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Letting the Gini out of the bottle? Challenges facing the relative income hypothesis

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Abstract

The relative income hypothesis interprets statistical associations between income inequality and average health status at the population level, as evidence that income inequality has a deleterious psychosocial effect on *individual* health. An alternative explanation is that these, population-level associations, are statistical artefacts of curvilinear, individual-level relationships between income and health. Indeed, provided the cost–benefit ratio of health-enhancing goods and services vary, the law of diminishing returns should produce curvilinear, asymptotic relationships between income and health at the individual level, which create ('artefactual') associations between income inequality and health at the population level. However, proponents of the relative income hypothesis have argued that these relationships are unlikely to be responsible for the associations observed between income inequality and average health status amongst *high-income* populations. In these populations, the individual-level relationships between income and health would be nearer their asymptotes, where a shallower slope should ensure that income inequality has little (if any) 'artefactual' effect on average health status. Yet this argument was based on analyses of population-level data which underestimated the slope and curvilinearity of underlying, individual-level relationships between income and health. It is therefore likely that (at least some part of) the population-level associations between income inequality and average health status (amongst low-, middle- *and* high-income populations) are 'artefacts' of curvilinear, individual-level relationships between income and health. Nevertheless, it is also possible that income inequality is somehow (partly or wholly) responsible for the curvilinear nature of individual-level relationships between income and health. Likewise, it is possible that income inequality alters the height, slope and/or curvilinearity of these relationships in such a way that income inequality has an independent effect on *individual* health. In either instance, the 'artefactual' effect of curvilinear relationships between income and health at the individual level would simply reflect the *mechanism* underlying the relative income hypothesis.

Keywords: Income inequality; Population health; Individual health; Artefact

"*Inequality of income takes the broad, safe, and fertile plain of human society and stands it on edge so that everyone has to cling desperately to her foothold and kick off as many others as she can*" Bernard Shaw (1928; p. 418).

Introduction

Over the past 20 years (Lynch & Kaplan, 1997; Judge, Mulligan, & Benzeval, 1998), a compelling body of ecological research has found statistical associations between various measures of income inequality and average health status at the population level, using cross-sectional (Rodgers, 1979; McIsaac & Wilkinson, 1997) and longitudinal approaches (Wilkinson, 1992; Fiscella & Franks, 1997), both within (Kaplan, Pamuck, Lynch, Cohen, & Balfour, 1996; Ben Shlomo, White, & Marmot, 1996; Wolfson, Kaplan, Lynch, Ross, & Backlund, 1999) and between countries (Flegg, 1982;

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Steckel, 1995; Ellison, 1999a). They include studies of high- (Kawachi, Kennedy, Lochner, & Prothrow-Stith, 1997), middle- (Davey Smith, 1996a) and low-income countries (Waldmann, 1992), relating the Gini coefficient (Wennemo, 1993), the Robin Hood index (Kennedy, Kawachi, & Prothrow-Stith, 1996), the prevalence of relative poverty (Wilkinson, 1996), the percentage share of income received by various centiles of each population (Daly, Duncan, Kaplan, & Lynch, 1998), the decile ratio, the Atkinson Index and Theil's entropy measure (Kawachi & Kennedy, 1997) to disparities in mortality (Wennemo, 1993), life expectancy (Le Grand, 1987), self-reported health status (Kennedy, Kawachi, Glass, & Prothrow-Stith, 1998a; Soobader & LeClere, 1999), obesity (Khan, Tatham, Pamuk, & Health, 1998) and stature (Steckel, 1995).

By 1996 the remarkable consensus between such a wide variety of different analyses led Wilkinson (1996, pp. 105) to conclude that "the income distribution relationship is now firmly established". He then set out what Gravelle (1998, p. 382) has subsequently called the "relative income hypothesis", which asserts that "an individual's health is… affected by the distribution of income within society". The hypothesis provides an increasingly popular explanation for the association between income inequality and average health status at the population level—that income inequality undermines social cohesion and has a detrimental psychosocial effect on *individual* health, so that individuals living in unequal societies have worse health than those living in more egalitarian societies (Wilkinson, 1996).

