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Luxembourg Income Study Working Paper Series

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Raising Utility and Lowering Risk through Adaptive Sustainability: Society and the Risk of Wealth Inequity in Western Australia

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Abstract

The Index of Sustainable Functionality (ISF) makes it possible to analyse domains and the sustainability of multiple systems from various perspectives. This paper uses available household wealth and income data to calculate the resource rich state of Western Australia's ISF from different wealth level perspectives. How wealth inequity may affect the stability of major systems including the social, terrestrial, water and mineral industry are discussed as are reasons behind recent changes in wealth distribution. The ISF results show that from the perspective of society's richest 20%, poorest 20%, mean wealth households and the environment, system decline has occurred over the past 20 years, even as the economy reached full functionality. Suggestions to improve functionality and long-term stability are made, with the major suggestion the introduction of a fund modelled on Norway's sovereign wealth fund.

Keywords: index of sustainable functionality (ISF); wealth inequity; sustainability; Western Australia (WA); Norway, sovereign wealth fund.

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1. Introduction

Western Australia (WA) is one of the largest and wealthiest regions in the world with high natural resource wealth and a population of 2.2 million people. WA covers a third of the Australian continent in area and has the highest Gross State Product (GSP) per capita of any state in Australia at US \$53,178 compared with the state average of US \$41,291¹. Western Australia's per capita production is therefore similar to Norway's (\$53,451) that according to the World Bank is the top country world-wide². It is easy to see how this is achieved as according to the Department of Mines and Petroleum (2008) Western Australia accounts for 19% of the world's iron ore production, 20% of alumina, 15% of nickel, 9% of (industrial) diamonds, 7% of liquefied natural gas (LNG), and 6% of gold with a total sales value of over \$US 65 billion per annum (\$US 30,000 per capita).

WA has been a commodity driven state since its establishment as a British colony in 1826 with agricultural and livestock industries. The discovery of gold in the 1890s, nickel in the 1960s and major natural gas fields in the 1970s through to today has encouraged population expansion through immigration and natural growth from a population of 40,000 in 1890. Over time large multinational mining and oil companies have invested in the state and now sell the majority (est. 90%) of mineral resources³.

The natural environment in Western Australia is one of the world's international biodiversity hotspots (Conservation International, 2009), and has changed throughout this time due to clearing for agriculture, mining and development that has led to significant reductions in habitat for much of the endemic flora and fauna. The Southwest region of WA alone, with less than 20 % of the total area, maintains 5710 known native species of flora and fauna, with a high rate of endemism (79%). (Beard, 2000)

In Western Australia, the State Sustainability Strategy (2003) defined sustainability in the following way:

¹ 2007 numbers calculated using World Bank and ABS - 1383.0 (Measures of Australia's Progress) data and an AUD/USD exchange rate of 0.90.

² This doesn't include countries with small populations used as tax havens such as Luxembourg and Lichtenstein.

³ The largest exporters of state resources include BHP Billiton, Rio Tinto, Shell and Chevron.

“Sustainability is meeting the needs of current and future generations through the integration of environmental protection, social advancement and economic prosperity”.

Definitions of sustainability vary and while there have been a number of sustainability indices used (Singh et al., 2008), such as corporate responsibility with the composite sustainable development index (Krajnc and Glavic, 2004), there is still no standardized methodology to enable consistent measurement and identification of sustainable options (Azapagic and Perdan, 2000). According to Costanza and Patten (1995) who provide more detailed discussions of sustainability, “the basic idea of sustainability is straightforward: *a sustainable system is one that survives or persists.*”

In industry measuring sustainability using the triple bottom line approach (environmental, economic and societal) is typical, but its limitations necessitate the continued search for better terms and frameworks (Mulvihill and Milan, 2006). Fricker (1998) suggests the best method for sustainability is a multi-dimensional one that links two or more categories (e.g. economy and environment).

Discussion of Gross Domestic Product (GDP) and the use of indicators in sustainability have highlighted that “no indicator is perfect and no one can give an exhaustive view of sustainable development” (Nourry, 2007). Torras and Boyce (1998) showed through the use of the Environmental Kuznets Curve that income equality, education and power variables are highly correlated to pollution levels and that the “results provide fairly robust support for the hypothesis that greater inequality in the distribution of power leads to more pollution”.

Imberger et al. (2007) take both systems and perspectives into account with the Index of Sustainable Functionality (ISF). As data capturing improves and new perspectives or indicators emerge, improvements to systems may be made by implementing the ISF and measuring indicators in real-time. When the ISF uses community evaluated weightings reflecting current value systems, the ISF becomes an objective measure of *Adaptive Sustainability*. Thus the ISF offers a quantitative and robust index of sustainability, with opportunities to dissect and identify areas of unsustainable practices and processes (Kristiana et al., 2009).

Importantly, the ISF methodology also introduces a clear demarcation between the objective indicators that reflect the functionality of the systems in the domain and the relative importance of these functions as determined by community consensus. Thus far the ISF has been successfully used to assess the impact of a major development in Singapore (Kristiana et al., 2008), the sustainability of the Gold Coast in Australia (Cirella et al., 2006), and of Western Australia from 1970 through to 2003 (Imberger et al, 2007).

Imberger et al. (2007) showed that for the 20 years to 2003, the functionality of the West Australian economic system increased, while the individual and social systems showed almost constant functionality. This result resembles other reports that show continued expansion of the Australian economy (since 1973-74) may be making the average Australian poorer, not richer (Lawn and Sanders, 1999) and introducing a greater element of “relative poverty” (Fig. 1).

The main conclusions reached from the previous ISF study of Western Australia (Imberger, 2007) included:

1. The ISF provides a quantitative and adaptive assessment of sustainability that allows the examination in detail of the ability of a system to recover after a disturbance;
2. The strength of the ISF lies in its ability to capture interactions between systems and perspectives; and
3. The ISF may be used to examine absolute functionality of a single domain in a time series analysis or in a relative sense to compare new developments and trends.

Looking at Western Australia’s sustainable functionality from the perspective of the wealthiest 20%, poorest 20% and mid-wealth level of households necessitates an introduction to wealth distribution measurements. The following quote by Headey et al. (2004) describing the situation in Australia (and WA) provides adequate reason for investigating sustainability from the perspective of wealth levels.

“Wealth is very unequally distributed, with the bottom half of the distribution owning less than 10% of total household net worth (assets less debts), while the wealthiest 10% account for 45% of total net worth”.

Wealth inequality has been measured in Australia only very rarely, with data gathered in 1915 (War Census) and 2002 (HILDA⁴ Survey). Estimates of wealth have most often been derived from income, for example from the 1986 Australian Bureau of Statistics (ABS) Income Distribution Survey (Marks et al., 2005). The HILDA Survey as well as ABS income statistics show the mean income at wealth quintiles that have been used in the development of indices in the ISF calculations in this paper. Since income inequality relationships based on time series can seriously affect results (Atkinson and Brandolini, 2009), for reasons including changes in type of data reported (e.g. gross income, net income, normalized net disposable income), we look at inequality as snapshots rather than in time-series when calculating the ISF.

Wealth and income distribution are commonly measured using ratios such as P90/P10 and P80/P20. The former ratio, for example, directly measures the wealth or income of the 90th percentile individual or household against the wealth or income of the 10th percentile household or individual. Household wealth distribution (P80/P20⁵) by Australian states in 2004 is shown in Table 1 where Western Australia had the lowest wealth inequity (highest equality) among the Australian states. The highest to lowest wealth quintile ratio (P90/P10) also puts WA among the lowest inequality states.

Recent studies of wealth and income inequality show that many social dysfunctions, including infant mortality, drug use, mental illness, death rates and health problems are strongly correlated to wealth inequality (Wilkinson and Pickett, 2009). Fig. 1 shows relative child poverty rates correlating in Australia with inequality.

Later we will show that Western Australia is especially interesting as the economy sets up a very strong wealth inequality, it is just that many very wealthy benefactors of the resources industry do not live in the state and thus the wealth inequity is not experienced by the rest of the community; this would suggest that as the wealth

⁴ Household, Income and Labour Dynamics in Australia (HILDA) Survey in 2005 was a household-based panel study involving 7,682 households and 19,914 individuals.

⁵ P80 here defined as the mean wealth of the 4th highest quintile, and P20 as the mean wealth of the lowest quintile. Strictly speaking it should be P70/P10 but the upper end quintile incomes are unavailable, and the implications for discussion purposes are the same.

inequity is not experienced by the community its effects on social malaise are reduced.

The steps for calculating the ISF are described in Fig. 2. To summarise, for each domain or sub-domain there are a number of systems (such as the environment); and perspectives in which to look at such systems (for example from the perspective of the wealthy). Functions are the outcomes that each system provides; (for example a function of the land could be to produce food); and indicators measure the performance of the functions (how much food is produced). Weightings represent the importance allocated to each system perspective (for example is food more important than mining, and if so by how much). A brief discussion on the use of weightings will be made (Section 1.2) and for this paper all perspectives, functions and indicators will be equally weighted. Equation 1 describes the ISF Aggregation Equation from Imberger et al. (2007).

$$ISF = \sum_{p=1}^{P^i} \sum_{s=1}^{S^i} \left[\frac{W_{ps}^i}{L_{ps}^i} \left\{ \sum_{f=1}^{L_{ps}} \frac{1}{M_{psf}^i} \sum_{m=1}^{M_{psf}^i} (I_{psfm}^i) \right\} \right]$$

Equation 1

Where:

i = subdomain 1,2,3,...

p = perspective 1,2,3...

s = system 1,2,3...

f = function 1,2,3...

L = number of functions in the matrix (*p,s*)

m = normalised indicator 1,2,3...

W = weightings 1,2,3...

1.1 Domain, systems and perspectives

The Domain chosen was the state of Western Australia that includes offshore areas and totals 2.5 million square kilometres. These areas are included in Western Australia's GSP and export income accounts.

The Systems (S_i) and Perspectives (P_i) used in the ISF calculations are provided in the Systems/Perspectives matrix in Appendix A. Each system (social, terrestrial, water and mineral industry) has related perspectives and both systems and perspectives should not be viewed in isolation.

Perspectives were chosen to provide results that could assess whether wealth inequity leads to instability in any systems or in WA overall. The perspectives of the wealthy, poor, mid-wealth, environment and economy were included in the ISF analysis. The wealthiest of the population are defined as having a mean annual income, as provided by the Australian Bureau of Statistics, in the top 20% of society. Similarly the poorest 20% of the population has a lowest quintile mean income. For the average wealth household, the mean income of the average wealth household was used.

1.2 Functions, indicators and weightings

Functions and indicators are described in Appendix B. The ISF requires careful selection of data such that it is both available over time and can be used as an indicator of system functionality. The choice of functions (F_i) (Appendix A) and indicators (Appendix B, I_i) were made by reading research reports and published papers on sustainability, financial markets, government policy, health trends, environmental functionality and social responsibility. Data that reflected the systems functionality was tested for suitability, availability and as having lower and upper bounds defining non-functioning and fully functioning respectively (for normalisation). For example, infant mortality (Appendix B, F_4 , I_6) was used as a measure of the progress of society (Freemantle, 2006). Therefore as infant mortality data exists from a reputable source (Australian Bureau of Statistics), and has been measured over time through surveys in 1980, 1990, 2000 and 2006, it was chosen as one indicator of functionality in the social system. The same methodology was applied to the economic perspective where growth (change in GDP) (F_{10} , I_{14}) and employment (F_{11} , I_{15}) are indicators that represent economic system functionality and are available over time.

The minerals industry system in Western Australia (Appendix A, S_4) is fully functional if it is profitable (F_{19}), maintains employee numbers (F_{20}), does not

deplete resources or impact the local environment beyond repair (F8, F9), provides energy and raw materials for use (F15) and supports the economy (F10). If the minerals industry did not provide at least one of these functions it wouldn't have a purpose and would therefore not exist.

Judgement regarding what is “significant” environmental damage or “many” people employed is open for argument and the choice of indices, data and normalisation functions (see Appendix B for descriptions) must be checked for sensitivity. It is important that upper and lower bounds, including the reasons for choosing them, be transparent so that results can be reproduced, tested for sensitivity and accurately identify changes in functionality. Bounds that are absolute should be chosen wherever possible, but this is not critical. By way of example, the ISF report on Western Australia (Imberger et al., 2007) used a 2% renewable energy upper bound as fully functional as this was the State's target at the time. In 2009 the use of renewable energy was over 3% of Western Australia's production, so the targets are moving, but the indicator (F7, I₉) still represents a fully functional situation. When the ISF is recalculated using higher targets, the improvement over time will be captured in this change, and hence the reliability of the methodology and integrity of results is maintained. Clearly, absolute bounds are preferable when data is available. In this example the fully functional bound would be that which would make Western Australia carbon and water neutral, bringing into focus the fact that bounds and indicators are sometimes conditional on other indicators.

