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The trade-off between equity and efficiency in population health gain: Making it real

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ABSTRACT

Two fundamental goals of health systems are to maximise overall population health gain (referred to as efficiency) and to minimise unfair health inequalities (equity). Often there is a trade-off in maximising efficiency *vis a vis* equity and the relative weight given to one goal over the other is acknowledged to be essentially a value judgement. Health systems necessarily make those value judgements but in making them would benefit from relevant and accurate opportunity cost information. Unfortunately the development of practical tools to measure equity-efficiency trade-offs has lagged theoretical advances in this area. We address this gap by presenting a practical technique to reveal opportunity costs of equity (and efficiency) gains in decentralised population-based health systems, applying stochastic data envelopment analysis to ethnic-specific life expectancy (LE) changes for 20 New Zealand (NZ) District Health Boards for the inter-census period 2006–2013, thereby deriving a notional health frontier from 10,000 Monte Carlo simulations. Four different ways to increase health equity emerge. These show that a trade-off between equity and efficiency does not always exist. In particular, improving both productive efficiency and allocative efficiency (up to its maximum) can also yield gains in equity through reductions in LE inequalities. However, in NZ's case, the opportunity cost (in sacrificed European life-years) of achieving gains in equity beyond the point of maximum productive and allocative efficiency is relatively high, even for quite small reductions in the LE gap between Māori and European populations. This high opportunity cost may explain why, despite governments' strong rhetorical commitment to equity, NZ's health gains have not strayed far from the path of maximising allocative efficiency. Nevertheless, this opportunity cost could be reduced significantly by measures which shift the health frontier outward, highlighting the importance of technical and organisational innovation as potential drivers of greater equity in health outcomes.

1. Introduction

Policymakers often give planners and commissioners of publicly funded health services responsibility for two important goals: maximising overall population health gain and reducing socio-economic inequalities in health outcomes. The World Health Organisation's Alma Ata Declaration of 1978 expressed this duality of goals in Article 1 which called for "the attainment of the highest possible level of health" and in Article 2 where it stated that "the existing gross inequality in the health status of the people particularly between developed and developing countries as well as within countries is politically, socially and economically unacceptable" (World Health Organization, 1978). Indeed, virtually all developed countries have policies to reduce or eliminate inequalities in health outcomes (Crombie et al., 2005). Reducing inequalities in health outcomes is one of the Common Values and Principles of European Health Systems (Council of the European Union, 2006). In New Zealand (NZ) the dual goals of maximising health gain and maximising health equity are also encapsulated in legislation through the NZ Public Health and Disability Act 2000 (Parliament, 2016).

Maximising aggregate health gain is often identified as an efficiency goal (James et al., 2005; Wagstaff, 1991). Although it embodies the

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principle that (quality adjusted) health gains are of equal value for all individuals, maximising total population health is clearly not necessarily consistent with maximising equity in health (i.e. minimising avoidable and unfair inequalities in health outcomes) (Culyer and Wagstaff, 1993). Often it is more difficult (and costly) to make health gains for some populations than for others. This has been referred to as the 'equity-efficiency' trade-off.

1.1. Why is it important to make this trade off explicit?

Public sector health planners are constrained in their ability to determine the mix of services by various factors including political imperatives, public expectations, and historical resource allocations, but they nevertheless have some scope to make choices. Decisions to fund (or not to fund) new medications, to introduce screening and immunisation programmes, or to incentivise primary care providers for their achievement of performance targets, are examples of the sort of choices that often can be made. These choices have both efficiency and equity implications.

Though much has been written about the equity-efficiency trade-off from a theoretical and ethical perspective, efforts to provide empirical quantifications of this trade-off that can guide the real-world decision-making of service planners and commissioners (or reveal the effects of current on-going decision-making) have to date met with little success. Williams, noting the importance of quantifying equity-efficiency trade-offs for establishing consistency and accountability in decision-making, expressed the problem thus:

> "… the work of economists in seeking greater quantification in this field falls into two classes: that which addresses equity-efficiency trade-offs in the distribution of health explicitly in a quantitative manner, but currently lack the empirical data with which to support the assumed numerical relationship; and that which attempts to estimate such trade-offs empirically using questionnaire methods, but without having an explicit theory of justice into which to insert and interpret the findings. It is a rather unsatisfactory state of affairs" (Williams and Cookson, 2000), p 1901.

In this paper we offer a method for doing the former – quantifying the equity-efficiency trade-off as experienced by real health systems. This should support more informed value judgements and facilitate effective community engagement and input. It will allow resource allocation decision-making to become more transparent and better targeted to increasing health equity.

2. The conceptual framework

We begin with the familiar Wagstaff "Health Frontier" (Fig. 1), (Wagstaff, 1991) in which the point of maximum efficiency (or aggregate community health) lies at point p where the marginal cost of health is the same for individuals in population A as it is for those in population B. In its original formulation the Health Frontier's x and y axes indicated the expected number of quality adjusted life years (QALYs) remaining before death of two populations of similar individuals A and B, with the curved line representing the health frontier of possible health states achievable with available resources. Each point on the frontier is Pareto-efficient (Culyer, 2006).

2.1. Using rate of life expectancy gain as a proxy for health gain

Our aim was to apply this formulation to the real-world case of NZ, whose health system must find an appropriate balance between maximising efficiency (total population health gain), and maximising equity, particularly by reducing health inequalities between the indigenous Māori and non-Māori populations. To do so we needed to determine empirically the position and shape of the health frontier.