Wilkinson's (1996) emphasis on the individual- and community-level processes (particularly social cohesion) that help protect health, rather than the structural, political and economic forces (particularly class relations) responsible for (re)producing inequality, has been criticised as prone to a "community-level version of 'victim-blaming'" (Muntaner & Lynch, 1999a, pp. 59, 1999b). Yet the three potential mechanisms that underpin the hypothesis (Kawachi & Kennedy, 1999) include individual, communal *and* structural processes (Wilkinson, 1999a). These suggest that:

(i) Individual—Income inequality creates a palpable sense of injustice and dissatisfaction, accompanied by damaging psychological (James, 1998) and psychosomatic (Brunner, 1997) effects.
(ii) Communal—Income inequality provokes social distrust (Kawachi et al., 1997), inter-personal violence (Kennedy, Kawachi, Prothrow-Stith, Lochner, & Gupta, 1998b) and civic unrest (Wilkinson, Kawachi, & Kennedy, 1998).
(iii) Structural—income inequality reflects inadequate sociopolitical support for redistributive fiscal policies which redress material poverty, provide universal access to health-enhancing public services (Davey Smith, 1996b), and thereby improve productivity and economic prosperity (Wilkinson, 1996).

All three mechanisms are supported by empirical epidemiological research (Kawachi & Kennedy, 1999) and each have appeared in policy documents published by the World Health Organisation (Braveman, Tarimo, Creese, Monasch, & Nelson, 1996; Wilkinson & Marmot, 1998). It is therefore somewhat heretical to question the very existence of the statistical association on which the relative income hypothesis depends. Yet a number of analyses find little evidence of a statistically significant association between income inequality and average health status at the population level, either before (Judge, 1995), or after (Saunders, 1996; Fiscella & Franks, 1997; Judge et al., 1998; Ellison, 1998) controlling for a variety of potential confounders, including: income, health care expenditure, the availability of public services, and female employment. While these negative findings have been attributed to poor quality data from incomparable and/or unrepresentative surveys (Judge, 1995; Judge et al., 1998; Wilkinson, 1995, 1998a; Daly et al., 1998; Martikainen & Valkonen, 1999), Wilkinson (1998a) has specifically questioned the validity of controlling for material and social factors which might themselves be the (in)direct *consequences* of income inequality. This applies to each of the potential mechanisms outlined above:

(i) Individual and (ii) Communal—Compulsory education and female emancipation might simply reflect a socially cohesive, egalitarian culture that promotes equal opportunities for all. Demonstrating that the statistical association between income inequality and average health status at the population level is weakened by controlling for secondary school enrolment (Ellison, 1998) and female participation in the workforce (Judge et al., 1998) might therefore be interpreted as evidence that income inequality fosters ignorance and resentment, leading to conflict and psychosocial stress.
(iii) Structural—Governments which lack comprehensive redistributive policies are less able to equalise incomes or transfer wealth to the sorts of health-enhancing public services that benefit the wellbeing of all (Davey Smith, 1996b) and thereby improve productivity and economic prosperity (Wilkinson, 1996). Demonstrating that the statistical association between income inequality and average health status at the population level is weakened by controlling for individual income (Fiscella & Franks, 1997), average income (Judge et al., 1998), expenditure on health care (Saunders, 1996) or secondary school enrolment and access to safe water (Ellison, 1998), might therefore be interpreted

as evidence that income inequality reflects inadequate sociopolitical support for health-enhancing fiscal policies.