The Centre for Water Research Real Time Management (RMS) program⁶ previously used to evaluate water systems was used to calculate the ISF using encapsulated fixed data and variable bounds for indicator normalisation. Using this program it was possible to calculate the ISF from each perspective for each system as well as test the robustness of results by changing indicator bounds and weightings.

Indicator, function and perspective weightings were considered equal during the calculations. System results for the overall ISF aggregation were weighted based on results from Google Trends (Ginsberg et al., 2009).

⁶ Formerly ARMS (Aquatic Real-time Management System) developed by the Centre for Water Research calculates the ISF using raw data and is used to show time series changes in systems, perspectives and functions.

Google Trends provides the ability to measure the amount of traffic over the internet on a particular topic in a geographical area (in this case Western Australia). While difficult to know if this matches society's values exactly it is most likely a reasonable measure of importance and as such was used for system weightings. The search terms "people", "mining", "water" and "land" for Western Australia were analysed using Google Trends⁷ as shown in Fig. 3 and the system weightings (W_i) are listed in Table 2.

2. Results

After normalising and aggregating the functions (Appendix B) and using Equation 1, the resulting ISF systems and perspectives are described as follows and shown in figures 4-8. Fig. 4 shows an improving social system (S1) from the perspective of the economy (P5) from 1993 to 2008 using a 3-year moving average. Other noticeable trends include the volatility of the economy, the long-term decline of the environment, and the large drop from the perspectives of the wealthy (P1), mid-wealth (P3) and especially the poor (P2) from 2005 to 2008, after a slight overall gain for all from 2001-2005. The initial improvement of the social perspectives in the growing economy of 2003-2005 is reversed during the very strong growth period 2006-2008. The precipitous drop in functionality coincided with very high housing costs and strong population growth.

From the perspective of the poor, a steady improvement between 1982 and 1994 was wiped out by 1998 and dropped further through to 2009. During the 27 years to 2009, functionality from the economic perspective was significantly greater than from the other perspectives, with close to full functionality occurring in 2007. Overall there was a decline in the social system from all perspectives except the economic (marginal increase) over the three decades to 2009. From the perspectives of both the wealthy and mid-wealth levels, there was a significant departure coinciding with the 1992 recession, leading to an increase from 1994 from both perspectives until 2005 when housing costs grew substantially faster than wages (I_5) and crime increased (I_2).

⁷ Google Trends (www.google.com/trends) was first used to predict outbreaks of flu across states and regions around the world based on search results (Ginsberg et al., 2009).

The 3-year moving average for all systems (Fig. 5) shows a steadily improving terrestrial system from 1990 to 2004 followed by a sharp decline caused in part by a decline in the value of agriculture, forestry and fishing (I_{20}). The water system is close to semi-functionality (ISF 0.55 to 0.60) and showed little change from 1995 to 2007. The striking result is the improvement in the minerals system from 1993 until 2008, which occurred during constant or slightly declining functionality for all other systems. When looking at the aggregated social system, a slight decline occurred (0.61 to 0.59) over the several decades to 2008.

Aggregating the perspectives (Fig. 6) shows steady improvement from the perspective of the average wealth holder from 1993 to 2008; and similarly for the poor to 2006 with a decline to 2008. The results include:

1. The dysfunctional wealth level perspectives, especially the poor; and
2. The increasing gap between the economic perspective and all wealth level perspectives during the strong growth (2004-2008) period.

Reviewing the aggregate ISF result plotted against real GSP per capita (1990 dollars) (Fig. 7) shows that the rate of increase of real GSP is higher than the ISF over the period 1990 to 2009; beyond 2000, the ISF essentially remained constant at a value around 0.6

Removing the mineral system from the ISF shows a greater disparity between the increase in GSP and the ISF aggregate for Western Australia (Fig. 7 vs. Fig. 8). While the real GSP per capita has increased by 60% to \$64,000, the ISF has decreased by 16% from 0.58 to 0.49. This shows the importance of the mineral system to the state.

3. Discussion

From the above results we see that the functionality of the systems making up Western Australia from all perspectives (except the economic) has not improved, despite the very high economic growth in the period from 2004-2008. Possible reasons for this apparent contradiction include the destination of resource wealth sales, changes to income distribution patterns, and the impact of trading.

3.1 Economic flow of resource wealth

Western Australia accounts for one third of Australia's total export income, mostly in the form of commodity sales that were AUD \$71.8 billion in 2008. WA produces 65% of Australia's gold (24 t / annum) and holds 6% of the world's total gold deposits (Geoscience Australia, 2008). 19% of the world's iron ore is also produced in the state making it the third largest producer in the world with export income over US \$25 billion per year (DMP, 2008). The iron ore is primarily used in steel manufacturing in Japan, China and South Korea.

The revenue of one dollar of iron ore sold from Western Australia, the state's largest export industry, is distributed according to the numbers shown in Fig. 9 and Fig.10. The largest component of the revenue (47.5 cents in the dollar) (BHP, 2008) goes to the company as profits for shareholders. The shareholders of these companies (primarily Rio Tinto and BHP Billiton) are based world-wide, and it is estimated that less than 3% reside in Western Australia.

Iron ore employees, contractors and suppliers are likely to be based in Western Australia. According to the Department of Mines and Petroleum (2008) it was estimated that 23,000 people are employed as a result of the iron ore sales, which is 2.6% of the 1.3 million people employed in the state (ABS 6202.0, 2008). For the mineral industry in total, including contractors and payments to oil and gas workers, 66,000 employees (5% of workforce; 3% of population) receive on average \$120,000 each (\$7,900 million in total). Local and international suppliers share the operations expenditure and thus it is estimated that about 20 cents of each dollar of mineral sales (including royalties and federal government payments) reach WA.

As royalty payments in 2008 (including oil and gas grants) were \$3,667 million (DTF, 2009), the general public received 4.8 cents in the dollar in the form of taxes and royalties, which was \$1,665 each. BHP (2007) states that its economic contribution "comprised \$1,108 million to the Federal Government, \$344 million to State Government, \$6 million to Local Government and \$12.5 million in direct community contributions." Revenue was over \$6,500 million and earnings over \$3,400 million. Thus in this case 5% of sales went directly to the state.

The above estimates are consistent with research by Ye (2008) who showed that \$20.4 billion in net present value (NPV) terms was returned to the West Australian population over 20 years to 2025 when assuming high growth (“Scenario 1”) iron ore exports. This equated to \$510 per person in 2003 Australian dollars.

When taking into account research by Layman (2006) and Ye (2008) that included “the effect of an inflow of labour and capital into a home state from other states or regions” and “deviations in per capita consumption aggregated over the population that would have been there without the project”, the result was a net benefit of \$11.8 billion over 20 years in 2003 dollars. With a population of 1.9 million people in 2003 this equated to \$6,200 per person in 2003 dollars.

Thus, in summary:

- (1) Approximately \$200 billion of iron ore sales over 20 years (asset depletion of \$105,000 per capita) was expected to return, on average, \$6,200 to each West Australian in total from 2005 in 2003 dollars; approximately \$310 per person per year. Environmental externalities are not in these estimates.
- (2) About 80 cents of every dollar of mineral sales do not reach the West Australian economy⁸.

The apparent mismatch between the benefits and costs of Western Australia’s mineral industry may be reflected in the declining social system from all perspectives (except the economic) during the recent 2004-2008 period of rapidly increasing commodity prices. Furthermore, the traditional “owners” of the land, the indigenous Australian aborigines, receive only a small portion of the so called “community contributions” of 0.2-0.4 cents per dollar of iron ore sales (Fig. 9) (BHP, 2007) (Rio Tinto, 2008). From these numbers it is seen that the general community of Western Australia receive few benefits from the mining activity and the owners, the indigenous people, receive essentially no benefits (Fig. 10). The low proportion of funds received in the state also contributes to WA having the highest wealth equality and GSP of all Australian states, but not the highest mean wealth (Table 1).

⁸ Companies with head offices and bank accounts outside WA need not transfer funds through the state and in most cases would not transfer funds into Australian dollars except to pay local employees and suppliers of goods and services.

Oil and gas is Western Australia's second largest export, but as the majority of reserves are found in federal waters, the royalties to the state (including Commonwealth grants) are even smaller than for iron ore (DTF, 2009). This is the case even though the sales are included in WA's GSP.

Western Australia's high mineral wealth and low population means the state maintains low unemployment rates and a strong balance of trade during periods of high commodity prices⁹. Low state government surpluses (\$647m in 2008-09) (DTF, 2009) can be explained by low (as little as 2.5%) royalty rates and a federal taxation structure that returns less to the state than is removed (\$8 billion net outflow in 2008), as the goods and services tax (GST), company tax and personal income tax are collected at a national level and distributed under the principal of 'horizontal fiscal equalisation' (DTF, 2009).

Ecosystems that rely on one source of nutrients are more susceptible to instability (Gunderson and Holling, 2001; Gotts, 2007). We propose that an analogy can be made to a state that is increasingly reliant on commodities and is therefore reducing its resilience to external shocks. Declining agriculture and manufacturing sectors as a proportion of economic activity have meant an increase in the power of the mineral industry in relation to other sectors of the economy as the state relies more heavily on mineral activity for revenue and employment. Table 3 shows the changes in select industries as a percentage of total production in Western Australia from 1990 to 2008. Noticeable in this table is the dramatic drop in agriculture, education and finance.

3.2 Changes to income distribution patterns

Piketty and Saez (2006) published a chart showing the source of the top 0.1% income earners in the United States from 1916 to 2003 (Fig. 11). The same data is not available for Western Australia, but studies have shown that the results are consistent among English speaking countries including Australia (Piketty and Saez, 2006). Fig. 11 clearly shows that wealth has been increasingly generated from high end salaries rather than earnings from capital or business income since 1980.

⁹ In 2008 Western Australian exports were \$68 billion and imports \$27 billion (Australian Bureau of Statistics).

In the United States between 1972 and 2001, income (in inflation adjusted dollar terms) at the 99th percentile rose 87%; at the 99.9th percentile rose 181%; and at the 99.99th percentile rose 497% (Krugman, 2006). At the same time the average hourly wage, since 1970, for non-supervisory workers actually reduced during this period. Krugman (2006) suggests that “the growth of inequality may have as much to do with power relations as it does with market forces”. Recent studies point to a similar trend in Australia (Atkinson and Leigh, 2006); paradoxically disclosure of executive pay is often cited as one of the causes of this escalation which has continued to climb in the face of attempts to curb its growth (Kovacevic, 2009).

Piketty and Saez (2006) showed that English speaking countries displayed a substantial increase in the top 0.1% incomes since 1980 compared with non-English speaking countries. In Australia CEO pay has increased among the top 50 publicly listed firms from 18 times the average worker salary in 1980 to 27 times in 1992 and 98 times in 2002 (Atkinson and Leigh, 2006). This change has coincided with the increasingly disproportionate allocation of income to the top 1% of income earners in Australia as shown in Fig. 12. According to Mandelbrot and Taleb (2005) “we live in a world of winner-take-all extreme concentration” where “one percent of the U.S. population earns 90 times what the bottom 20% does, and half the capitalization of the stock market (close to 10,000 companies) is in fewer than 100 corporations.” In Australia, close to 50% of company profits are generated by just 10 corporations (BRW, 2008)¹⁰.

Since few executives of Australia’s largest corporations live in Western Australia¹¹, and even fewer executives of multi-national corporations reside in the state¹², the effect is that Western Australia has a relatively equitable distribution of wealth with a lower mean wealth than states with head offices such as New South Wales and Victoria (Table1). As the power centres are outside the state, this may be contributing to decisions that don’t improve the environment or the social systems, hence the declining environmental and social systems observed in the results.

¹⁰ Calculations made from Business Review Weekly data, “Australia’s top 1000 enterprises”, December 2008.

¹¹ Only one company (Wesfarmers) has its head office in Western Australia among the top 50 largest Australian companies by revenue in 2008 (BRW, 2008).

¹² The largest exporters of state resources include BHP, Rio Tinto, Shell and Chevron. BHP has 3/12 executive board members residing in Australia, and none in WA. Similarly Shell and Chevron have no WA residents as board members, and Rio Tinto has one.

3.3 The impact of trading

In Australia it has been shown that financial assets, especially equity investments and superannuation, are heavily concentrated in the hands of high-income earners (Creedy and Tan, 2007), even though superannuation is compulsory for all workers. Bouchaud and Mezard (2000) showed that in a simple model of an economy, the distribution of wealth tends to become broad when trades are limited. Frequent trades would therefore tend to concentrate wealth around fewer individuals (wealth condensation); and under certain conditions “one of the systems will favour condensation and wealth will flow towards it” (Burda et al., 2002). This is well known in ecology where Imberger et al. (1983) showed that if transaction times are short compared to the time scales of the system as a whole, then the domain exhibits very strong gradients. We propose this effect might further explain changes to wealth inequity overall (Fig. 1) and in relation to comparisons between states (Table 1).