We make two crucial modifications to Wagstaff's original form for

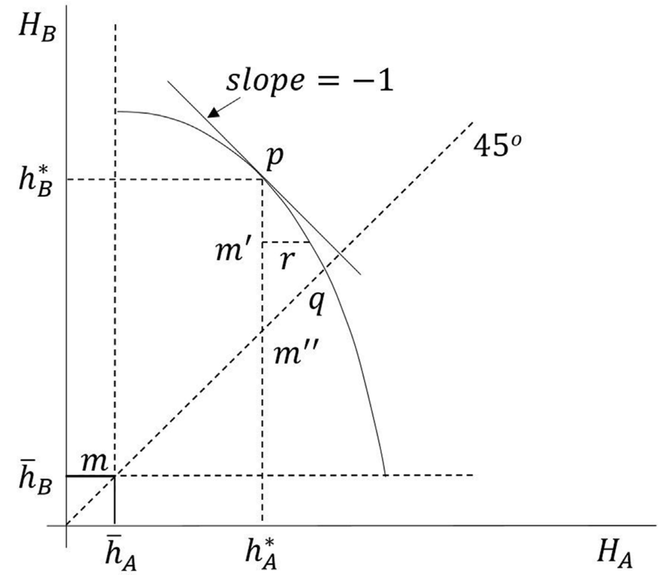

Fig. 1. The health Frontier [a].
Reprinted from J Health Economics 10, 1991, p. 24, with permission from Elsevier.

the health frontier. Firstly, we set the origin of the graph at the current health status of the two populations. Each axis now represents the gain in health of populations A and B over a certain time period and the health frontier now depicts the range of possible changes in health status that can be achieved for each of those populations within that time period.

The second modification is to make the units of health gain changes in LE rather than QALYs or some other measure of health. There are several reasons for making this change, some of which will become more evident as the formulation progresses. Firstly, from a population perspective LE gain is a legitimate goal for public investment. Health expectancies, which reflect both quality and quantity of life, could equally be used but the necessary data is not as widely available, particularly for the subgroups of interest within a population, whereas life expectancies are routinely measured at sub-population level by national statistics agencies. Anyway, for examining trade-offs between equity and efficiency in population health, life expectancies are likely to be closely correlated with health expectancies.

A second reason for using LE gains is that there is evidence that investments in health are increasingly important drivers of life expectancy gains in developed as well as developing countries (Bendavid and Bhattacharya, 2014; Layte et al., 2011; Nolte et al., 2002; Peters et al., 2015). A major catalyst of improved LE has been the dramatic reduction in coronary heart disease and stroke mortality (up to 70% since 1980) and over 90% of this decline has been attributed to health sector treatments and primary and secondary prevention interventions, including smoking prevalence reduction, coronary revascularization, and the treatment of acute myocardial infarction, hypertension, and dyslipidaemias(Mensah et al., 2017). Similarly in cancer, another major cause of death which is also trending downwards, Jemal et al. (2010) concluded that reductions in tobacco use, increased screening and improvements in treatments for specific cancers were responsible for most of these declines.

This is not to suggest that income growth or reductions in socioeconomic inequality are irrelevant to changes in LE. Higher and more evenly distributed income lead to high government revenues (Petek et al., 2014) and (usually) greater public sector investment in health services. Higher incomes also permit private investment in health-enhancing goods and services such as better nutrition. However, while a population's absolute level of LE is correlated with wealth, income, education and other social factors (within and between countries), the rate of change in LE now has at best a weak association with economic factors (Casabonne and Kenny, 2012; Kenny, 2009; Preston, 1975; Riley, 2005), and the association between income and absolute LE has weakened substantially over time (Preston, 1975; Riley, 2005).

The third reason is that LE gain, when seen as a product of health system investment (in the same way that literacy and numeracy are products of education system investments), exhibits some useful features: an efficient health system can be viewed as one that achieves the maximum possible gains in population LE with the available (fixed) resources and existing technologies. Importantly, studies have shown that the rate of increase in population LE does not depend upon the starting level, at least in relatively brief time periods (Oeppen and Vaupel, 2002;Sandiford et al., 2017). In this previous paper we reported that the change in LE was unrelated to the initial LE, either for Māori or for Europeans ($r = 0.19$, $p = 0.42$; $r = 0.16$, $p = 0.19$ respectively). However, there are potentially significant differences between populations in the maximum rate of LE increase, which may depend on cultural, structural or other factors. Hence, we cannot assume that the horizontal and vertical portions of the health frontier (i.e. the asymptotes) will be at the same level for Population A as for Population B.

The fourth reason for using LE gain to determine the health frontier is that it facilitates consideration of the equity-efficiency trade-off. A commonly accepted equity goal, and one consistent with the thesis of Culyer and Wagstaff (1993), is equality of health outcomes such as life expectancy at birth. If the starting difference in LE between Population A and Population B is known, then lines can be drawn on this health frontier that corresponds to achieving that goal (as demonstrated below).

Fig. 2 is a hypothetical example of this revised health frontier chart. At the outset (the origin on the graph) Population A has a maximum possible gain in LE of 1 year during the period (say five years), while Population B has a maximum possible LE gain of 3 years. Population A starts the period with a LE 3 years greater than population B (the origin of the graph lies on the 3-year LE gap isoquant).

If Population A and B are equal in size then a tangent with a slope of -1 touches the health frontier at point P_1 where the opportunity cost for LE gain is the same for the two populations and this is the point at which total population years-of-life (YoL) gained is maximised. If YoL are valued equally for the two populations it is also the point of ***allocative efficiency*** (see Online Supplementary Material) and henceforth we use ‘point of allocative efficiency’ to refer to that point on the frontier at which the maximum total YoL are gained.

However, if populations A and B are not equal in size, then this point no longer corresponds to the point of allocative efficiency (i.e. maximum total health gain). Here the point of allocative efficiency lies where the slope of the tangent is equal to the ratio of the proportion of population A to population B (see Online Supplementary Material). The points of allocative efficiency lie at P_2 and P_5 when the population ratios of A to B are 2:1 and 5:1 respectively. This is important because populations for which there are equity concerns are often minorities.