However attractive and plausible these arguments might be, none of the cross-sectional ecological studies cited above can actually establish that income inequality *precedes* the social and material circumstances which undermine health at an individual level. Longitudinal studies, multi-level modelling and path analyses should provide better evidence of causality, but these techniques have produced equivocal results (compare Wilkinson (1992) with Judge (1995); Fiscella and Frank (1997) with Daly et al. (1998) and Kennedy et al. (1998a), and Kawachi et al. (1997) with Ellison (1999a)). Wilkinson (1996) did identify one randomised controlled trial of income supplementation (negative taxation) which found a significant decline in the prevalence of low birth weight babies amongst mothers at high risk of poor pregnancy outcome living on welfare in Indiana (Kehrer & Wolin, 1979). Yet the type of experimental design used could not distinguish between the material benefits of an increase in income at the individual level, and the psychosocial benefits of a decline in income inequality at the population level.

In the absence of more appropriate experimental studies, Gravelle (1999) has emphasised the need for further research into the independent effect of income inequality on individual health, using a combination of population- *and* individual-level data. This is particularly important given that many of the studies cited above failed to consider an alternative explanation for the association between income inequality and average health status at the population level. This, 'artefactual explanation', poses a more fundamental challenge to the relative income hypothesis by suggesting that the association between income inequality and health at the population level may simply be a "statistical artefact" of underlying, curvilinear relationships between income and health at the individual level. The aim of this paper is to: 1. re-examine the evidence for the 'artefactual explanation', and 2. establish whether it necessarily invalidates the relative income hypothesis.

Could the association between income inequality and average health status at the population level be a statistical artefact?

To assess whether the association between income inequality and average health status at the population level is a statistical artefact of a curvilinear relationship between income and health at the individual level, it is worth examining: 1. why the relationships between income and health at the individual level are thought to be curvilinear and asymptotic; 2. how curvilinear asymptotic relationships between income and health at the *individual* level might influence the associations between income inequality, average income and average health status at the *population* level; and 3. whether the evidence used to formulate the relative income hypothesis (specifically the population-level associations between average income, income inequality and average health status amongst *high-income* countries) might have underestimated the impact of curvilinear asymptotic relationships between income and health at the individual level.

Why are the relationships between income and health at the individual level thought to be curvilinear and asymptotic?

There are four good reasons why the relationships between income and health at the individual level are, or appear to be, curvilinear and asymptotic:

(i) Whenever income accurately reflects each individual's ability to obtain the material goods and services necessary to sustain life, zero income (i.e. absolute material poverty) inevitably leads to death from dehydration, starvation and/or exposure.

(ii) Whenever finite measures, such as survival risk, are used as measures of 'health', they impose an absolute upper limit on health (i.e. a survival risk of 1) beyond which no further improvements are possible.

(iii) As long as technological innovations fail to protect individuals from chance physiological or environmental events, even absolute wealth (i.e. all income) can not guarantee a survival risk of 1.

(iv) As long as the cost–benefit ratio of health-enhancing goods and services vary (e.g. water, food and shelter vs. tertiary health care), the law of diminishing returns will apply to relationships between income and health so that improvements in income are likely to result in ever smaller improvements in health.

Fig. 1 provides a schematic representation of these four points, showing a hypothetical relationship between income (as a measure of material wellbeing) and survival risk (as a measure of health), in which: (i) zero income (absolute material poverty) is associated with a survival risk of 0; (ii) there is a finite upper limit to health, equivalent to a survival risk of 1; (iii) chance events and technological limitations impose an *achievable* upper limit on health somewhat less than a survival risk of 1; and (iv) improvements in survival risk decline as incomes increase, creating a curvilinear asymptotic relationship towards the achievable upper limit of health (iii).

Clearly, curvilinear asymptotic relationships between income and health at the individual level seem highly plausible. However, the theoretical model presented in

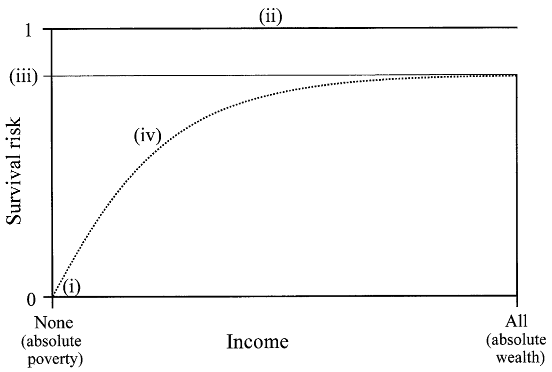


Fig. 1. A theoretical curvilinear and asymptotic relationship between income and health (survival risk) at the individual level (see text for details regarding points (i), (ii), (iii) and (iv)).