The rate of transactions in the Australian economy has increased substantially since the 1980's (Fig. 13) and correlates strongly with income trends (Fig. 12). The clear uptrend since 1985 in the earnings of the wealthiest 1% Australian's (and in other English speaking countries) coincides with the widespread introduction and use of new technology such as the mobile phone, personal computers, the internet and electronic trading. The increase in trades also coincides with the introduction (in 1992) of compulsory superannuation in Australia.

The result of these introductions was a substantial increase in the number of trades made on the Australian Securities Exchange (ASX, 2007). For the 25 years to 2009, the number of trades increased more than five times to almost 40 million. In 2005, for the first time ever, the value of shares traded eclipsed Australia's GDP (Fig. 13).

Fig 13 also shows that the trend of rapid trading growth compared with GDP does not appear to be abating. The result may be that the increase in transaction rates leads to greater wealth inequity, that is, greater gradients. As the majority of financial institutions, including all of Australia's major banks and superannuation funds, are located in New South Wales (Sydney) and Victoria (Melbourne) it is not surprising that these are the states with the highest P90/P10 wealth inequity and highest mean wealth (Table 1).

Reviewing data on individual company transactions shows the trend of trading clearly increasing on a micro level. For BHP Billiton (Melbourne based), Australia's largest company and one of the largest employers in Western Australia, Fig. 14 shows financial transactions against the company's real value as measured in revenue and market capitalisation. Until the year 2000, the number of shares traded in dollar terms for BHP was less than the revenue of the company. From 1995 onward a clear increase in the number of dollars traded commenced and is now more than twice the revenue of the company. In the 15 years to 2008, BHP's dollars traded to revenue ratio increased by 720%. This result is not limited to BHP, but is widespread in all companies; in ecological words, companies have become the hosts and financial firms the parasites.

As it would be hard to argue that there is extra value to the companies themselves when its shares are turned over far in excess of the revenue of the company (given liquidity is already sufficient), the effect may be that the increase rates of change in wealth distribution are favouring the wealthiest through transaction rate increases consistent with the simple model of Bouchaud and Mezard (2000). This may help explain the increase in wealth inequality over time (Fig. 1), the differences in intra and inter-state P80/P20 and P90/P10 ratios (Table 1), and why the increase in GSP per capita is not captured in the ISF (Fig. 7). These changes also match the fact that states with the highest wealth inequity among very richest to poorest (P90/P10) are those with more head offices and greater financial service industries (New South Wales (4/ top 10 companies by profit) and Victoria (6/ top 10) (BRW, 2008)).

3.4 Comparison with resource rich Norway

In natural systems reliance on one source of nutrients can be detrimental to survival. For example those animal species that rely on particular plants are more at risk of sudden decline than other species that gain nutrients from a variety of sources. It has long been recognised that diversification leads to stability (Patten and Jorgensen, 1995). Furthermore reliance on one industry has shown, over time, to be unstable and can lead to dramatic changes in conditions for society. Examples include the motor industry in Detroit, finding of oil and gas by the Dutch and high mineral wealth in countries such as Nigeria.

As WA's non-mineral related activities such as agriculture, education and financial services, as a proportion of total economic activity, dropped significantly between 1980 and 2008 (Table 3), the society's wealth and health is increasingly reliant on non-renewable commodities. Reliance on one industry is more likely to lead to instability and large dramatic changes including declines. The increasing reliance on mineral exports thus leaves WA open to greater instability and further declines in social, environmental and overall functionality as seen in figures 4-6.

The results indicate that the improved economic system has not led to an improvement in functionality for the social system for the population as a whole. As understanding of environmental and social externalities associated with mineral wealth production is now greater than when royalties were established, and as royalty rates (as low as 2.5%) in WA for iron ore haven't changed for the majority of production since the 1960s, the return to the owners may not include these externalities. More sustainable alternatives to the current West Australian scenario (where the Government and companies work together to sell as much as possible) are models offered by Saudi Arabia and Norway. King Abdullah of Saudi Arabia said regarding new oil finds, "leave it in the ground, with grace from God, our children need it." (FT, 2008) Norway by comparison (noted for best resource wealth management practice world-wide) is not keeping its wealth "in the ground", but is similarly keeping it for future generations (and diversifying at the same time) through the use of a sovereign wealth fund (NMF, 2008).

Norway is one of the most equitable countries in the world with a P90/P10 income ratio of 2.8 (Western Australia's is 4.1 for P90/P10 and according to UNICEF (2000) Norway has one of the lowest child poverty rates (one third of WA's) and happens to have high mineral (oil and gas) wealth¹³ with similar exports to WA (Norway exported \$68 billion worth of oil in 2008 (EIA, 2009)). Fig. 15 shows a comparison of income inequality (P90/P10) ratios and child poverty rates across the United States, Norway and Western Australia in 2003-2004 using data from the Luxembourg Income Study (LIS, 2009). This shows a trend of lower social dysfunctions among more equal societies. Norway has been able to retain the benefits while side-stepping the pitfalls of high natural resource wealth by creating a petroleum fund (also called a sovereign

¹³ Norway is the 6th largest exporter of oil and 3rd largest exporter of gas (EIA, 2009)

wealth fund) (NMF, 2008) that channels export earnings from its resource wealth into other investments while at the same time maintaining one of the world's most equitable societies (LIS, 2009). According to the Norwegian ministry of finance the wealth fund (established in 1990) has a value of \$400 billion (NMF, 2008)¹⁴. The other positive effects of this approach include lower exchange rates (helps exporters) and stability during periods of high volatility in commodity prices. For the ISF to increase overall rather than just for economic progress for the economy's sake (economic perspective), then Western Australia should follow the Norwegian model. Fig. 16 shows the affect on export revenue destination after a 5% contribution from mineral exports to a West Australia fund (called here WA Sustainability Fund).

For example if a 4.7% contribution (\$3.5B in 2008) was directly allocated toward the poorest 20% of the population, the increase in disposable household income would rise 50% (from \$308 per week to \$461 per week). The income inequality among the population would drop by approximately 20% (see Fig. 17). WA's major mineral export commodity prices fluctuate more than 5%¹⁵ each year without disruption to long term projects, so the introduction of the fund would not significantly impact exports or employment. Projects that are compromised by a 1-5% revenue change are not sustainable in the long-term regardless. If commodity prices were to fall below a certain level then percentage contributions could change in line with a commodity index on a quarterly basis. Obviously there is also a need to recognise the capital contribution of each project and the specific nature of certain industries (such as the long term LNG contracts).

In the Norwegian model (NMF, 2008), fund assets are invested internationally in order to avoid overheating the local economy and to reduce the likelihood of corruption; with earnings spent on social programs. Fig. 18 shows the effect on functionality in WA of a fund that collects between 1 and 10% of exports (on top of current royalties) for non-renewable exports when commodity prices reach certain levels¹⁶. The impact on the ISF shows a dramatic 18-25% improvement in overall functionality compared with the current ISF between 1990 and 2008. Under this

¹⁴ The fund had US \$450 billion in assets as of Sept, 2009.

¹⁵ The WA Commodity Price Index (WACPI) volatility can move 20% in one year as seen in Ye (2008).

¹⁶ Numerous commodity price Indices measure the pricing of a number of metals and oil/natural gas commodities. For example 1% of revenue contribution when iron ore price is \$51-\$60/tonne, 2% at \$61-\$70... 5% at \$100, and 10% when \$140+.

scenario fund interest and dividends are invested in long-term projects to protect the natural environment and improve social functions (especially for the poorest 20%) of society through spending on infrastructure assets such as public transport, education and hospitals.

3.5 Controllable and uncontrollable drivers

Drivers of the ISF are those indicators or bounds that affect the ISF results. We define controllable drivers as those drivers located inside the domain that are changeable through policies, tools or systems using current technology. Uncontrollable drivers are affected by changes outside the state or are a direct result of controllable drivers. Appendix C lists the controllable drivers that were adapted to produce the ISF that introduced a sustainability fund (Fig. 18).

4. Conclusion

The Index of Sustainable Functionality was used to conclude that, for the resource rich state of Western Australia, the economic functionality has improved over the past three decades, while from all wealth-level perspectives there has been no improvement in social functionality and the environmental system has declined.

Western Australia's wealth distribution is more equal than other Australian states and this may be correlated to indicators of social functionality. However wealth inequality in Western Australia is only "visibly" low as many of the very top beneficiaries of the Western Australian economy live outside the state. The case of Western Australia is thus a good example that shows that inherent wealth inequity is not the problem, but rather, it is the visibility of wealth inequity that leads to loss of functionality from the social perspective. Declines in agriculture, education and finance as a proportion of economic activity over the last 20 years have occurred as the mineral system reached full functionality, which means that the state is becoming less resilient to external shocks. During the same period the environmental and social systems have declined, most likely due to the flow of resource wealth, changes to income distribution patterns and increased trading.

Redirecting a proportion of mineral export revenue to a fund that over the long term promotes social, educational and environmental initiatives that support the poorest

20% of households would improve sustainability from all wealth level perspectives. A contribution of 5% of exports to a West Australian sustainability fund structured similarly to that of Norway's petroleum fund was shown to increase the functionality from the poor, mid-wealth and wealthiest perspectives by 18-25%; and if allocated to the lowest wealth quintile would reduce income inequality by 20%. Furthermore the risk of instability caused by wealth inequity and external shocks such as financial crises would be reduced.

Finally, to further explain and understand the impact of wealth inequity in society, data needs to be gathered on the highest 1% income and asset holders, as well as on the homeless and negative income generators not measured (regularly) by the Australian Bureau of Statistics.

Acknowledgements

The authors would like to thank the Centre for Water Research, the University of Western Australia and in particular Lee Goodyear for his help with the Real Time Management System ISF calculations. Also thank you to Professor Reg Appleyard at the UWA Business School for his review. None of the above people are responsible for the conclusions reached in the paper.

Tables

Table 1 – Wealth inequality of Australian states in 2004. Data from ABS Cat. No. 6530.0 (Household Expenditure Survey (2003-2004))

State	P80/20 Wealth Ratio	P90/10 Wealth Ratio	Mean Wealth
Western Australia (WA)	19.18 (lowest)	53.92 (3 rd Lowest)	\$418,389 (3 rd)
Victoria (VIC)	19.70	58.70 (highest)	\$484,474 (2 nd)
Queensland (QLD)	20.08	54.97	\$407,327
Tasmania (TAS)	20.16	45.39	\$328,019
New South Wales (NSW)	20.34	56.49 (2 nd)	\$564,879 (highest)
South Australia (SA)	20.59 (highest)	49.34	\$357,911

Table 2 – System Weightings (Wi)

System (search term)	Google Trends Result (from Fig. 3)	ISF System Weighting (Wi)
Water (water) (W1)	1.38	0.375
Social System (people) (W2)	1.00	0.272
Terrestrial Environment (land) (W3)	0.68	0.185
Minerals Industry (mining) (W4)	0.62	0.169
Total:	4.74	1.000

Table 3 –West Australian economic activity by sector from 1990 to 2008 (ABS Cat. No. 5220.0)

Year	Agriculture	Mining	Manufacturing	Education	Finance
1990	4.51%	26.79%	7.97%	4.30%	5.17%
2008	2.46%	29.82%	8.49%	2.64%%	4.11%
Change	-2.05%	3.03%	0.52%	-1.66%	-1.06%

Figures

Fig. 1 – Changes in income inequality (P90/P10) and relative child poverty in Australia (LIS, 2009)