Fig. 2 shows how different points on the health frontier reflect different levels of equity (meaning the difference in LE between the two populations). Thus, point ***Q*** on the health frontier, with no difference in LE represents the point of health equity (and 100% productive efficiency but not allocative efficiency).

From the point of allocative efficiency (e.g. P_5 when Population B is a fifth the size of Population A), movements along the frontier to the right and downwards result in an increased LE gap. On the other hand, movements along the frontier to the left of P_5 lead to reductions in the LE gap, but only as far as Point Q, where the LE of the two populations is equal, beyond which a LE gap would open favouring Population B

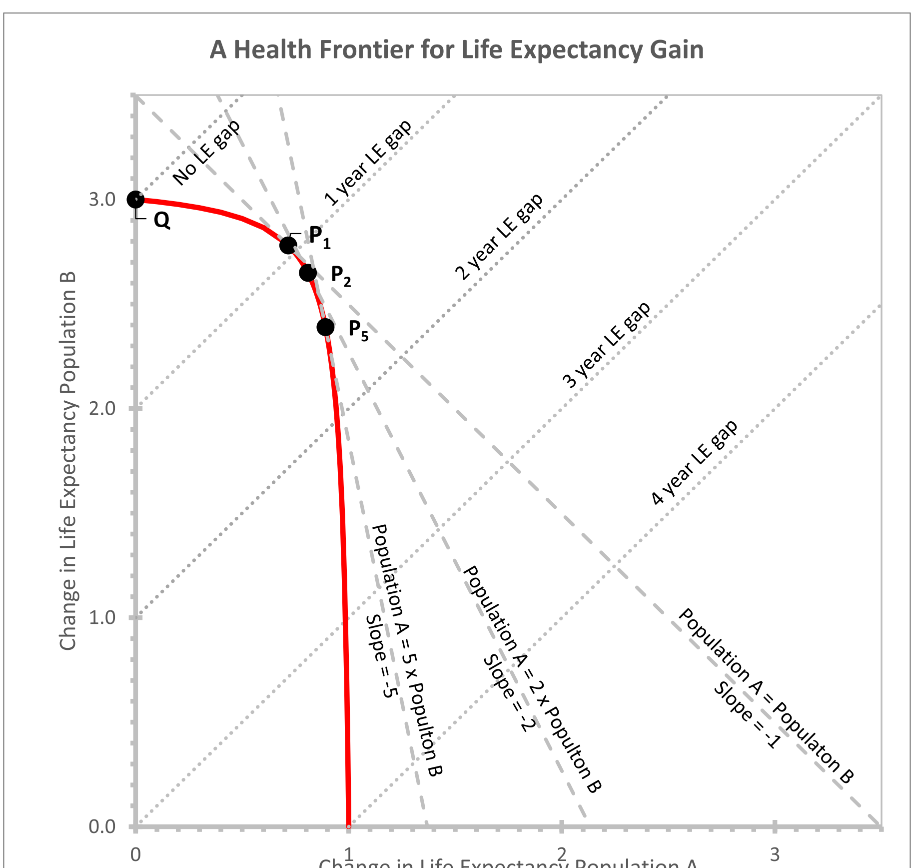

Fig. 2. A health frontier for life expectancy gain.

over Population A.

Note that when starting anywhere on the frontier below and to the right of the allocative efficiency point (e.g. P_1 or P_5) it is possible to gain additional YoL ***and*** reduce LE inequalities by moving up towards that point. In this case there is no trade-off between equity and efficiency because increasing efficiency also increases equity. In contrast, to achieve greater reductions in the LE gap than those obtained at the allocative efficiency point (by moving from the up and to the left on the health frontier), it is necessary to sacrifice some of the total YoL gained.

For example, if population A is twice as large as B, then the point of allocative efficiency (maximum health gain) is at P_2 where the resulting LE gap is about 1.2 years. To achieve greater equity, would require moving upwards and to the left along the frontier towards point Q but this would also imply lower total health gain than that achieved at point P_2. Hence, in this case there is a trade-off between efficiency and equity and the cost of achieving this point of equity can be expressed as YoL foregone.

We now illustrate how this analysis can be applied in practice with real world data from NZ.

3. Methods

3.1. General approach to creating the empirical health frontier

We demonstrate how a health frontier for two populations can be derived empirically with reference to the experience of NZ's 20 semi-autonomous health jurisdictions known as District Health Boards (DHBs) for the period from 2006 to 2013. To do so, we apply a technique known as data envelopment analysis (DEA) which creates a production frontier based on the experience of the 'decision-making units' (DMUs) which in this case are the DHBs. Each DHB is conceived as a unit receiving equal inputs to produce two outputs: Māori and European LE gains. (see Online Supplementary Material for the mathematical formulation of the DEA model).

3.2. Study population

NZ has a multi-ethnic population divided broadly into the indigenous Māori (16% in 2013), Asians (12%), Pacific who identify with one of the Pacific Islands (6%), and the rest (66%) who are overwhelmingly of European ethnicity and will be referred to as European. The Māori and Pacific populations experience higher levels of deprivation and have lower life expectancies. Equity in health in NZ is measured mainly in terms of the reduction or elimination of health inequalities between Māori and Pacific, and European (sometimes grouped with Asian). Considerable effort has been devoted to ensuring that ethnicity is measured completely and accurately in the census and other national databases, including the mortality collection (Blakely et al., 2008). Individuals can have multiple ethnicities, however many analyses (and the population-based funding formula) apply a prioritisation to produce a single ethnicity code where Māori overrides all other ethnicities, Pacific overrides all but Māori, and Asian is recorded in priority to European (Ministry of Health, 2004).