Fig. 1 makes a number of assumptions about the nature of 'income' and 'health' which limit its validity and generalisability. In particular, the model takes a rather narrow, and explicitly materialistic, view of both 'income' and 'health' by assuming that income accurately reflects each individual's ability to obtain the material goods and services which benefit health, and that material goods and services are the most important (if not the only) determinants of health.

The *New Oxford Dictionary of English* (Pearsall, 1998) defines income as "money received, especially on a regular basis, for work or through investments". Yet cash income may bear little relation to material well-being in subsistence agricultural economies where many of the goods and services necessary for survival (such as water, food and shelter) are obtained directly from the environment, and where other goods and services may be available through barter rather than cash. Even in exclusively cash-based economies, formal redistributive policies (such as the US welfare or the UK social security schemes) and informal social structures (such as kin- and community-based support networks), provide an alternative source of goods, services and even cash for individuals with little or no 'income'. In either instance, lower 'incomes' would have less impact on health than that predicted in Fig. 1, particularly amongst those individuals receiving no 'money ... from work or investments'. On the other hand, the strictly materialistic view of health presented in Fig. 1 ignores the potential impact of 'income' (however defined or measured) on psychological wellbeing, and ignores the evidence linking psychological wellbeing to health and health-seeking behaviour. Wherever 'income' is indicative of social status or power, and thereby elicits psychological effects on health and health-seeking behaviour irrespective of material wellbeing, lower 'incomes' would have a greater impact on health than that predicted in Fig. 1.

These methodological issues raise important questions about the definition, measurement and interpretation of both 'income' and 'health', and while there is growing empirical evidence that relationships between the two are curvilinear and asymptotic at the individual level (Backlund, Sorlie, & Johnson, 1996; Ecob & Davey Smith, 1999; Ellison, 1999b; Wolfson et al., 1999), the precise nature of these relationships (their height, slope and curvilinearity) seems to depend upon which measures of 'income' and 'health' are used (compare Ecob and Davey Smith (1999) with Der, MacIntyre, Ford, Hunt, and West (1999)). More important still, the height, slope and curvilinearity of the relationships between *identical* measures of 'income' and 'health' differ from one country to the next (Ellison, 1999b). It therefore seems unlikely that exactly the same relationship exists between income and health at the individual level across all populations, regardless of how 'income' and 'health' are measured. This possibility has important implications for the relative income hypothesis and will be discussed in more detail in the section *Does the 'artefactual explanation' necessarily invalidate the relative income hypothesis?* below. In the meantime, perhaps the somewhat equivocal conclusion that can be drawn from the empirical evidence available is that the relationships between income and health at the individual level *appear* curvilinear and asymptotic.

How might curvilinear relationships between income and health at the individual level influence the association between income inequality, average income and average health status at the population level?

Whatever the limitations of the model presented in Fig. 1, curvilinear asymptotic relationships between income and health at the individual level have two important consequences for comparisons of average health status at the population level:

(i) They create 'artefactual' associations between income inequality and average health status.
(ii) They disrupt the relationship between average income and average health status.

