiclesper1000people \\ +electricpowerconsumptionkWhpercapita \\ +mobilecelluarsubscriptionsper100people \\ +internetusersper100people \end{pmatrix} \tag{3}$$

$$
\begin{aligned}
&\text{SustainabilityIndexforParity} \\
&\text{Ginicoefficient} \\
&= \frac{1}{8}
\begin{pmatrix}
\text{proportionofpeopleinpublichousing} \\
+\text{numberofmonthstobuyamedianpricedhouse} \\
+\text{environmenalandecologicalbudgetratiotototalgovernmentbudget} \\
+\text{socialwelfareexpendituretototalexpenditure} \\
+\text{crimerate} \\
+\text{suiciderate} \\
+\text{numberofhealthcareworkers}
\end{pmatrix}
\end{aligned}
\qquad (4)
$$

The overall sustainability index is subsequently calculated as the average of these three constructed indices. Results from the simple arithmetic average and the geometric average do not vary much.

3. Results

The population dimension incorporates indicators of temporary inhabitant population rate, primary school student ratio per teacher, divorce rate, fertility rate, mortality rate, dependency ratio, marriage rate, and finally, the ratio of the population with a college level education. Since some indicators, such as temporary inhabitant population rate, primary school student ratio per teacher, divorce rate, mortality rate and dependency ratio are negatively related with the sustainability measure, the values of these indicators should be reversed via ($Y^* = 1 - Y$) so that a value towards 1 indicates improved sustainability.

The values of primary school student ratio per teacher and infant mortality rate have increased gradually over time, indicating that these two indicators have contributed towards sustainability. However, other indicators, such as the dependency ratio and temporary inhabitant population rate are approaching 0, suggesting further deviations from sustainability. Divorce rate, however, seems to be constant after 2004.

Other indicators, such as the ratio of population with a college level education and marriage rate, have kept increasing over the past few years, indicating progress towards sustainable development, whilst fertility rate has been decreasing and implies a negative impact on population sustainability.

Figure 1 shows the sustainability trend of the population over the period examined. It is observed that the sustainability sub-index of the population has declined from the beginning till 2003, and then it trends upwards afterwards, except for temporary drops in 2010 and 2013.
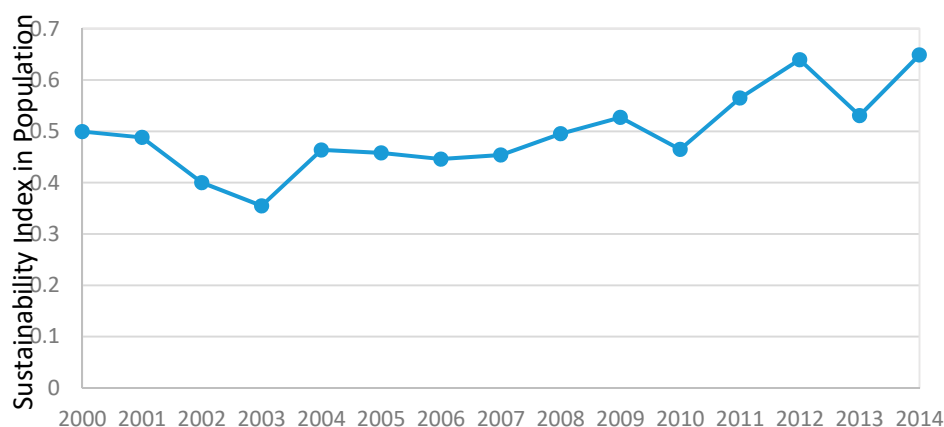

Figure 1. Sustainability trend of the population.

The standardized indicators of passenger cars, vehicles, motor vehicles, GDP per capita, electric power consumption, mobile cellular subscriptions and internet users have all displayed an increasing trend, suggesting annual improvement in productivity development.