DHBs serve populations ranging (in 2013) from 33000 to 552000. They receive funding on a capitation basis using a population-based funding formula with weightings and adjustments to reflect differences in expected health-service costs. We make a key assumption that per capita inputs are equal for all DHBs. The validity of this assumption was supported by previous work which has demonstrated that the efficiency of each DHB at achieving LE gains for its Māori and European populations is unrelated to the size of the population (hence there are constant returns to scale) and unrelated to the ethnic or demographic mix (Sandiford et al., 2017). Thus, the population-based resource allocation formula used in NZ compensates DHBs for their differences in demographic, ethnic and other factors. Hence, we assume that each DHB has a similar capacity to produce gains in LE for their respective populations with its assigned budget.

3.3. Data sources

The main data used in this analysis were period life tables produced by Statistics New Zealand for each ethnic group in each DHB from the 2006 and 2013 censuses and mortality data from the periods 2005–7 and 2012–14. The life tables were produced using a hierarchical Bayesian model that copes with sparse data by sharing information across estimates, avoiding the need for manual smoothing. The methods yield explicit measures of uncertainty reflected in the 95% credibility limits provided with each table. A full description of the methods is provided by Statistics NZ (2015). The change in Māori and European LE was derived for each DHB from these life tables.

3.4. Stochastic data envelopment analysis

Efficiency was measured using DEA under the assumption of constant returns to scale (Charnes et al., 1978). This assumption was justified on the grounds that gains in LE for Māori and European were unrelated to the size of the population served by the DHB (Sandiford et al., 2017). Note that this assumption holds even in international comparisons where changes in LE at country level are unrelated to the size of the country. Each DHB is treated as a single DMU giving a sample of 20 which satisfies rules of thumb regarding minimum sample sizes (Banker et al., 1989).

It is known that traditional DEA estimates of efficiency made from data with measurement error or sampling variation are subject to bias (Dyson and Shale, 2010; Kao and Liu, 2009; Simar, 2007). A number of approaches have been applied to deal with uncertainty, including bootstrapping, chance-constrained DEA and imprecise DEA. When existing or external estimates of variance in the underlying data are available the Monte Carlo simulation method has been recommended (Dyson and Shale, 2010) and shown to perform well (Ceyhan and Benneyan, 2014). Whereas Kao and Liu and most other Monte Carlo simulations of stochastic DEA have used panel data to estimate the measurement error, here we use the 95% credibility limits provided by Statistics NZ for each LE estimate. Ten thousand replicates of Māori and European LE at birth were generated for 2006 and 2013 and for each DHB, with a normally distributed mean equal to the central estimate provided by Statistics NZ, and a standard deviation equal to the difference between the upper and lower 95% credibility limits divided by 1.96. For each simulation, a DEA estimate of efficiency was calculated for each DHB. The median of these simulated estimates was used as the cited DHB efficiency which are those that have been published previously (Sandiford et al., 2017).

3.5. Fitting the health frontier

This has been described in greater detail in our previous publication (Sandiford et al., 2017). The Monte Carlo simulation made it possible not only to produce an unbiased estimate of efficiency for each DHB, but also to impute the position of specific points on a stochastic PPF as radial projections outward from the observed data points. To illustrate this process, consider the example of a DHB which has gained one year of LE for European and 2 years for Māori and is estimated to be operating at 80% productive efficiency. We extend a line from the origin (0,0) through that point on the graph (1,2) to a new point which is where that DHB would be if it had operated at 100% efficiency without changing the ratio of Māori to European years of LE gain. That point would be at (1.25,2.5). Percentile confidence limits can be placed on this point based on the Monte Carlo simulations (Buckland, 1984).

A smoothed stochastic PPF was created by fitting an empirical curve through these imputed points using weighted least squares regression, weighting each point by the reciprocal of the variance (expressed as inefficiency, i.e. 1-efficiency). A variety of functional forms for the

Table 1
Actual improvements in Māori and European health outcomes between 2006 and 2013, and productive efficiency, by DHB.

	Initial LE		LE gain		YoL gained			Reduction in LE gap	Productive Efficiency
	Māori	European	Māori	European	Māori	European	Total		
Auckland	77.1	83.5	2.29	1.02	79,264	212,562	291,825	1.27	86.1%
Bay of Plenty	72.5	82.0	2.42	1.15	116,422	141,800	258,222	1.28	94.6%
Canterbury	76.5	81.0	2.21	0.91	88,185	305,701	393,886	1.30	80.6%
Capital and Coast	75.9	81.8	2.20	0.98	66,552	169,120	235,673	1.22	82.7%
Counties Manukau	72.5	82.5	2.26	1.22	159,325	217,531	376,856	1.04	98.3%
Hawke's Bay	71.2	80.8	2.68	1.17	94,266	106,942	201,208	1.51	99.7%
Hutt	73.8	80.9	2.41	0.99	51,485	79,204	130,689	1.42	87.8%
Lakes	71.6	80.8	2.00	1.04	60,116	52,526	112,642	0.96	84.5%
Midcentral	73.5	80.7	2.20	1.13	63,687	117,442	181,129	1.07	91.8%
Nelson Marlborough	77.7	81.0	2.60	1.19	33,540	120,325	153,865	1.41	99.4%
Northland	71.2	81.6	2.29	1.02	110,360	83,738	194,097	1.27	86.0%
South Canterbury	77.7	80.5	2.37	0.93	9518	37,424	46,942	1.45	85.5%
Southern	76.1	80.4	2.34	0.95	61,807	197,980	259,787	1.39	84.8%
Tairawhiti	70.3	80.7	2.30	1.11	45,011	21,004	66,015	1.19	91.3%
Taranaki	73.5	80.6	2.37	1.10	43,294	80,927	124,221	1.27	91.3%
Waikato	72.3	81.0	2.12	1.23	158,053	262,642	420,695	0.89	98.5%
Wairarapa	72.0	80.5	2.16	0.98	13,392	26,854	40,246	1.18	82.2%
Waitemata	77.7	84.4	2.48	1.10	125,592	341,731	467,323	1.38	92.8%
West Coast	75.3	79.9	2.38	0.98	7685	22,507	30,192	1.40	86.7%
Whanganui	71.0	80.5	2.45	1.02	34,323	37,041	71,364	1.43	89.6%
NEW ZEALAND	73.2	81.6	2.33	1.06	1,442,998	2,629,557	4,072,555	1.27	88.7%