The first of these points was originally raised by Adelman (1963), although it was Gravelle (1998) who articulated this more forcibly in what has become known as the 'artefactual explanation' for the association between income inequality and average health status at the population level. Gravelle's (1998) argument is summarised in Fig. 2, which demonstrates not only the effect of differences in income distribution (point (i)), but also the effect of average income (point (ii)), on the average health status (survival risk) of three hypothetical populations (A, B and C): two with identical average incomes ($\bar{I}$) but different income

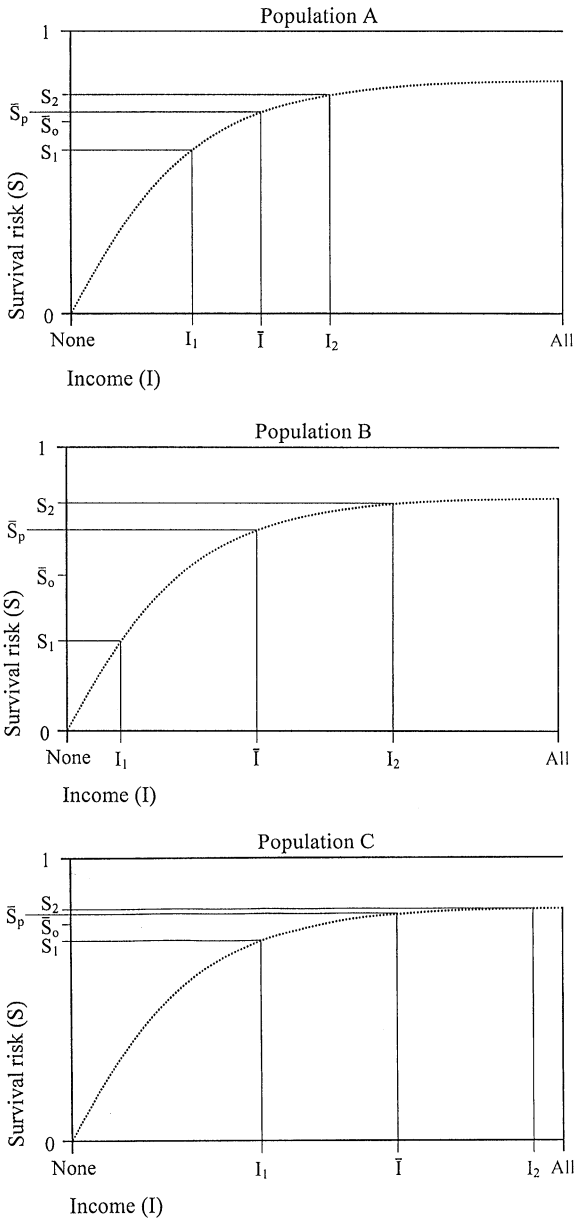


Fig. 2. The impact of differences in average income and income distribution on the difference between average health status observed ($\bar{S}_o$) and that predicted ($\bar{S}_p$) by average income ($\bar{I}$) in three hypothetical populations (A–C) with identical curvilinear asymptotic relationships between income and health.

distributions (I_1 to I_2; populations A and B), two with identical income distributions (I_1 to I_2) but different average incomes ($\bar{I}$; populations B and C). To simplify this demonstration each population contains just two individuals (1 and 2), and each population has the same curvilinear asymptotic relationship between income and health at the individual level as that proposed in Fig. 1. In all three populations, the ill-effects of lower-than-average incomes on the health of the poorest individuals (S_1) are greater than the (comparatively modest) benefits of higher-than-average incomes on the health of the wealthiest individuals (S_2). The average health status observed ($\bar{S}_o = (S_1 + S_2)/2$) is therefore lower than that predicted ($\bar{S}_p$) for an individual receiving an average income ($\bar{I}$). Furthermore, a comparison between populations A and B reveals that the average health status observed ($\bar{S}_o$) is lower in populations with greater income inequality (in this case, population B). Likewise, a comparison between populations B and C reveals that the effect of income distribution on the difference between average health status observed ($\bar{S}_o$) and that predicted by average income ($\bar{S}_p$) is greater in populations with lower average incomes (in this case, population B), whose individual incomes fall further away from the asymptote, on a steeper part of the curve (the assumptions underlying this effect are discussed in the appendix). These comparisons help elaborate both of the points outlined above: (i) Amongst populations with similar average incomes but different income distributions (such as A and B), curvilinear relationships between income and health at the individual level produce differences in average health status, so that average health status declines as income inequality increases. (ii) Amongst populations with similar income distributions but different average incomes (such as B and C), relationships between income and health at the individual level that are both curvilinear *and* asymptotic, exacerbate the effect of income inequality on the average health status of poorer populations. Under these circumstances, the population-level relationships between average income and observed average health status are *steeper* than those predicted for individuals on average incomes.