Figure 2 depicts the sustainability trend of productivity. Since each of the indicators used to measure the sub-index of productivity sustainability is improving, the aggregate productivity measure moves healthily upward except for the years 2002, 2009 and 2013, in which a little decline has occurred due to negative changes, mainly in the unemployment rate indicator.
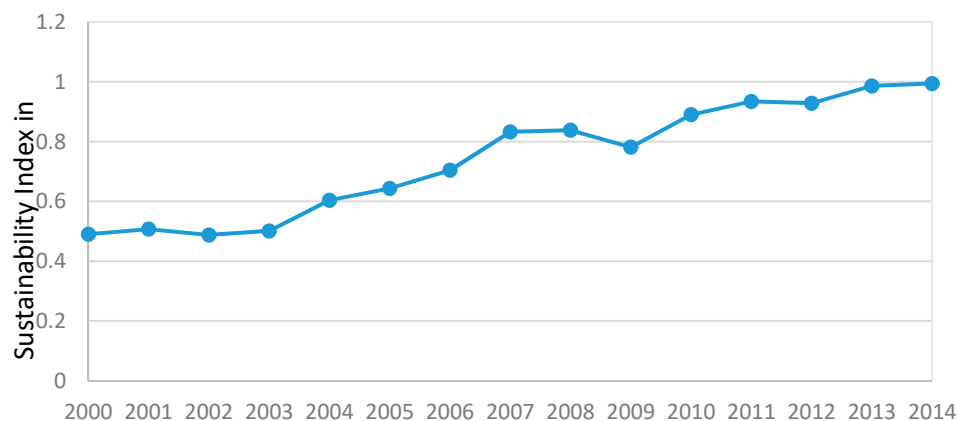

Figure 2. Sustainability trend of productivity.

Amongst the eight indicators used for the parity dimension, the reversed and standardized Gini coefficient experiences a fluctuation during the past decade, and reaches its peak in 2013. The higher proportion of people in public housing, the more equality, because the variance of HDB prices is far lower than that of private housing. The indicator decreases from 2000 until 2011 and afterwards increases slightly in 2012 and 2013; indicating that income inequality has generally widened.

Figure 3 shows the sustainability trend of parity. It reveals that the sustainability index for the parity dimension had improved before 2002, but it fluctuated afterwards until 2012. Since 2012, the parity sub-index has increased stably; indicating that the parity development of Singapore has gradually moved from an unsustainable situation towards sustainability.
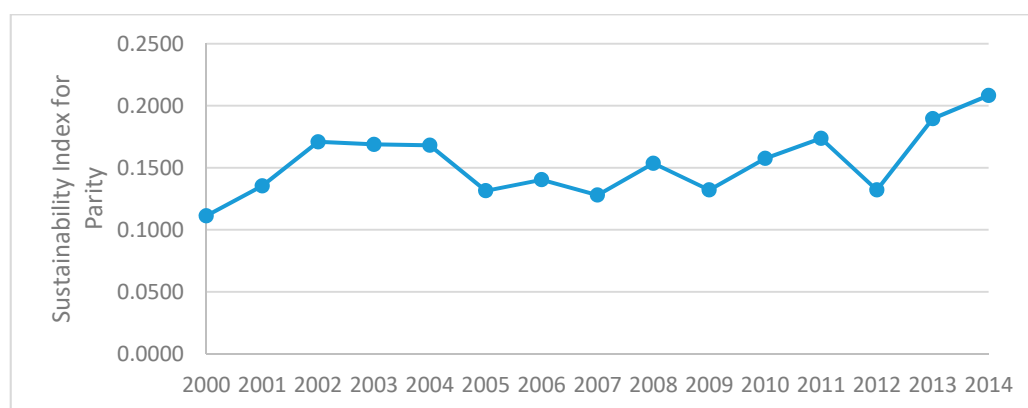

Figure 3. Sustainability trend of parity.

4. Analysis of Results

Based on the 3Ps framework and an equal weighting method, the overall sustainability index for Singapore can be constructed. Results are shown in Table 3 and Figure 4. It clearly shows that the sustainability index for Singapore has gradually increased year by year, and improvement on the sustainability of productivity in recent years has been the key reason for the increase of the sustainability index.

Table 3. Sustainability index for Singapore.