frontier were explored, but finally the curve was fitted to the following rectangular hyperbolic form:

$$\Delta e_{0,Maori} - \alpha = \frac{\mu}{\Delta e_{0,European} - \beta}$$

The fitted curve had an R^2 of 0.98. Although a hyperbolic relationship was chosen because of its very close fit to the data, this form makes intuitive sense because the constants α and β can be interpreted as asymptotic maximum limits to gains in LE achievable with existing technologies and resources. The third parameter μ is the constant product of the two populations' differences between achieved LE gain (on the frontier) and their maximum possible LE gain. It can be interpreted as a scalar of the opportunity cost function for changes in European (Population A) LE gain since opportunity cost, as the slope of the PPF, is given by:

$$OC = -\frac{\mu}{(\Delta e_{0,European} - \beta)^2}$$

A separate frontier was fitted for each of the first 2000 Monte Carlo simulations and 95% percentile confidence limits for all fitted frontier parameters were calculated from these replications in accordance with Buckland's method (Buckland, 1984).

Māori and European changes in LE for each DHB and NZ were plotted along with the fitted health frontier. Productive efficiency was calculated as the observed change in LE for one population divided by the change in LE of that same population at a point on the health frontier with an equal ratio of Māori to European LE (i.e. at the intersection of the health frontier with a radial projection from the origin through the point corresponding to the DHB's actual LE gains). Monte Carlo 95% confidence limits based on 10,000 simulations were calculated for the NZ estimates of LE and YoL potential gains at 100% productive efficiency. Monte Carlo confidence limits for the LE and YoL changes in moving from 100% productive efficiency to allocative efficiency (the Pareto optimum) were obtained from the first 2000 fitted frontier simulations. Simulations where a frontier could not be fitted (mainly because the frontier points formed a straight line) comprised just 24 of the total (1.2%) and were excluded from these estimates. The points of allocative efficiency for the simulated frontiers were identified as lying at the gradient that yielded the same median LE gap as that at the allocative efficiency point for the overall fitted frontier. Since life tables could not be generated for each simulated frontier, the potential YoL gained/lost for Māori and European by moving to the Pareto optimum were calculated based on the proportions obtained for the summary frontier, thus assuming a linear trajectory between the two points on the curve.

For each DHB we calculated expected YoL gained by multiplying the age-specific changes in LE from 2006 to 2013 by the number of people in that age group in 2013. This was done separately for Māori and European and then summed to give net YoL gained. The YoL that would have been gained had the DHB operated at 100% efficiency was also calculated by using the LE gains corresponding to the intersection of the line projected from the origin through the DHB's actual gains out to the PPF, as described above. To calculate this hypothetical number of expected YoL gained it was necessary to produce new life tables for Māori and European corresponding to these higher LEs. For this we assumed that mortality rates were reduced by a constant proportion in each age group from those in the 2013 life tables.

As stated above, where the DHB's 100% productive efficiency point lies to the right and below the point of allocative efficiency there is no trade-off between equity and efficiency in moving up along the frontier to that point. However, in those cases where the 100% productive efficiency point lies to the left and above the point of allocative efficiency a trade-off does exist, and the magnitude of this trade-off was quantified by calculating the 'cost' of the equity gain (reduction in life expectancy disparity) in terms of the proportion of total potential YoL gained at the maximum that had to be foregone to achieve the equity gain. As a more intuitive alternative way to express the cost of the equity-efficiency trade-off the relative implicit value of a Māori year of life compared with a European year of life was also calculated.

4. Results

Table 1 presents, for each DHB, the initial and actual gains in life expectancy and expected YoL for Māori and European, and the reduction in the life expectancy gap between Māori and Europeans from 2006 to 2013. It also gives the DHBs' estimated productive efficiency (from the Monte Carlo simulation). Though only two DHBs operated at close to 100% productive efficiency (Hawkes Bay and Nelson Marlborough), substantial health gains were made for both Māori and European populations in all DHBs, and all but two also managed to reduce the LE gap between Māori and European by at least one year.

In Table 2 we show what health gains could be achieved, over and

Table 2
Additional health gains that would be achieved if DHBs operated at 100% productive efficiency.