The first of these points is the crux of Gravelle's (1998) 'artefactual explanation' for the relative income hypothesis, since it demonstrates how a curvilinear relationship between income and health at the individual level creates an ('artefactual') association between income distribution and average health status at the population level. The relevance of the second of these points will become apparent in the next section, since it affects some of the evidence originally used to formulate the relative income hypothesis.

Can the population-level association between income inequality and average health status amongst high-income countries be explained by curvilinear relationships between income and health at the individual level?

The two preceding sections suggest that Gravelle's (1998) 'artefactual explanation' provides a robust challenge to the relative income hypothesis. Yet the use of the term 'artefactual' is problematic from both a semantic and an analytic perspective. First, it tends to denigrate what might well be an important mechanism underlying the association between income distribution and average health status at the population level (i.e. curvilinear relationships between income and health at the *individual* level) and thereby dismisses as 'artefactual' a potentially *real effect* of income inequality on population health (Sutton, 1998; Wilkinson, 1999b). Second, it implies that the association between income distribution and health at the population level is simply a serendipitous consequence of curvilinear relationships between income and health at the individual level. It therefore ignores the possibility that income inequality might influence the height, slope and/or curvilinearity of these relationships in such a way that creates and/or accentuates the association between income inequality and average health status at the population level (Ellison, 1999c; see the Section *Does the 'artefactual explanation' necessarily invalidate the relative income hypothesis?* below). It was, however, not this second possibility which persuaded Wilkinson (1996) that income inequality at the population level had an independent effect on health at the individual level, even though he cited research by Vagerö and Lundberg (1989) and Leon, Vagero, and Otterblad Olausson (1992) which found a lower and shallower relationship between occupational class and mortality in ('egalitarian') Sweden than that in ('unequal') Britain (Wilkinson, 1996; Fig. 5.7, pp. 86–87). Instead, his relative income hypothesis was based on analyses of data from high-income countries which appeared to defy the 'artefactual explanation'.

Writing before Gravelle (1998), Wilkinson (1996) nonetheless grasped the significance of the 'artefactual explanation'. Drawing on research by Rodgers (1979) he described in some detail how curvilinear relationships between income and health at the individual level would create an ('artefactual') association between income distribution and average health status at the population level (Wilkinson, 1996, pp. 102–107). Yet because the curvilinear relationships between income and health at the individual level were likely to be asymptotic, Wilkinson (1996) argued that they could not explain the strong associations between income inequality and average health status at the population level, which he (and others) had found amongst *high-income* countries. He believed that the high incomes of individuals living *within* these countries should place them close to the asymptote of any individual-level relationships between income and health, where a shallower slope would ensure that income distribution had little (if any) 'artefactual' effect on average health status (just like population C in Fig. 2). Wilkinson's (1996) argument was based on analyses of average income ('income per capita') and average health status (life expectancy) in high-, middle- and low-income countries (Fig. 3.1, p. 34) which generated similar curvilinear asymptotic relationships at the *population* level to that proposed in Fig. 1 between income and health at the *individual* level. Wilkinson (1996) pointed out that these asymptotic relationships (Fig. 3.1, p. 34) flattened off at higher (average) incomes, and by restricting his analysis to 23 OECD countries he demonstrated there was no evidence of a statistically significant association (curvilinear or otherwise) between average income (GDP per capita at purchasing power parity) and average health status (life expectancy) amongst these high-income countries (Fig. 5.2, p. 74).