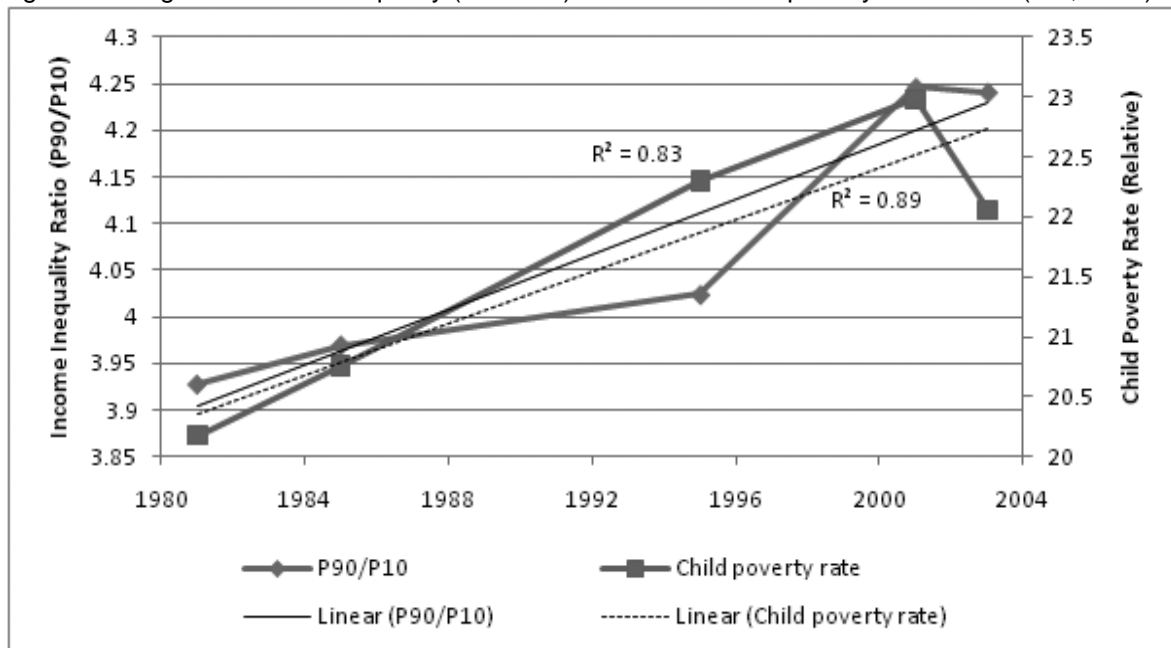


Fig. 2 – Process for calculating the Index of Sustainable Functionality (ISF)

STEP 1: Define the Domain

The domain, D , is the geographic entity under consideration, with N sub-domains

STEP 2: Define the Systems and Perspectives

Systems, S , are collections of processes organized to accomplish specific functions; whilst perspectives, P , are viewpoints or stakeholders. Collectively they comprise the matrix approach to measuring sustainability

STEP 3: Define the Functions

Functions, F , are actions of a system that provide services to a particular perspective

STEP 4: Define the Indicators

The indicators, I , are the datasets which quantify the functionality of each function (or which capture the changes in sustainability over time)

STEP 5: Data Normalisation

Normalisation sets the indicator values between zero and one so that they can be compared and aggregated

STEP 6: Weighting and Aggregation

The weightings reflect the importance of the different elements of the fundamental matrix across all stakeholders. The final values are then averaged to form the final ISF

Fig. 3 – System weightings using Google Trends for Western Australia

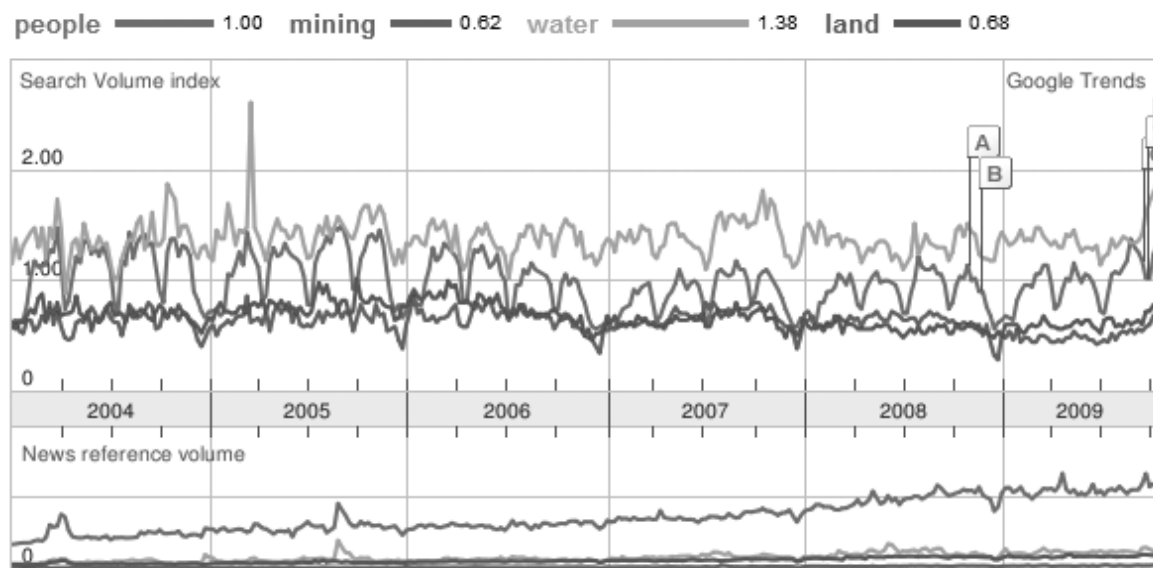


Fig. 4 – Social System ISF

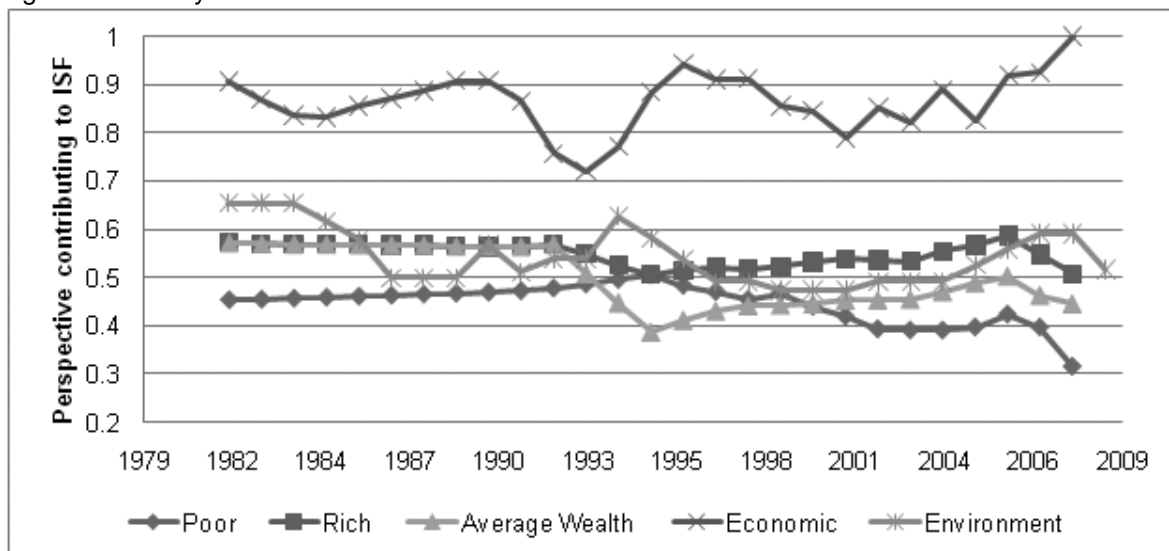


Fig. 5 – All Systems (3-yr moving average)

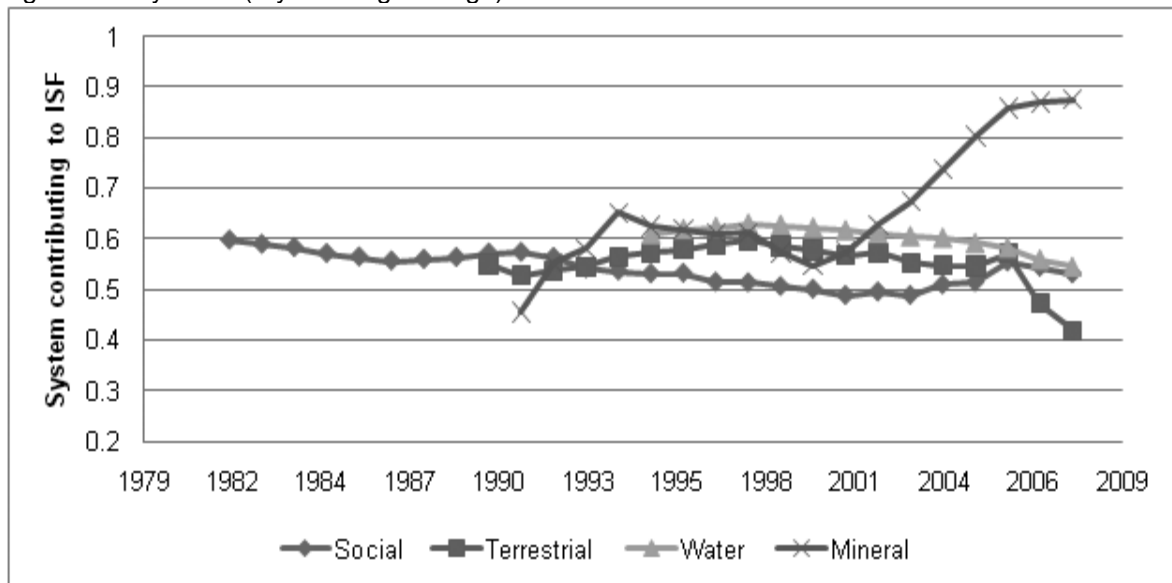


Fig. 6 - ISF from all Perspectives (3-yr moving average)

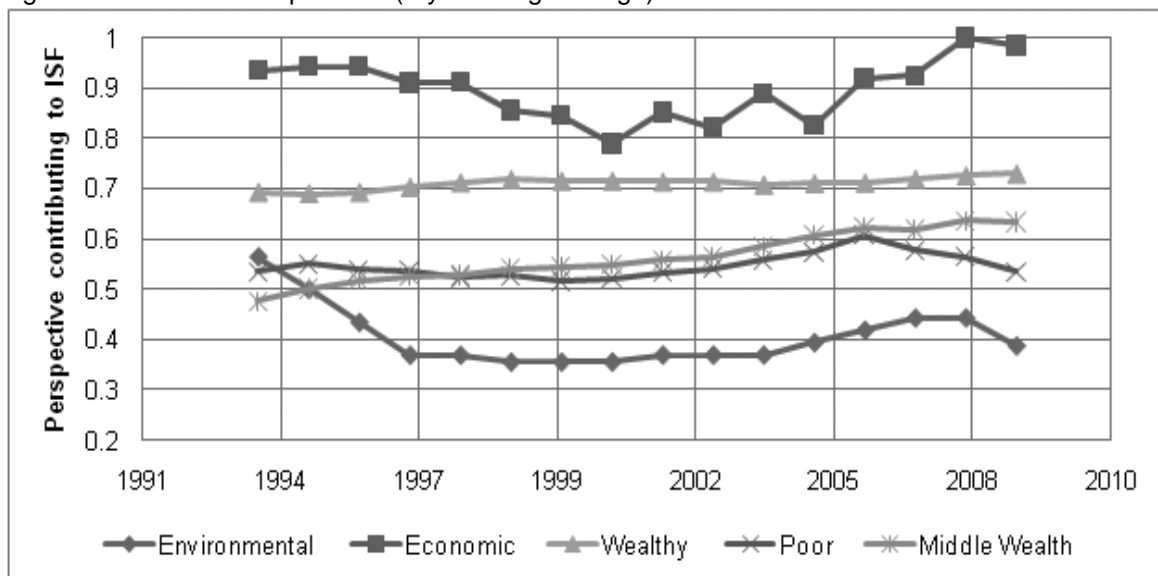


Fig. 7 – Aggregate ISF versus real Gross State Product per capita

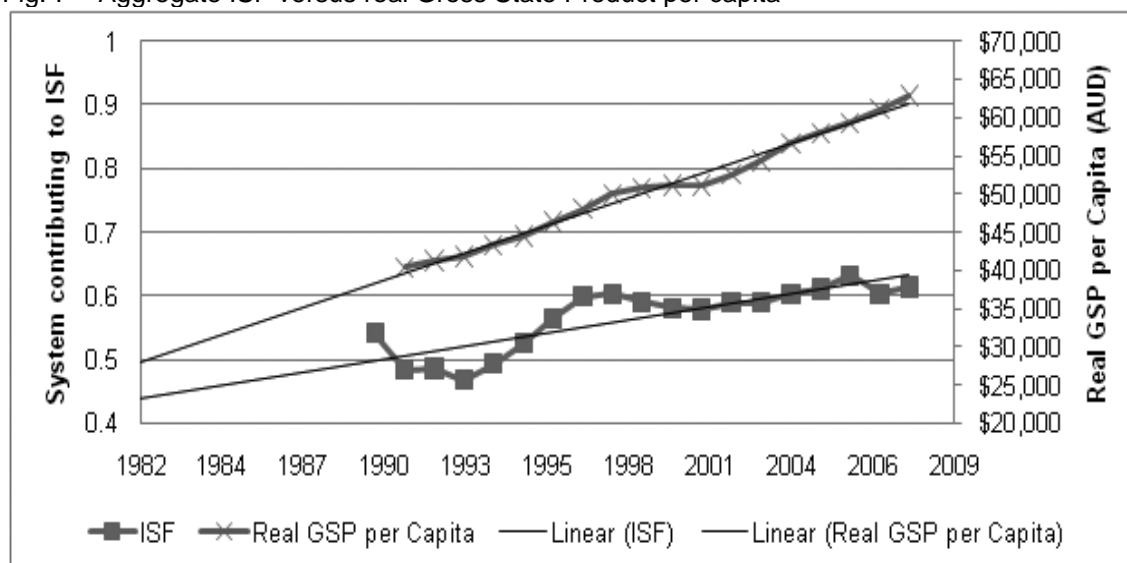


Fig. 8 – Aggregate ISF without Mineral System versus real Gross State product per capita