Year	Population	Productivity	Parity	Sustainability Index
2000	0.1665	0.1634	0.1113	0.4412
2001	0.1627	0.1690	0.1354	0.4671
2002	0.1334	0.1625	0.1709	0.4668
2003	0.1183	0.1670	0.1688	0.4541
2004	0.1546	0.2013	0.1681	0.5239
2005	0.1526	0.2145	0.1315	0.4986
2006	0.1486	0.2347	0.1403	0.5237
2007	0.1513	0.2774	0.1280	0.5567
2008	0.1651	0.2794	0.1536	0.5981
2009	0.1757	0.2604	0.1321	0.5682
2010	0.1549	0.2967	0.1575	0.6091
2011	0.1883	0.3113	0.1737	0.6733
2012	0.2132	0.3094	0.1321	0.5386
2013	0.1769	0.3287	0.1896	0.5308
2014	0.2163	0.3313	0.2083	0.5902
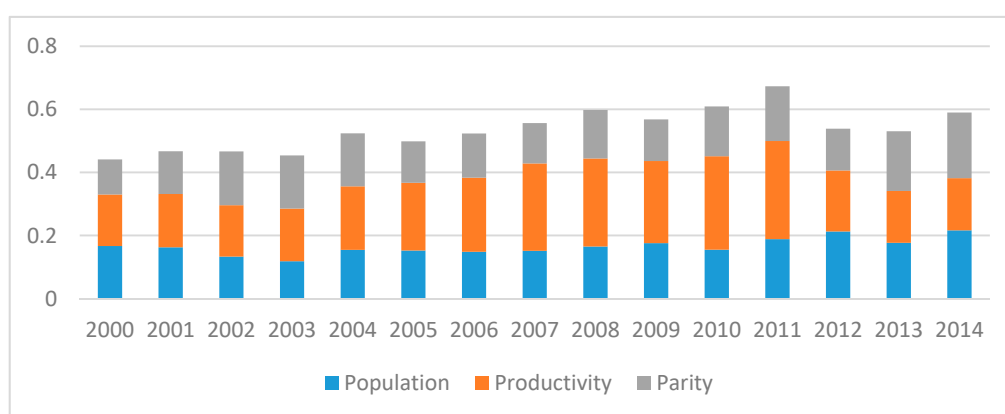
Figure 4. Trend of sustainability for Singapore.

The foregoing analysis is based on our index as developed in this paper. Essentially, we provide a new approach to measure sustainable development. However, like most other research, we focus on method development rather than on the implementation of the method. Therefore, in order to improve the practicability and widespread use of this index, empirical surveys could be sought from relevant government ministries in order to examine both the practicability of the method, the interpretation of the results of the data, as well as the possible consequences of changing the method of evaluating sustainability in real world terms [52]. Therefore, other than considering theoretical contributions, the next section considers some practical policy implications that could be put forward to practitioners.

5. Conclusions and Policy Implications

Our study constructs a sustainability index framework for a metropolis by taking Singapore as a case, and integrates the 3P concept, namely, population, productivity and parity—and estimates the sustainability of the metropolis from a non-environmental perspective. The indicators, constructed from a compilation of available data from the World Bank, CEIC and government database, were selected with reference to relevant international and local studies, and were discussed with experts and scholars Intensive discussion with experts on the indicator selection was carried out during a sustainability workshop held at Nanyang Technological University, Singapore in April 2016 so as to provide greater external validity for our indicators. As a result, a set of 24 sustainability indicators for the period of 2000 to 2014 were constructed as the 3P sustainability index for Singapore.

The 3P concept adopted in this study is a novel approach. The main contribution of this study is a new sustainability index framework which emphasizes the non-environmental side of sustainability and provides a counterbalance to current studies that tend to focus only on ecology, for example, sustainability issues relating to the environment, energy and water management. It is postulated, instead, that the societal and economic aspects of sustainable development are equally important, and thus these are given due consideration in the construction of the index. Although the sustainability index proposed in this study does not provide an absolute, once-for-all precise measure of Singapore's sustainability status, it does, however, enable preliminary evaluation as to whether Singapore has achieved progress toward 3P sustainability over the past 15 years. This study also differentiates which of the 3P or 24 sustainability indicators in Singapore are showing trends towards or away from sustainability. Relevant policies and measures are therefore suggested to improve sustainability.

To be specific, results from the constructed 3P sustainability index of Singapore for the period from 2000 to 2014 suggest that productivity has gradually moved towards sustainability, while population sustainability has remained relatively unchanged even though it increased in 2014 as compared to the year 2004. Before 2002, the parity dimension has also moved toward sustainability, but it has experienced ups and downs afterward till 2012.

For the population dimension, the temporary inhabitants' rate is the main factor that drives the index away from sustainability. One of the possible policy implications drawn from this result would be that the Singapore government could take certain measures to address this issue (for example, by formulating, and more stringently applying, higher standards for work and employment passes, so that the incoming migrants would be those that could potentially contribute more to the economy). The parity index has fluctuated in the past decade, and environmental and ecological expenditure to total government budget also display non-sustainability, so the implication is that the government could increase the budget in these areas.