Wilkinson (1996) interpreted the absence of a curvilinear relationship between average income and average health status at the population level *across* high-income countries as evidence that curvilinear relationships between income and health did not exist at the individual level *within* high-income countries. He, therefore, concluded there was no basis upon which (non-existent) curvilinear relationships between income and health at the individual level could explain the statistically significant associations he observed between various measures of income inequality and life expectancy amongst 9 'developed' (Fig. 5.3, p. 76) and 11 OECD countries (Fig. 5.6, p. 84). Believing the 'artefactual explanation' did not apply to high-income countries encouraged Wilkinson (1996) to interpret these *population-level* associations between income inequality and average health status as evidence that income inequality had a deleterious (ecological) effect on health at the *individual* level.

While Wilkinson's (1996, 1998b, 1999b) reasoning might appear sound, confining his analysis to 23 OECD countries (Fig. 5.2, p. 74) limited his ability to predict the underlying relationships between income and health amongst those individuals with lower (and higher) incomes than the average incomes of the poorest (and wealthiest) countries. Indeed, if the underlying relationships between income and health at the individual level *are* curvilinear, extrapolating from population-level to individual-level relationships between income and health would be an ecological fallacy, because average health status at the population level would be the *product* of average income *and* income distribution (Gravelle, 1998). For these reasons, Wilkinson's (1996) reliance on population-level analyses (between average income and average health status), to predict the impact of individual-level relationships (between individual income and individual health) on the association between income inequality and average health status at the population level, undermined the validity of the relative income hypothesis on two counts. The relationship between average income and average health status at the population level will only *approximate* the relationship between income and health at the individual level: (i) for those individuals whose incomes are the same as the average incomes of the populations examined; and (ii) if income distribution has no effect on average health status.

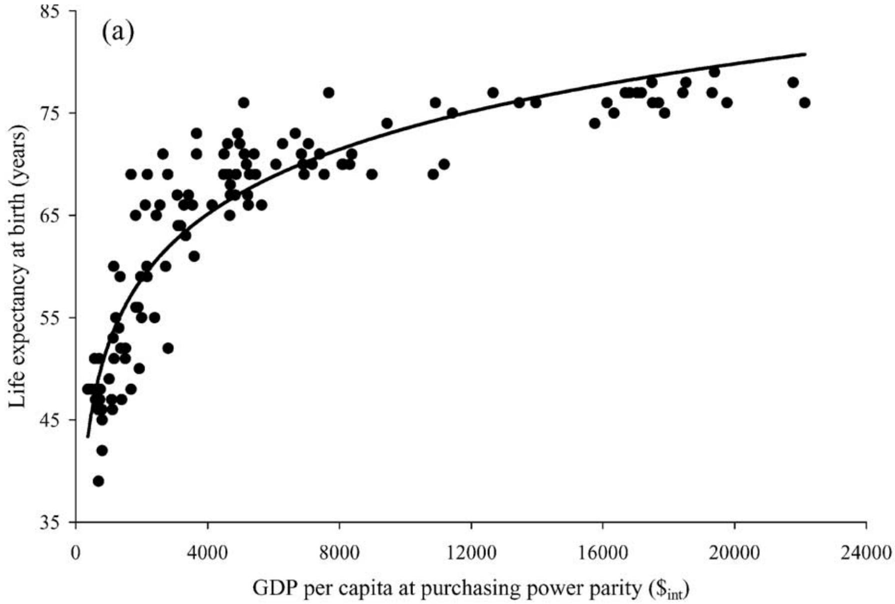
To demonstrate why each of these points undermines the reasoning behind the relative income hypothesis, it is worth repeating Wilkinson's (1996) analysis using similar, population-level data. The analyses that follow use data on life expectancy and gross domestic product (GDP) per capita at purchasing power parity in international \$ ($\$_{int}$) for 1991 amongst 120 countries covered by the 1993 *World Development Report* (World Bank, 1993, Table 1, pp. 238–239, Table 30, pp. 296–297). For 80 of these countries, 8 comparable measures of income inequality were obtained from the 1998/99 *World Development Report* (World Bank, 1999; Table 5, pp. 198–199) for income or expenditure surveys conducted up to five years either side of 1991 (i.e. between 1986 and 1996). These measures comprised the percentage share of income/consumption received/consumed by the lowest 10% (S10), 20% (S20), 40% (S40), 60% (S60), 80% (S80), and highest 10% (TOP10) and 20% (TOP20) of each population, as well as Gini coefficients (GINI) of income/consumption distribution.