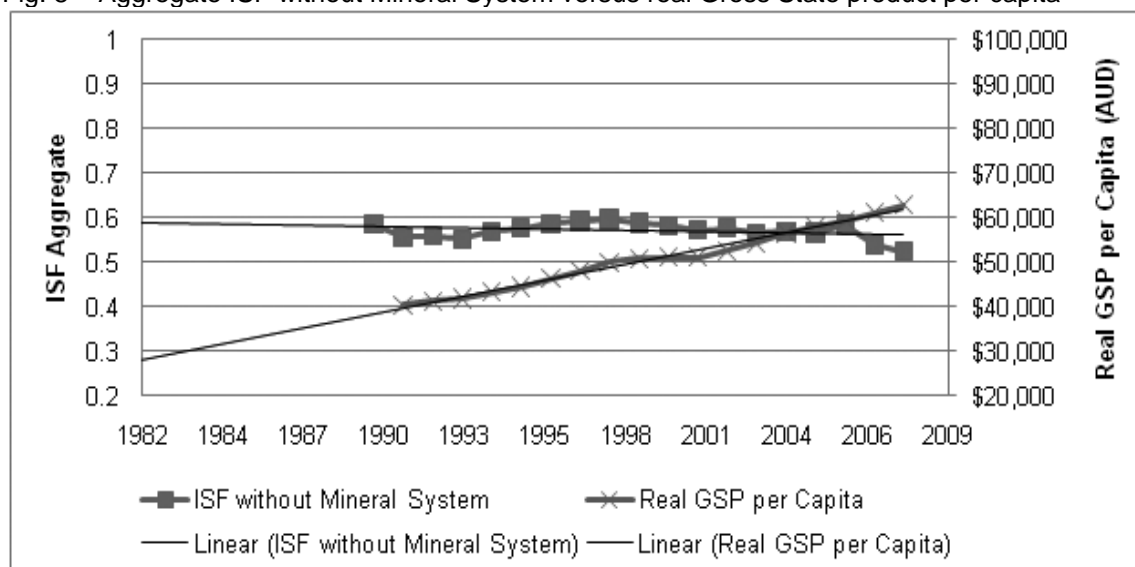


Fig. 9 – Final destination per dollar of resource exports (iron ore and petroleum) for 2008-2009

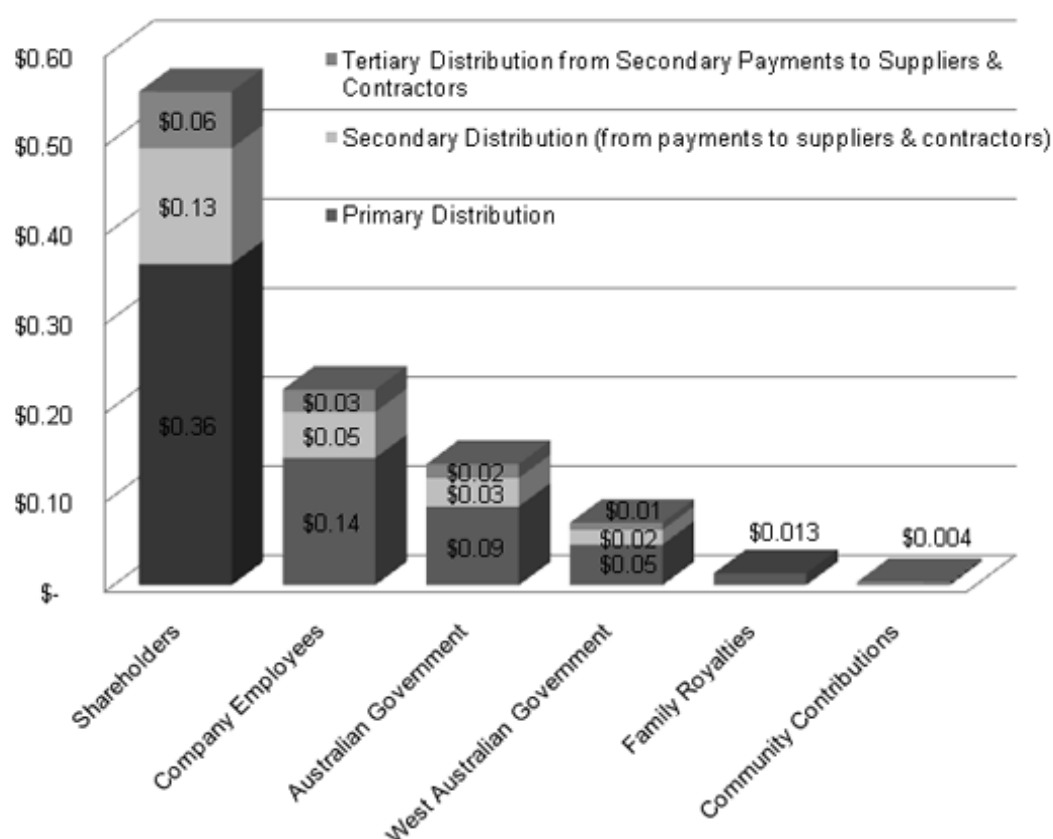


Fig. 10 - Destination per dollar of mineral revenue in Western Australia for 2008-09

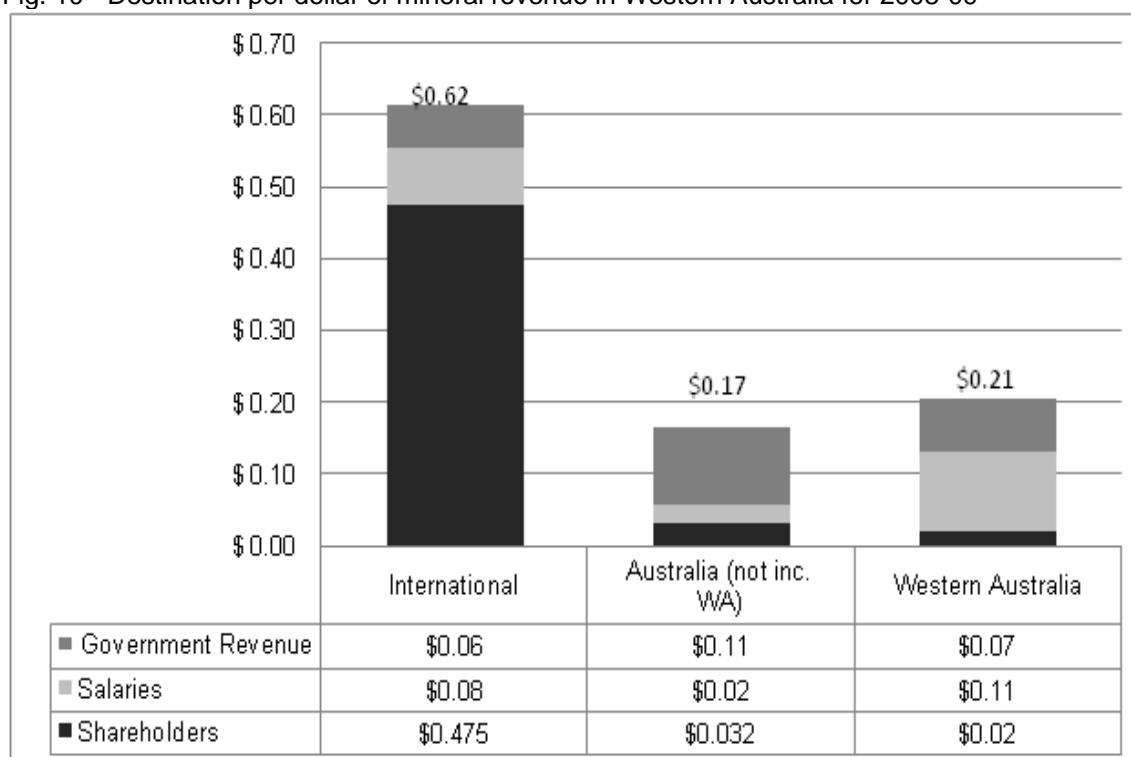


Fig. 11 - Source of top 0.01% income earners in the United States as percent of total income (y-axis)
(Piketty and Saez, 2006)

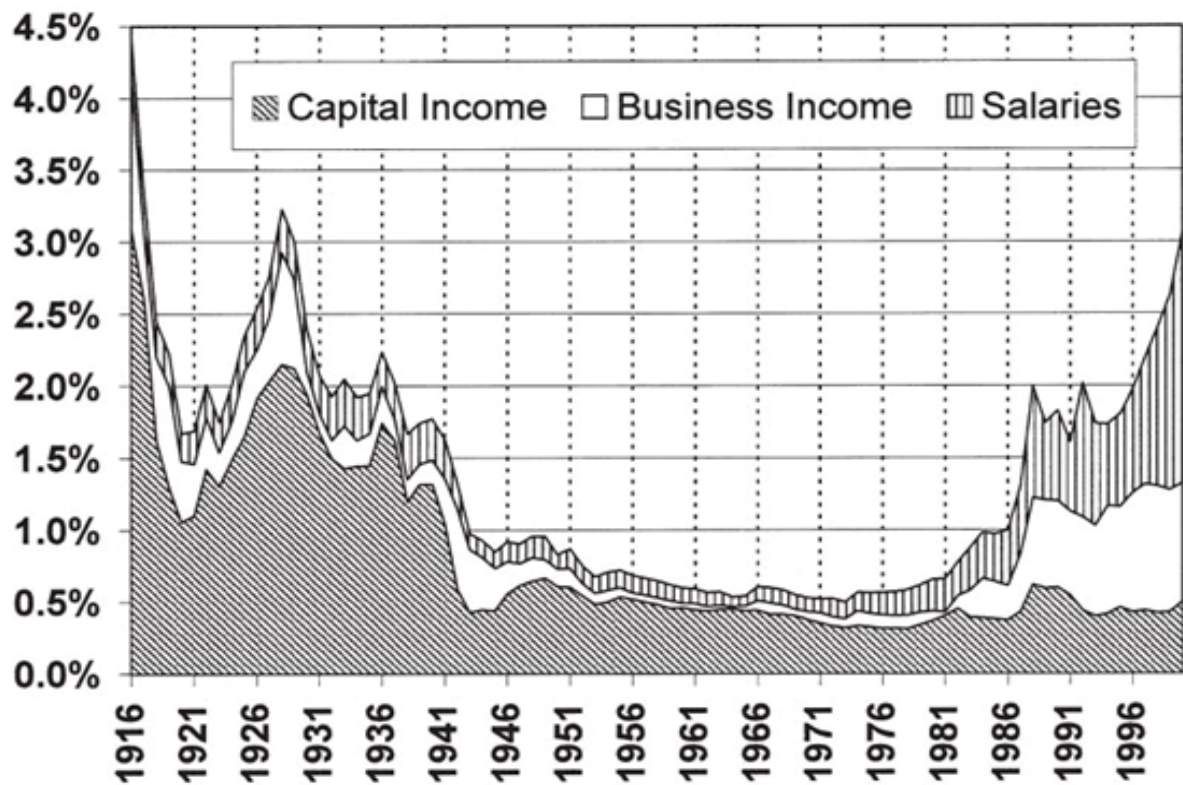


Fig. 12 – Distribution of top 0.1%, 0.5% and 1% income as a proportion of total income in Australia
(Atkinson and Leigh, 2006)