At this juncture, we would like to address the initial question that was posed at the start of the study. How well has this paper taken into account the three conditions that Mori and Yamashita (2015) [18] propose for a more complete, holistic measure of sustainable development? According to Mori and Yamashita (2015) [18], and earlier elaborated upon by Mori and Christodoulou (2012) [19], the three conditions for sustainability are as follows: (1) Strong sustainability; (2) distinction between absolute and relative assessments, and (3) leakage effect. With regard to the first condition, Mori and Yamashita (2015) [18] note that it is critical that assessments of sustainability should be done on the basis of strong sustainability alone—i.e., the assumption that physical, social, human, and natural capitals–are non-substitutable. Given that this paper's argument is focused on non-environmental factors, we are trying to take a strong sustainability stand, i.e., that this cannot be discounted from the equation if we wish to do a holistic assessment of sustainability. Additionally, Mori and Yamashita (2015) [18] note that we cannot prioritize economic and social benefits without also considering environmental preservation, or even social considerations such as equity. In our calculations, we have factored in the equity indicator.

With regard to Condition 2, the Mori and Christodoulou (2012) [19] paper states that absolute evaluation with certain standards or thresholds, to the extent possible, should be done. The researchers note that, "in terms of city sustainability, absolute evaluations are crucial." They cite Bithas and Christofakis (2006) [53], who explain that when certain biological elements have deteriorated beyond some crucial levels, a city would fare very poorly in terms of absolute evaluation of sustainability. Therefore, when assessing absolute evaluation, Mori and Christodoulou (2012) [19] note that it is difficult to set absolute limits due to lack of practical definition; however, still the effort should be made, and one possible method to assess this would be in terms of subjective local criterion (i.e., by local standards). We therefore argue that local standards should be used to evaluate absolute sustainability. In the case of the metropolis of Singapore, the argument is that local standards, rather than global standards, are a good litmus test for absolute evaluations. This is because Singapore's case as a metropolis is unique in terms of resource endowment as well as cultural backdrop and land

size. Additionally, the context that policy makers are facing is particularly important. In Singapore, the issue of immigration has become a hot-button issue in elections. The Population White Paper, a governmental policy paper that, in 2013, set out the yearly target rate of desired immigrants into Singapore, had to be more or less rescinded in the face of mounting public criticism. Recently, however, there has been growing recognition amongst the population that there must be some tradeoff in terms of productivity should Singapore wish for a lowered rate of immigration (initially, since Singaporeans were unable to accept an annual target workforce growth of between 1% to 2%, productivity rate fell by 0.1 per cent in 2015, according to Cheng, 2017) [54]. In that sense, therefore, for Condition 2 of sustainable development, this paper posits that steps have indeed been made to incorporate local standards of evaluation with regard to population, the key hot-button issue. On a separate note, in terms of relative sustainability, future researchers are encouraged to study sustainability using our proposed index by comparing with other countries.

With regard to Condition 3, this paper was unfortunately unable to evaluate the extent of leakage effect. This is because the authors could not find any coherent data that appropriately measures the external environmental impacts of Singapore beyond its borders [19]. In particular, there was a lack of data on the impact of Singapore's pollution on its neighboring countries. However, it is arguable that Singapore's pollution footprint is not what concerns environmental observers the most- in actual fact, it is Indonesia who tends to raise more ecological alarm to its neighbors on a yearly basis, during the dry season of May to August every year when the country conducts its annual slash-and-burn clearing of land for agricultural use. For example, in September 2015, the Pollutants Standards Index (PSI) in Singapore hit 341 in one day due to the smog from Indonesia [55]. Lack of data, in this context, appears to be the case for the foreseeable future. The suggestion raised is that future researchers with a different metropolis context could consider leakage effects if they have the data.

Finally, another caveat we wish to make is with regard to the connection between the availability of public housing and equality. The relationship between public housing and equality is probably more significant for Singapore and a few other similar land scarce city state jurisdictions. In general, the relationship between public housing and equality is not so direct and linear. Recognizing this issue, we raise caution in the context of interpreting our results.

Overall, this study reviews the 3P sustainable development of Singapore for the past 15 years using 24 indicators (partially due to the availability of data). Analysis for a longer time span could be carried out in the future. Apart from extending the period of analysis, sustainability indicators should be reviewed every three to five years so as to re-estimate their suitability and make forecasts, or even issue advance warnings on sustainability maintenance.

There is also an urgent need to look at sustainability issues within Asian metropolises because of their rapid urbanization, and yet the majority of the research is still being conducted in American (or European) contexts. Those who are interested in constructing non-environmental side sustainability indices for other contexts may leverage this study as a starting point for research. However, such researchers may have to contend with a lack of data with regard to leakage effect, especially for some places in Asia. Despite this, by having more studies in this field, a systematic framework could be formulated, and thence applied, to make some cross-country comparisons.

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