	Life expectancy change		Person-years-of-life change			LE gap change
	Māori	European	Māori	European	Total	
Auckland	0.37	0.16	13,253	35,471	48,724	−0.21
Bay of Plenty	0.14	0.07	6653	8291	14,944	−0.07
Canterbury	0.53	0.22	21,635	77,385	99,020	−0.31
Capital and Coast	0.46	0.20	13,965	36,591	50,556	−0.26
Counties Manukau	0.04	0.02	2860	3849	6709	−0.02
Hawke's Bay	0.01	0.00	240	276	516	0.00
Hutt	0.34	0.14	7279	11,530	18,809	−0.20
Lakes	0.37	0.19	11,618	9963	21,581	−0.18
Midcentral	0.20	0.10	5739	10,786	16,525	−0.10
Nelson Marlborough	0.02	0.01	208	762	970	−0.01
Northland	0.37	0.17	18,044	14,396	32,440	−0.21
South Canterbury	0.40	0.16	1640	6769	8409	−0.24
Southern	0.42	0.17	11,303	37,829	49,132	−0.25
Tairawhiti	0.22	0.11	4377	2020	6397	−0.11
Taranaki	0.23	0.10	4186	7914	12,100	−0.12
Waikato	0.03	0.02	2516	4207	6723	−0.01
Wairarapa	0.47	0.21	2921	5986	8907	−0.25
Waitemata	0.19	0.08	9850	27,079	36,929	−0.11
West Coast	0.36	0.15	1197	3649	4846	−0.21
Whanganui	0.29	0.12	4002	4520	8522	−0.17
NEW ZEALAND	0.30	0.14	186,838	347,438	534,276	−0.16

above those in Table 1, if all DHBs had operated at 100% productive efficiency (as Nelson Marlborough and Hawkes Bay did). For NZ, improvements in productive efficiency could have increased the number of expected YoL for both Māori and European by 13.1%, whilst also reducing the 8.4-year LE gap in 2006 by 1.9% (0.16 years; Monte Carlo 95% confidence interval 0.11–0.23). Confidence limits for the other NZ outcomes are presented in Table 4.

Fig. 3 shows the fitted health frontier for New Zealand DHBs from 2006 to 2013. Parameter values and their confidence limits are provided in Table 4. The *y*-axis intercept, representing the maximum LE gain possible for Māori without a reduction in European LE, lies at 2.86 years (95% confidence interval 2.63–5.42). The *x*-axis intercept, the maximum LE gain for Europeans, is at 1.27 years (1.21–1.58). The actual gains in LE for all NZ were 2.34 and 1.06 years for Māori and European respectively. A radial projection from the origin through this point crosses the health frontier at the point (R_{NZ}) representing the LE gains that would have been achieved if NZ had achieved 100% productive efficiency.

On the frontier slightly below and to the right of R_{NZ} is the point of allocative efficiency (point P_{NZ}). The fact that P_{NZ} is below and to the right of R_{NZ} implies a (slight and statistically non-significant) pro-equity bias such that if the country had operated at 100% productive efficiency it would have gained a 0.05-year reduction in the 8.39 year LE disparity between the Māori and European populations that existed in 2006 (Table 3) but at a cost of 3802 YoL sacrificed. Compare this with the aforementioned 0.16-year reduction in Māori-European LE disparity that NZ could achieve by increasing productive efficiency from 89% to 100% (Table 2). Since the country operated at just 89% productive efficiency, the actual contribution of this slight pro-equity bias in health policy to the reduction in the LE between 2006 and 2013 was only 0.04 years (and the actual sacrifice in YoL was also 89% lower at 3371.

The marginal cost of the (very small and statistically insignificant) equity gain that NZ's slightly pro-equity bias achieved is assessed by comparing the relative number of European and Māori lives gained. Table 3 shows that the net gain of 3802 YoL that would result from operating at maximum allocative efficiency would be achieved by trading off 27907 European for 24105 Māori YoL and at a cost of a 0.05-year increase in the LE disparity between Māori and Europeans (see Table 4 for confidence limits on these figures for NZ as a whole). This means that New Zealand's *de facto* pro-equity bias has implicitly valued a Māori year of life at 1.16 times the value of a European year of life. Note that the equal LE isoquant does not intersect with this health frontier, implying that equity in LE is not feasible within the time frame being considered.

5. Discussion

5.1. Multiple paths to equity gains

Moving along the health frontier upward and to the left of the point of maximum health gain is just one of several paths to increased equity. A second is to increase productive efficiency (provided that the radial projection is at an angle is at least as great as the LE gap isoquants). Equity gained in this way does not involve any YoL sacrifice by the less deprived population. If a country is operating at low productive efficiency, increasing productive efficiency may be the most cost-effective way to improve equity.

A third way to increase equity is to shift the health frontier upward and outward. Although nominally 'impossible', the health frontier only defines the limit of what is possible in terms of the actual achievements of other DMUs (DHBs in this case). Innovations which increase LE more for disadvantaged groups have the effect of pushing the frontier out more vertically than horizontally. An example of this in NZ could be new treatments or preventive strategies for lung cancer (e.g. higher tobacco taxes).

5.2. The implications of population heterogeneity

Heterogeneity in the distribution of population within a country means that the point of maximum health gain will vary by DMU/DHB as was illustrated in Fig. 2. DHBs with a high proportion of Māori have a point ***P*** that is higher on the health frontier than DHBs with a low proportion of Māori (such as South Canterbury): Tairawhiti with a high proportion of Māori can increase Māori LE by 2.74 years before further increases must come at the cost of European lives, while South Canterbury, with a lower proportion of Māori, can increase it by only 2.42 years before a trade-off ensues. Thus, variation between DHBs in the extent to which they implement pro-equity policies can be consistent with maximising efficiency and does not necessarily mean that one is making greater sacrifices for equity than another.