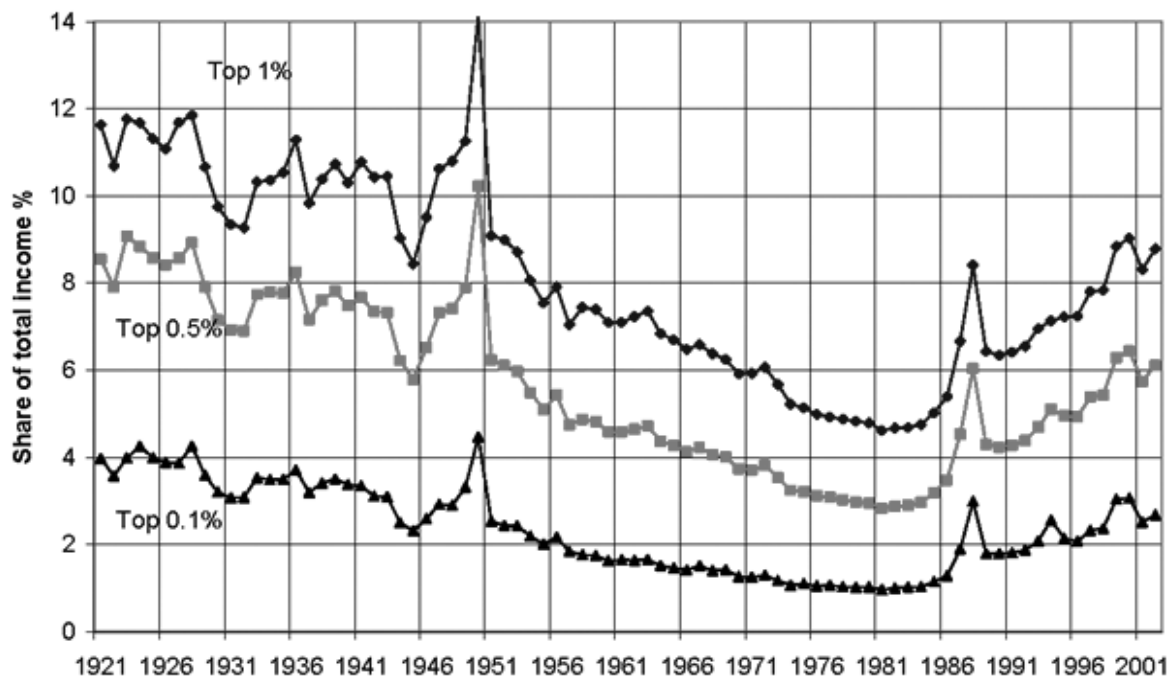


Fig. 13 – Volume and value of share trades in Australia (ASX, 2007) vs. Australian GDP

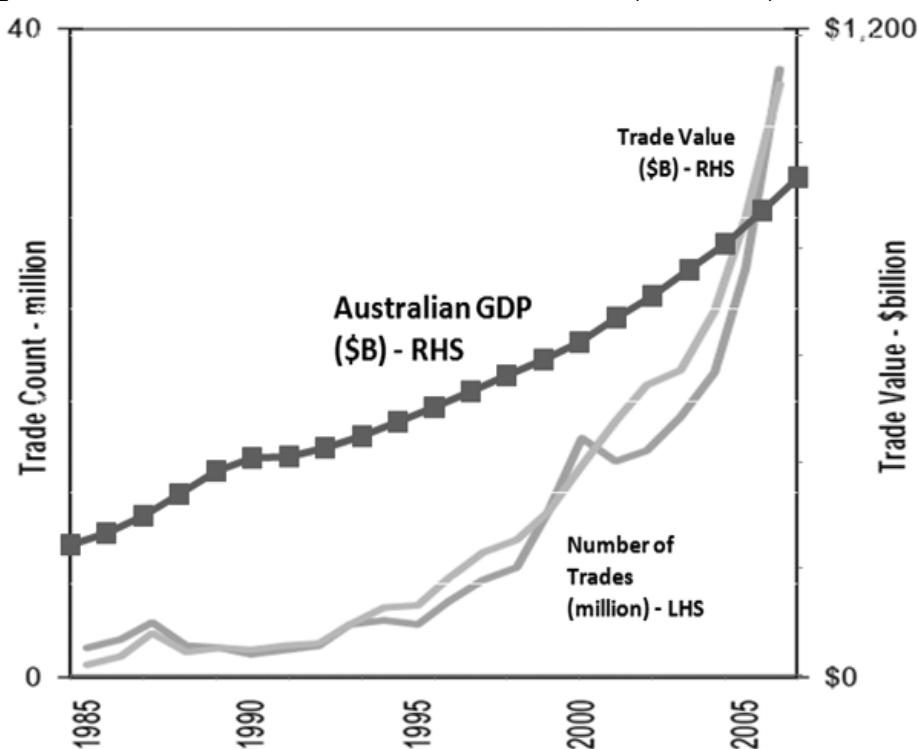


Fig.14 – Ratio of BHP Billiton shares traded (in \$ terms) vs. revenue and market capitalisation from 1990 to 2008 (data from Reuters)

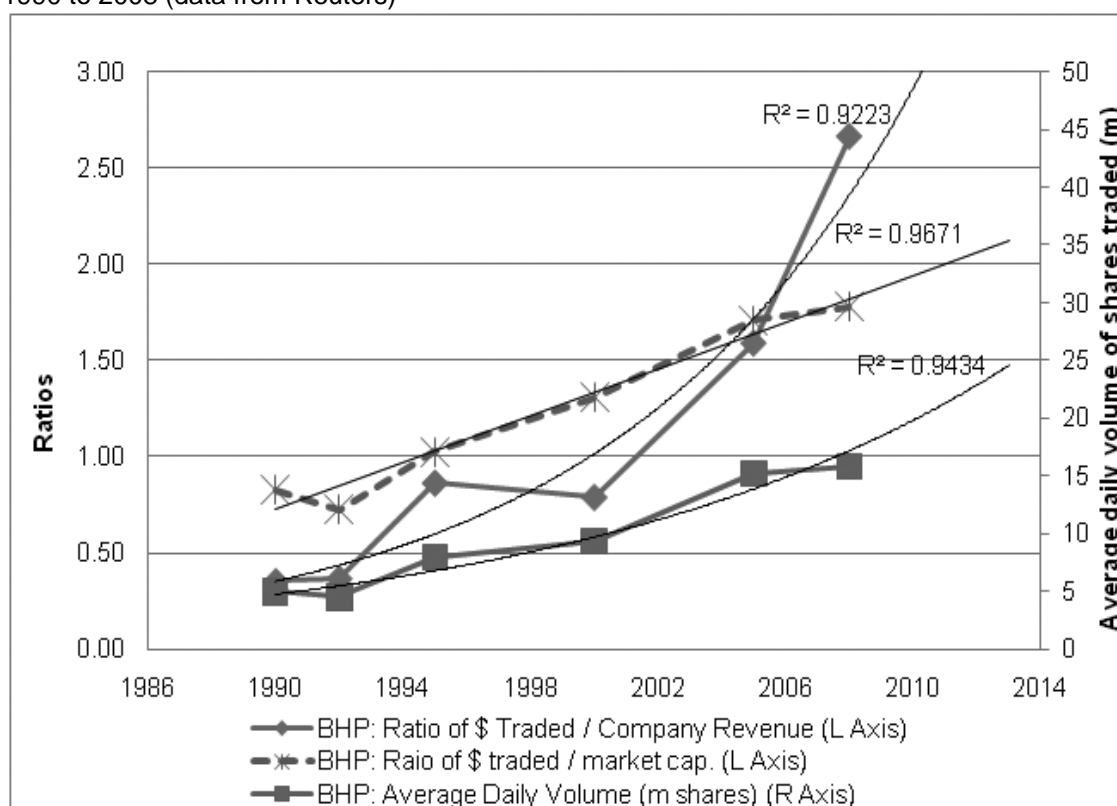


Fig.15 - Comparison of Income Inequality and Child Poverty Rates between Western Australia, Australia, Norway and the United States of America in 2003 (LIS, 2009; ABS 6523.0, 2004)

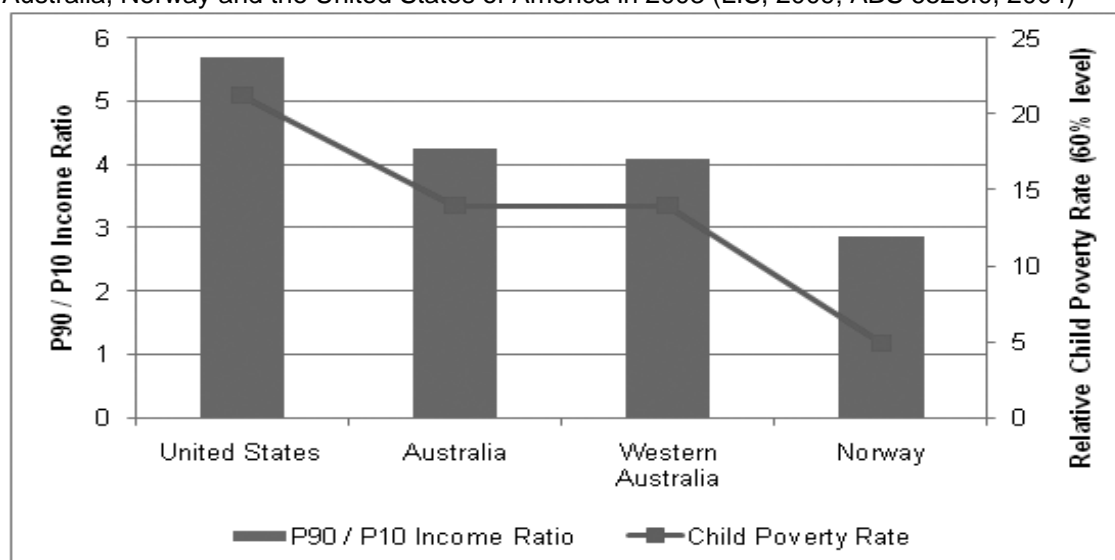


Fig. 16 – Destination of \$1 in mineral revenue with the introduction of a 5% contribution to a wealth fund in WA (2008 dollars)

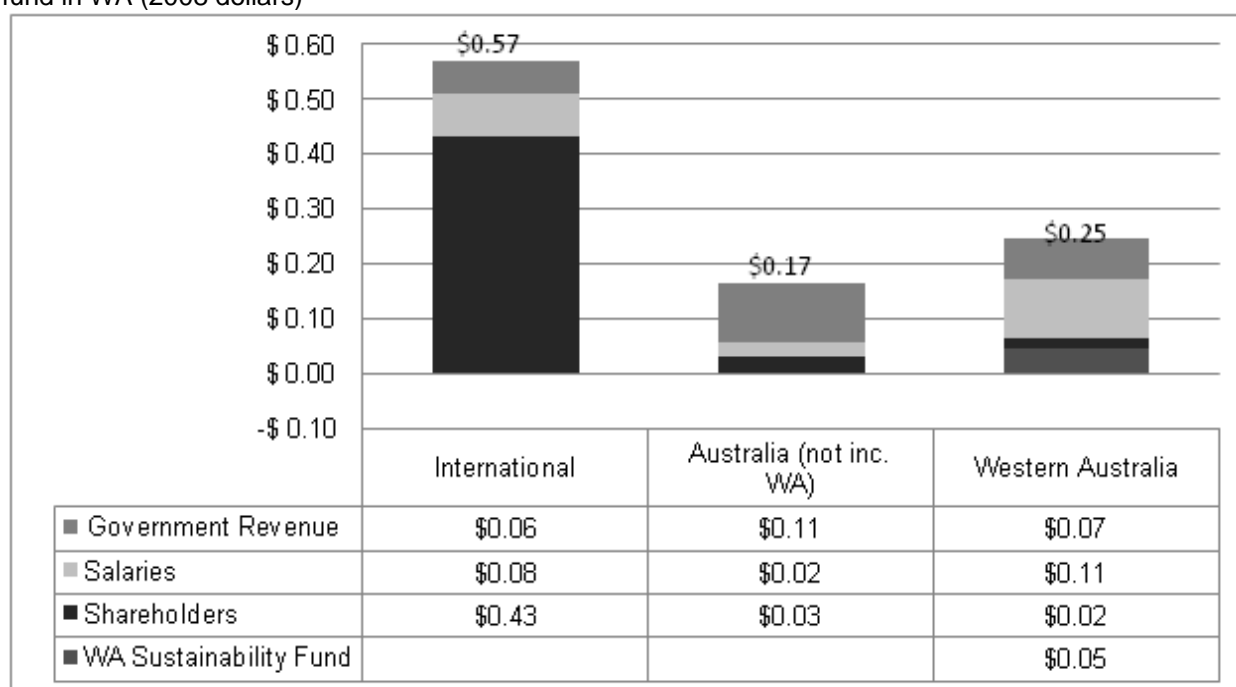


Fig. 17 – Gross weekly income for WA net worth quintiles with 5% mineral revenue contribution to the lowest quintile

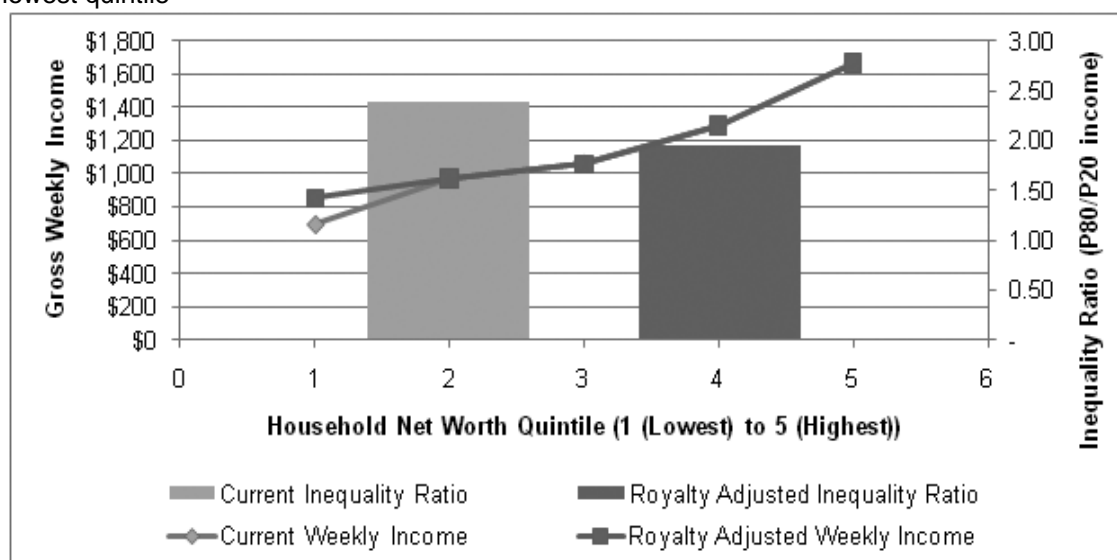
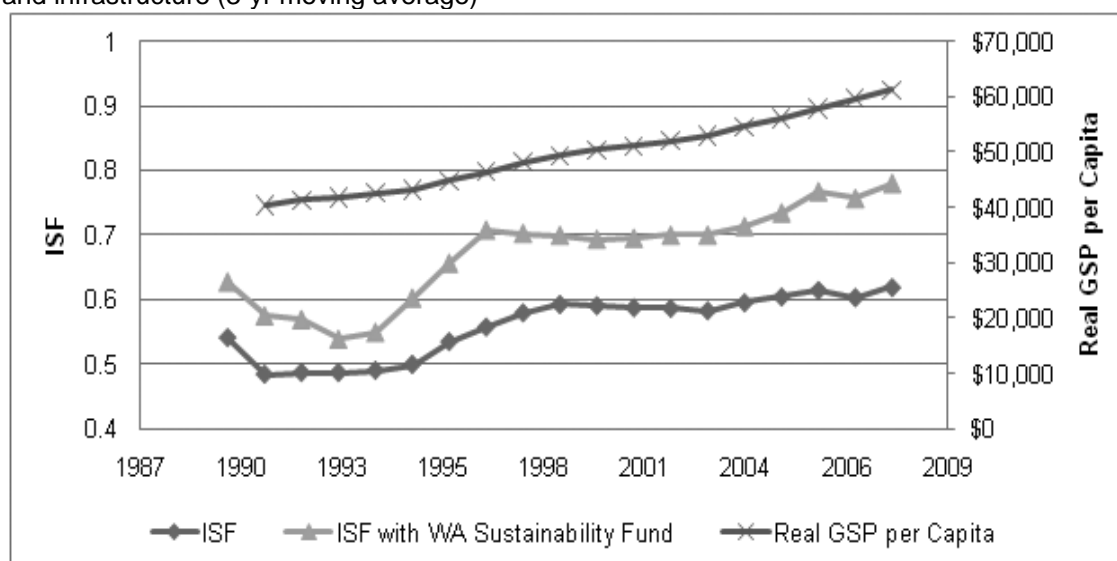


Fig. 18 – ISF with introduction of WA sustainability fund contributing to the poorest 20%, environment and infrastructure (3-yr moving average)



Appendix A

System Perspective	Social (S1)	Terrestrial Environment (S2)	Water Environment (S3)	Minerals Industry (S4)
Wealthiest (P1)	Functions are to provide: (F1) A feeling of security (F2) Provide fulfilment (F3) Provide housing (F4) Quality healthcare (F5) Roads clear of congestion	(F12) Provide clean air (F13) Provide accommodation (F14) Provide natural resources (F15) Provide renewable energy (F16) Provide food	(F17) Maintain clean ground water (F18) Provide low cost drinking water	(F19) Provide a return on assets
Poorest (P2)	(F1), (F2), (F3), (F4) (F6) Provide public transport	(F12), (F13), (F14), (F15), (F16)	(F17), (F18)	(F20) Provide employment
Average Wealth (P3)	(F1), (F2), (F3), (F4), (F5)	(F12), (F13), (F14), (F15), (F16)	(F17), (F18)	(F20)
Environment (P4)	(F7) Use renewable energy (F8) Provide protection of land (F9) Provide protection of water resources from pollution			(F8) (F9)
Economy (P5)	(F10) Provide a growing economy (F11) Make productive use of human capital			(F19) (F20)

System	Description
Social (S1)	Incorporates human interactions and man-made functions.
Terrestrial Environment (S2)	Land which provides shelter, water, food and other natural resources.
Water Environment (S3)	The aquatic environment which provides water, food and aesthetic qualities.
Mineral Industry (S4)	Largest industry in Western Australia including oil and gas, iron ore and other mineral production exported from the domain.

Perspective	Description
Wealthiest (P1)	The 20% of households that have the most wealth as defined by their assets in monetary terms.
Poorest (P2)	The 20% of households that own the least as defined by their monetary assets.
Average wealth (P3)	Households that are in the mid three quintiles of household wealth measured as mean wealth.
Environment (P4)	The perspective of native plants and animals whose goal is survival, reproduction and protection from pollution.
Economic (P5)	The perspective of the economy, which includes capital flow as measured by GDP and provides work measured by employment.

Appendix B

Functions	Indicators (I _i)
(F1) To provide a feeling of security	Break and enter rate (I ₁); proportion of people faced with blackmail or extortion (I ₂). Crime data was obtained from Australian Bureau of Statistics (ABS) Category Number (Cat. No.) 4102.0 (Australian Social Trends). Data was normalised using a lower bound for a functional blackmail and extortion rate of 1 per 100,000 people which was bettered four times between 1993 and 2007 (when data was available). The upper bound was 5 per 100,000 which was exceeded only once between 1992 and 2007. The lower bound for unlawful entries was 20 per 1000 people (bettered twice between 1993 and 2007) and the upper bound 50 per 1000.
(F2) To provide fulfilment	Suicide rate across society (I ₃). Suicide rate data was obtained from ABS Cat. No. 3302.0 (Deaths) and the lower bound set at 5 per 100,000 people and an upper bound of 20 per 100,000 people. The choice of bounds was based on 14 countries having suicide rates higher than 20 per 100,000; and 10 countries having a rate less than 2 per 100,000 (according to the World Health Organisation). From the poorest perspective, another indicator of fulfilment was included with equal waiting to suicides. This indicator was the waiting time for public housing (I ₄) with a functional bound of 20 weeks and a dysfunctional bound of 50 weeks. Data was taken from the Government of Western Australia State Homelessness Strategy, and ABS Homeless Survey 2001.
(F3) To provide housing	Change in cost of housing relative to mean income of P80; P50 and P20 wealth quintiles (I ₅). House prices were obtained from ABS 6416.0 and Real Estate Institute of Australia (REIA) data. The functional bound was set at annual mean income equal to annual house prices. The dysfunctional bound was set at house prices 20 times higher than P80 mean income. Mean income data was taken from ABS category 6523.0 quarterly publications. The fully functional

	($I=1$) condition was set at annual income equalling average house price, and the dysfunctional ($I=0$) bound was where the average cost of housing was 20 times higher than the annual income of P20, P50 and P80.
(F4) To provide quality healthcare	Infant mortality rate (I_6). The source of data was ABS Cat. No. 3302.0 (Deaths, Australia). Data was provided for 1980, 1990, 2000 and 2006 (filled in with straight line series between each data point). The functional bound was where the infant mortality rate was 0 per 1000 and the dysfunctional bound was 20 per 1000 (approximate to the highest OECD figure and allowed for a robust time-series comparison).
(F5) To have roads clear of congestion and easily move around	From the perspective of the wealthy that are more likely to drive cars, the greater public transport use the less traffic is on the roads. The measure of road congestion is therefore based on the annual public transport trips per capita (I_7). Data was sourced from ABS 4605.0 - 1997 for 1971, 1981, 1991 data; and the Public Transport Authority 2008 Annual Report for 2007 and 2008. The functional condition was set at 100 trips per capita per year; and the lower bound at 25. In 1970 the condition was fully functional, but since this time there has been a slow and steady decline in the rate that reached 49 in 2007. In 2009 there was a slight increase to 49.7, most likely as a result of a new train line, however this still is less than half the rate of 40 years prior and therefore less than a functional condition.
(F6) To provide public transport	This indicator (I_7) uses the same data and bounds as F5, however from the poor perspective that may not have the same car availability. This is probably an over simplistic analysis and the rate of public transport use may be declining overall as even the lowest socioeconomic group may be able to afford cars. However the indicator is still relevant as in this case, greater public transport use would benefit this group for the same reasons as the wealthy. Again this indicator has shown a steady decline to below 50% functionality.
(F7) To provide efficient use of energy resources	This function aggregates the energy generated by industry per unit of GSP (I_8) with the renewable energy use as a fraction of overall energy used (I_9). Energy use data was published by the Australian Bureau of Agriculture and Resource Economics (ABARE). GSP data was published by the ABS (Cat. No. 5520.0). The bounds for renewable energy use were set at 0% (dysfunctional) and 5% (fully functional) in accordance with an exponential increase to the 2020 target of 20% renewable energy use.
(F8) Provide protection of land	Data was sourced from ABS Cat. No. 1367.5 (West Australian Statistical Indicators). No annual change in the area affected by dry land salinity (I_{11}) was

	considered functional and an increase in dry land salinity of 5% dysfunctional.
(F9) Provide protection of water	The number of oil spills (I_{12}) and the volume of oil spilt (I_{13}) per annum provided one of the indicators. Having no spills was considered functional and 3 spills dysfunctional. Volumes less than 1000 litres were functional and greater than 20,000 litres dysfunctional. Data was provided by the Australian Maritime Safety Authority.
(F10) Provide a growing economy	Economic growth was measured in terms of annual change in real GSP per capita (I_{14}). The dysfunctional bound was set at -5% growth (contraction) and fully functional bound at 3% increase. Data was provided by ABS Cat. No. 5220.0 (State Accounts).
(F11)	The productive use of human capital is represented by the unemployment rate (I_{15}). The dysfunctional bound was set at 30% unemployment; and the functional at 4% unemployment. Data was provided by ABS Cat. No. 6202.0 (Labour Statistics).

(F12) Provide clean air	All members of society benefit from clean air and a stable climate. Clean air was calculated using absolute production of CO ₂ -e (I_{16}). Data was sourced from ABS 4613 (Australia's Environment: Issues and Trends). The fully functional bound for WA was set at 50 mt CO ₂ -e per annum (1980 level) and the dysfunctional bound at 200 mt per annum. In 2006 WA reached 70 mt per annum.
(F13) Provide accommodation	The purpose of the terrestrial environment from the perspective of all wealth levels in society is to provide shelter and the indicator chosen was the ratio of income to house prices (I_{17}). The ability to afford housing is a measure of the terrestrial environments functionality in that respect. For the wealthiest, mid-wealth and poorest in society, the respective disposable income was sourced from ABS 1383.0 (Measures of Australia's Progress). House prices were sourced from ABS 6416.0 (House Price Indexes) for 1990 to 2009 and REIA data for 1970-1989. The functional bound was set at the average house price 2x the annual disposable income; and dysfunctional bound set at 20x the annual disposable income. These bounds were chosen based on historical data.
(F14) Provide natural resources.	The terrestrial environments ability to provide natural resources is a measure of its functionality from the perspective of all society. For the wealthy in WA mining is also a generator of income. Data for the percent of the economy derived from mining income (I_{18}) was sourced from ABS 5220.0 (State Accounts). As WA is a globally significant mining region 10% was the dysfunctional bound and 30% was the functional bound. Above 30% reduced the functionality as this level was deemed very high historically and reduced the ability for other terrestrial industries (such as agriculture) to function effectively (refer to comments on the Dutch Disease in the paper (Section 3)).
(F15) Provide renewable energy.	The bounds for renewable energy as a percentage of overall energy use (I_{19}) were set at 0% (dysfunctional) and 5% (fully functional) in accordance with an exponential increase to the 2020 target of 20% renewable energy use. Data was sourced from ABARE Energy 2009.
(F16) Provide food	The provision of food is an important terrestrial function. The fully functional condition was set at 5% agriculture, forestry and fishing production as a proportion of total economic activity (I_{20}). 1% was the dysfunctional bound. Data was sourced from ABS 5520.0 (State Accounts).
(F17) Maintain clean ground water	Maintaining clean ground water is fundamental to the water system for the health of all members of society. Levels of arsenic (I_{21}) and the pH of ground