Two important implications arise from this. One is that

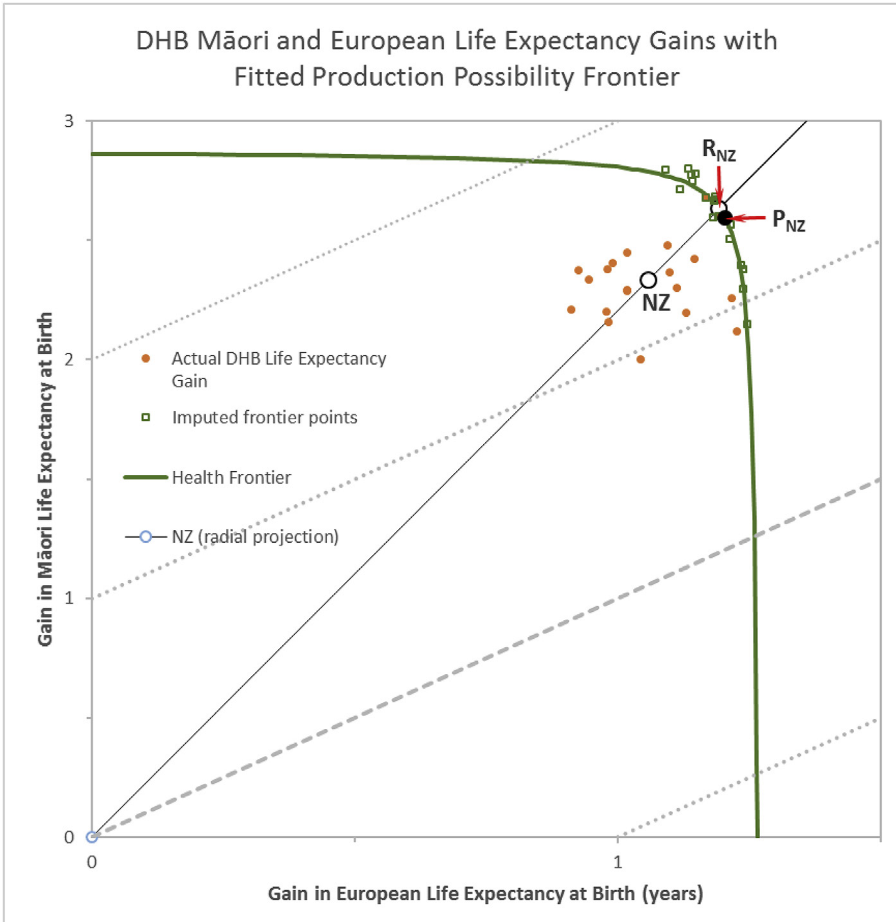

Fig. 3. DHB Māori and European life expectancy gains with fitted production possibility frontier.

decentralisation offers a 'fourth way' to increase equity by giving individual jurisdictions the opportunity to make policy and resource allocation decisions that maximise their efficiency and by doing so, achieve greater equity. Table 3 shows that over 40,000 YoL could have been gained along with a reduction in the LE gap if Waikato and Counties Manukau had implemented more pro-equity policies addressing the needs of their relatively large Māori populations. The second implication is that efforts at national level to homogenise the range of services delivered across all jurisdictions may limit not only equity gains but also efficiency.

Table 3
Additional health and equity gains achievable at the point of maximum allocative efficiency (Pareto optimum)from the point of 100% productive efficiency.

	Life expectancy change		Change in expected YoL			LE gap change
	Māori	European	Māori	European	Total	
Auckland	−0.12	0.03	−4463	7029	2566	0.16
Bay of Plenty	0.09	−0.02	4407	−3134	1273	−0.12
Canterbury	−0.27	0.09	−10985	32691	21706	0.36
Capital and Coast	−0.12	0.03	−3740	5849	2109	0.16
Counties Manukau	0.36	−0.05	25965	−9835	16130	−0.42
Hawke's Bay	−0.04	0.02	−1242	1472	230	0.05
Hutt	−0.14	0.07	−3009	6108	3099	0.21
Lakes	0.33	−0.07	10450	−3677	6773	−0.40
Midcentral	0.22	−0.03	6358	−3496	2862	−0.25
Nelson Marlborough	−0.13	0.02	−1715	2576	861	0.16
Northland	0.03	−0.01	1429	−1234	195	−0.04
South Canterbury	−0.35	0.15	−1437	6367	4930	0.50
Southern	−0.28	0.11	−7502	24459	16957	0.39
Tairawhiti	0.22	−0.09	4519	−1706	2813	−0.31
Taranaki	0.00	0.00	61	−60	1	0.00
Waikato	0.49	−0.06	37474	−12185	25289	−0.55
Wairarapa	−0.04	0.01	−268	314	46	0.05
Waitemata	−0.14	0.04	−7097	11744	4647	0.17
West Coast	−0.24	0.09	−802	2231	1429	0.33
Whanganui	−0.06	0.07	−1231	1989	758	0.14
NEW ZEALAND	−0.04	0.01	−24105	27907	3802	0.05

Table 4
Model parameter and NZ Outcome Estimates with Monte Carlo 95% Confidence Limits.

	95% C.L		
	Median	Lower	Upper
Fitted frontier parameters			
x axis intercept	1.27	1.21	1.61
x axis asymptote (β)	1.27	1.21	2.27
y axis intercept	2.86	2.64	5.20
y axis asymptote (α)	2.88	2.65	7.46
Opportunity cost scalar (μ)	0.019	0.0001	4.77
NZ Outcomes			
Shift to 100% productive efficiency from actual			
Net reduction in LE gap	0.16	0.10	0.25
Māori increase in LE	0.30	0.18	0.45
European increase in LE	0.14	0.08	0.21
Māori YoL gain	186,838	112,495	284,371
European YoL gain	347,438	210,005	529,803
Total YoL gain	534,276	324,428	816,069
Shift from 100% productive efficiency to Pareto optimum			
Overall reduction (increase) in LE gap	(0.05)	(0.66)	0.91
Māori increase (reduction) in LE	(0.04)	(0.69)	0.60
European increase (reduction) in LE	0.01	(0.07)	0.20
Māori YoL gain (loss)	(24,105)	(431,925)	378,657
European YoL gain (loss)	27,907	(185,290)	514,449
Total YoL gain (loss)	3802	(17,720)	274,418

However, once a DHB with a high proportion of Māori reaches the health gain maximum, further gains in equity are costlier than for DHBs with a smaller proportion of Māori (since the slope of the curve beyond that point is lower – there are fewer non-Māori YoL to exchange for Māori YoL). Also, one must consider whether this potential benefit of decentralisation, the ability to gain more YoL, is not eroded through lower productive efficiency that might result from smaller economies of scale or variation in capacity to exploit the benefits of a decentralised system.