	<p>water (I_{22}) in the northern suburbs of Perth were selected as indicators. The functional bounds for arsenic was 0.1 parts per million (ppm) and the dysfunctional bound 0.5 ppm. The functional pH levels were between 6 and 8; and the dysfunctional less than 3 or greater than 10. Data was sourced from Appleyard et al. (2006).</p>
(F18) Provide low cost drinking water	<p>Low cost (and safe) drinking water is vital for the health and well-being of all society. The absolute cost of water (per kL) (I_{23}) and cost of water (per kL) relative to disposable income (I_{24}) were used to calculate the functionality from each wealth level perspective. For the absolute cost, the functional bound was set at less than \$0.50 per kL (~cost of supply) and the dysfunctional bound \$5 per kL (significant premium to cost). The functional bound relative to disposable income was set at 2% of annual disposable income; and the dysfunctional bound set at 10% of disposable income. These levels were chosen based on historical ranges and expected problems in a society for those that spend more than 10% of disposable income on a basic need such as water. Water prices were sourced from DFT (2009).</p>
(F19) Provide a return on investment for mineral assets	<p>From the perspective of the wealthy, mineral assets in WA provide income. As WA is a commodity based economy, returns were estimated using the Dow Jones Commodities Index (I_{25}). Index values ranged between a low of 87 in 1999 and 172 in 2007. The dysfunctional bound was set at 50; and the functional bound at 150. Data was sourced from Reuters and an annual average was used.</p>
(F20) Provide employment	<p>The WA mineral industry employs approximately 75,000 people out of 1,112,000 workers (ABS 1367.5; 2008). For the mid-level wealth and poorest members of society, the industry provides work. The number of people employed by the minerals industry as a percentage of total employment (I_{26}) was used in this indicator. Data was sourced from ABS Cat. No. 1367.5 (WA Statistical Indicators). The dysfunctional bound was 1% of state employees, and the functional bound 2.5%.</p>

Appendix C

Controllable Driver (CDi) with corresponding function (Fi) and (System/Perspective)	Description (to be read in conjunction with descriptions of functions in Appendix A)
CD1 – Waiting time for public housing (F2) (Social / Poorest)	Waiting time for public housing forms half of the function to provide fulfilment. The dysfunctional bound was changed to 100 weeks instead of 50 weeks in order to represent a 50% improvement in indicator performance (i.e. halving the waiting time for public housing for the poor). CD1 is considered only from the perspective of the poorest 20%.
CD2 – Affordable housing (F3) (Social / Poorest)	Affordable housing is the driver of the function to provide affordable housing. The functional bound was changed from 20x annual income to 10x annual income to represent a combined increased 50% disposable income and public housing for the poorest; and the flow on effects with greater supply of housing to the mid-level (P50) society.
CD3 – Public transport (F6) (Social / Poorest)	The use of public transport in WA has dropped from 97 trips per year in 1970 to less than 50 in 2008. The functional bound was changed to 50 from 150 to represent the improvement to the poor by increasing access to public transport by two thirds. No changes were made to the other perspectives even though positive impacts would be felt from reduced traffic congestion and additional public transport access for all.
CD4 – Renewable energy (Social/Environment) (Terrestrial/Wealthy,Mid,Poor)	The proportion of renewable energy used forms half of the function to make efficient use of energy. The use of renewable energy was doubled while the energy use generated by industry per GSP was unchanged.
CD5 – Water protection (F9) (Social / Environment) (Minerals / Environment)	The protection of water was adjusted using the controllable driver of more stringent regulations and practices with regards to oil spills. The dysfunctional bound was increased to 6 oil spills per year (from 3) and the volume increased to 40,000 (from 20,000) litres to calculate the impact of halving the occurrence and impact of oil spills.
CD6 – Greenhouse gas emissions (F12) (Terrestrial/Poor, Mid, Wealthy)	The impact of CO2 emissions will be felt by all (including the wealthy with houses near the WA coast) through increased insurance and environmental costs. The net greenhouse emissions bounds were changed from 200 (MtCo2-e) to 400 to represent reducing (or offsetting) half of WA emissions.
CD7 – Agriculture, forestry and fishing as percentage of industry (F16) (Terrestrial/Poor, Mid, Wealthy)	Increasing the proportion of business based upon improved renewable natural resources such as agriculture, forestry and fishing (over the long term) through environmental improvements such as re-forestation, water quality improvements and aquaculture would improve the terrestrial environment's ability to produce food. This is represented in the change of bounds (F16) to double the output.
CD8 – Clean ground water (F17) (Water / Poor, Mid, Wealthy)	The bounds for pH and arsenic were changed by 10% to reflect the ISF result of reducing pollutants in ground water in the Perth area.
CD9 – Price of water (F18) (Water/Poor, Mid, Wealthy)	The bounds for the price of water relative to income and absolute price was changed by 50% to reflect a 50% reduction in price for all members of society.

References

- Appleyard, S.J., Angeloni, J., Watkins, R., 2006. Arsenic-rich groundwater in an urban area experiencing drought and increasing population density, Perth, Australia. *Applied Geochemistry*. 21, 83-97.
- Atkinson, AB., Brandolini, A., 2009. On data: a case study of the evolution of income inequality across time and across countries. *Cambridge Journal of Economics*. 33, 381-404.
- Atkinson, A.B., Leigh, A., 2006. The Distribution of Top Incomes in Australia. Centre for Economic Policy Research: Australian National University. Discussion Paper No. 514.
- Australian Securities Exchange Limited (ASX), 2007. Half-Year Results (2006-2007). Sydney, Australia.
- ABS & AIHW (Australian Bureau of Statistics and Australian Institute of Health and Welfare), 2005. The health and welfare of Australia's Aboriginal and Torres Strait Islander peoples, 2005. ABS Cat. No. 4704.0; AIHW Cat. No. IHW14. Canberra: ABS & AIHW.
- Azapagic, A., Perdan, S., 2000. Indicators of sustainable development for industry: A general framework. *Process Safety and Environmental Protection*. 78, 243-261.
- Beard J.S., 2000. Species richness and endemism in the Western Australian flora. Western Australia: Department of Conservation and Land Management.
- BHP Billiton (BHP), 2007; 2008. Iron Ore Sustainability Report, 2007; Annual Report, 2008.
- Bouchaud, J.P., Mezard, M., 2000. Wealth condensation in a simple model of economy. *Pysica A-Statistical Mechanics and its Applications*. 282, 536-545.
- Burda, Z., Johnston, D., Jurkiewicz, J., Kaminski, M., Nowak, M.A., Papp, G., Zahed, I., 2002. Wealth condensation in pareto macroeconomies. *Physical Review*. 65, 026102.
- Business Review Weekly (BRW), 2008. Australia's top 1000 enterprises, November 20-December 10, 58-98.
- Conservation International, 2009. World Biodiversity Hotspots. Internet Site www.conservation.org. October 20, 2009.
- Creedy, J., Tan, L., 2007. The relationship between personal income and net worth in Australia. *Australian Economic Review*. 40, 165-181.
- Costanza, R., Patten, B.C., 1995. Defining and predicting sustainability. *Ecological Economics*. 15(3), 193-196.

Department of Industry and Resources, 2009. Quick Resource Facts, Government of Western Australia.

Department of Mines and Petroleum (DMP), 2008. Western Australian Mineral and Petroleum Statistics Digest 2008. Perth: Government of Western Australia.

Department of Treasury and Finance (DTF), 2009, Government of Western Australia, 2009-2010 Economic and Fiscal Outlook and Budget Fact Sheet. Pp. 229.

Energy Information Administration of the U.S. Government (EIA), 2009. Country Analysis Brief: Norway Energy Data, Statistics and Analysis, August 2009.

Financial Times (FT), 2008. Saudis put off longer-term oil capacity rise. April 20.

Freemantle, C. J., de Klerk, N., Read, A., Stanley, F., 2004. First Research Report of the Advisory Council for the Prevention of Death in Children and Young People, Department for Community Development, Government of Western Australia.

Fricker, A., 2008. Measuring up to sustainability. *Futures*. 30(4), 365-375.

Ginsberg, J., Mohebbi, M.H., Patel, R.S., Brammer, L., Smolinski, M.S., Brilliant, L., 2009. Detecting influenza epidemics using search engine query data. *Nature*. 457, 1012-1014.

Geoscience Australia, 2008. ABARE Australian Mineral Statistic March Quarter 2008. Canberra.

Gotts, N. M. 2007. Resilience, panarchy, and world-systems analysis. *Ecology and Society* 12(1): 24

Gunderson, L.H., Holling, C.S., 2001. *Panarchy: Understanding Transformations in Human and Natural Systems*. Island Press. Washington DC.

Heady, B., Marks, G., Wooden, M., 2004. The Structure and Distribution of Household Wealth in Australia. Melbourne Institute Working Paper No. 12/04. The University of Melbourne.

Imberger, J., Mamouni, E.-A. D., Anderson, J., Ng, M.-L., Nicol, S., Veale, A., 2007. The index of sustainable functionality: a new adaptive, multicriteria measurement of sustainability - application to Western Australia. *Int. J. Environment and Sustainable Development*, 6, 323-355.

Imberger, J., Berman, T., Christian, R.R., Sherr, E.B., Whitney, D.E., Pomeroy, L.R., Wiegert, R.G., Weibe, W.J., 1983. The influence of water motion on the distribution and transport of materials in a salt marsh estuary. *Limnology and Oceanography*. 28(2), 201-214.

Krajnc, D., Glavic, P., 2005. How to compare companies on relevant dimensions of sustainability. *Ecological Economics*. 55, 551-563.

Kristiana, R., Imberger, J., Antenucci, J.P., 2009. Sustainability assessment of the impact of the Marina Bay Development on Singapore: Application of the Index of Sustainable Functionality (ISF), In Press.

Kovacevic, S., 2009. Disclosed: An exploration of board remuneration committee challenges. *Asia Pacific Journal of Human Resources*. 47, 201.

Krugman, P., 2006. Graduates Versus Oligarchs, *New York Times Op-Ed Contribution*. NY Times, New York.

Lawn P.A., Sanders, R.D., 1999. Has Australia surpassed its optimal macroeconomic scale? Finding out with the aid of 'benefit' and 'cost' accounts and a sustainable net benefit index. *Ecological Economics*. 28(2), 213-229.

Layman, B., 2006. Issues for major project assistance analysis using computable general equilibrium models. *Western Australian Economic Summary No. 3*, Department of Treasury and Finance, Perth, WA.

Luxembourg Income Study (LIS) Key Figures, 2009. Norway, Australia and United States Figures. <http://www.lisproject.org/key-figures/key-figures.htm>. Date visited November 4, 2009.

Mandelbrot, B.A., 2005. How the Finance Gurus Get Risk All Wrong. *Fortune*, 99-100.

Marks, G. N., Headey, B., Wooden, M. (2005). Household wealth in Australia - Its components, distribution and correlates. *Journal of Sociology*. 41, 47-68.

Newman, P., Armstrong, R., McGrath, N. 2005. Pilbara Regional Sustainability Strategy - A Discussion Document. Murdoch University, Institute for Sustainability and Technology Policy, Perth.

Norwegian Ministry of Finance (NMF), 2008. Petroleum fiscal regimes and revenue management systems. African Development Bank Seminar - July 9, Kampala.

Nourry, M., 2008. Measuring sustainable development: Some empirical evidence for France from eight alternative indicators. *Ecological Economics*. 67(3), 441-456.

Patten, B.C. and Jørgensen, S.E., 1995. *Complex Ecology. The Part-Whole Relation in Ecosystems*. Prentice Hall, New Jersey.

Piketty, T., Saez, E., 2006. The Evolution of Top Incomes: A Historical and International Perspective. *American Economic Review*. 96(2), 200-205.

Rio Tinto, 2008. Iron Ore group in Western Australia Sustainable Development Report, 68 pp.

Singh, R.K., Murty, H.R., Gupta, S.K., Dikshit, A.K., 2008. An overview of sustainability assessment methodologies. *Ecological Indicators*. 9, 189-212.

State Sustainability Strategy, 2003, State Government of Western Australia Department of Environment and Conservation, pp. 12.

Torras, M., Boyce, J.K., 1998. Income, inequality and pollution: a reassessment of the environmental Kuznets Curve. *Ecological Economics*. 25 (2), 147-160.

UNICEF, 2000. A league table of child poverty in rich nations. Florence, Italy.

Wilkinson, R., Pickett, K., 2009, *The Spirit Level: Why More Equal Societies Almost Always Do Better*, Penguin Group, London.

Ye, Q., 2008. Commodity booms and their impacts on the Western Australian economy: The iron ore case. *Resources Policy*. 33(2), 83-101.