5.3. Limitations of the analytic framework

We emphasise that the use of this framework for analysing equity/efficiency trade-offs does not eliminate the need to make value judgements in deciding goals for population health. What it offers is a way to visualise a population's current equity/efficiency status and the possible pathways to achieving whatever goal that has been set. In NZ's case it is clear that despite substantial rhetoric about the importance of reducing inequalities between Māori and non-Māori populations, the gains in life expectancy that have been achieved in the inter-census period deviate little from the path of maximising efficiency. On the other hand, it is also clear that any significant change to reduce the LE gap between Māori and European by moving further up and left from the point of allocative efficiency would come at a considerable cost in European lives as evident from the rapidly declining slope of the Health Frontier above that point.

Our framework for analysing equity-efficiency trade-offs does rely on some important assumptions which we have highlighted above. These include the assumption that gains in LE can be attributed primarily to the actions of health system decision-making units (DHBs) although these themselves are dependent on changes in income and particularly government revenues. We have provided evidence in support of this assumption for recent changes in LE over short time frames. This assumption may not continue to hold in the future or may be less valid over longer time frames. Furthermore, it is not a simple matter to control for the effects on health outcomes of national-level interventions or non-health sector factors within this framework. For the period 2007–2014 (data was not available for 2006) which covered the Global Financial Crisis, median household income rose by 1.7% per year in NZ (Perry, 2017). For Māori, income grew at a slower rate than for Europeans (1.7% vs 2.3% per annum) (Perry, 2017). Between 2006 and 2013 total NZ health expenditures in current prices grew at an annualised rate of 5.6% (OECD, 2017).

The framework neglects the potential impact on LE gain of the private sector in health. In principle though, if the data were available it would be possible to incorporate private sector expenditures on health. This analytic approach also relies on the assumption that within the population groups being studied (in our case Māori and European) there is a common Health Frontier for each DHB. In reality the frontier may vary in different areas of a country for reasons unrelated to health care.

5.4. Limitations in this application of the analytic framework

NZ's population is far more ethnically diverse than just Māori and European, with a significant proportion who identify with Asian and Pacific Island ethnicities. These population groups have not been considered in this analysis, as it would introduce considerable computational complexity to do so. However, there is nothing that would preclude analysing more than two population groups using this approach. The ability to replicate such an analysis in other settings would depend upon the availability of life tables spanning one or more periods, disaggregated by jurisdiction and by the social parameter(s) of interest from an equity perspective (in this case ethnicity but it could equally be social deprivation). The number of jurisdictions needs to be sufficient to be able to model the health frontier.

This analysis was inevitably limited by the relatively small size of New Zealand's population and the low proportion of Māori within it. The effect of this is that the estimates we generate naturally have wide confidence limits, limiting our ability to make concrete judgements. This method would be better suited to situations where it is possible to compare more decision-making units and where larger populations allow narrower confidence limits on the original life expectancy data. From an input perspective the method would be more robust if it were possible to quantify stochastic variation in levels of input and draw on other research to confirm the assumptions of equal per capita input and constant returns to scale.

The construction of the empirical health frontier relied on the assumption that each DHB had equal resources with which to make LE gains for their Māori and European populations. Sandiford et al. (2017) have tested this assumption and no obvious violation of it was found. Being able to assume equality of inputs simplified the construction of the health frontier. In settings where equality of inputs between jurisdictions cannot be assumed this would need to be considered in the construction of the health frontier.

This analysis has also relied on the assumption that the production possibilities for each DHB in terms of ethnic-specific life expectancy are the same which was supported by the finding that there was no correlation between either the proportion of Māori in a DHB or the initial level of LE, and the gain in LE achieved (Sandiford et al., 2017). Nevertheless, this may not remain the case forever, and the assumption may not hold in other countries.

5.5. What this adds

In attempting to 'make real' the notion of a health frontier and the trade-off between equity and efficiency we have produced a modified health frontier which we believe facilitates greater application and understanding of this trade-off. We have highlighted how equity gains can be made in at least four different ways: moving upward along the health frontier; operating at greater productive efficiency; shifting the Māori health frontier outward; and effective decentralisation without loss of productive efficiency. For none of these four ways of achieving greater equity is a loss of efficiency inevitable, but once the system operates at maximum productive and allocative efficiency, only shifting the health frontier upward can avoid a trade-off between the two, highlighting the importance of technical and organisational innovation.

We have shown that it is possible to quantify this trade-off between equity and efficiency and demonstrated that NZ's rhetorical commitment to greater equity is not reflected in a clear willingness to make a significant sacrifice of efficiency for equity. By establishing a *de facto* price of equity gains we have opened the possibility of national debate on willingness to pay this, or even a higher price, to reduce what are widely agreed to be unacceptable ethnic inequalities. Equally, the findings permit scrutiny of the extent to which other government declarations of commitment to greater equity are consistent with actual achievements.

In conclusion, this framework represents a tool which may be help decision-makers at both national and local level become more aware of efficiency-equity trade-offs. If health systems are to get beyond rhetorical commitments to reducing health inequities, then this analytic framework and the methods described should be used to identify these trade-offs and make them quantitatively explicit.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.socscimed.2018.07.005.

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