Despite considerable variation in life expectancy across the whole range of GDP, the relationship between average income (GDP) and average health status (life expectancy) amongst the 120 countries examined does appear curvilinear and asymptotic (see Fig. 3(a)). Indeed, a linear regression between untransformed GDP and life expectancy explained just 56.3% of the adjusted variance in life expectancy, while a curvilinear Log_{10}-linear regression provided a better statistical fit between $\text{Log}_{10}\,\text{GDP}$ and life expectancy (adjusted $r^2 = 83.2\%$) than any of the nine other models tested (see Table 1). This Log_{10}-linear population-level relationship is very similar to those observed by Wilkinson (1996; Fig. 3.1, p. 34) and closely resembles the theoretical relationship between income and health at the individual level proposed in Fig. 1. If, as Wilkinson (1996) assumed, these population-level Log_{10}-linear relationships (Wilkinson, 1996; Fig. 3.1, p. 34 and Fig. 3(a) here), between average income and average health status *across* countries, reflect the individual-level relationships, between income and health, *within* countries, they lend themselves to his argument (Wilkinson, 1996, 1998b, 1999b) that the high incomes of individuals living in the wealthiest countries place them close to the asymptote of any individual-level relationships between income and health, where a shallower slope ensures that income distribution has little (if any) 'artefactual' effect on average health status (just like population C in Fig. 2). This is clearer still when countries classified as high- ($n = 22$), middle- ($n = 61$) and low-income ($n = 37$) economies (according to World Bank criteria; World Bank, 1993, Table 1, pp. 238–239) are analysed separately (see Table 2 and Fig. 3b). As expected, the slope of the regressions between GDP and life expectancy were steeper amongst low- and middle-income countries than amongst high-income countries (see Table 2). Whilst a linear regression provided a better statistical fit between GDP and life expectancy amongst low-income countries, and a Log_{10}-linear regression provided a better statistical fit between GDP and life expectancy amongst middle-income countries, neither regression was statistically significant amongst high-income countries (see Table 2). This is precisely what Wilkinson (1996) found in his comparable analysis of 23 OECD countries (Fig. 5.2, p. 74). However, neither of these population-level analyses provide a true reflection of the underlying relationships between income and health at the individual level *within* high-income countries. At best they only reflect the relationships between income and health for those individuals whose incomes fall within the range of average incomes (i.e. GDP per capita) of the countries examined (see (i) above).

To provide a better indication of what relationships exist between income and health at the individual level it would be necessary to include data for individuals across the full range of income—particularly those with lower-than-average incomes, whose disproportionately worse health would have a greater impact on average health status. Given that the official European Community Poverty Line is defined as '50% of the average equivalent household disposable income', and since 6.6% to 23.2% of households in each of the 15 historically high-income countries examined by the Luxembourg Income Study (LIS, 1999) between 1989 and 1992 had equivalised incomes below this level, 50% GDP should provide a conservative estimate of equalised incomes amongst the poor in each of these

Table 1
Zero-order linear and curvilinear estimation of the relationship between life expectancy at birth (Y) and GDP per capita in 1991 (X) amongst 120 high-, middle- and low-income countries

Model	Adjusted r^2
Linear (life expectancy $= b_0 + \{b_1\,\text{GDP}\}$):	56.3%
Logarithmic (life expectancy $= b_0 + \{b_1\,\text{Log}_{10}\,\text{GDP}\}$):	83.2%
Inverse (life expectancy $= b_0 + \{b_1/\text{GDP}\}$):	70.5%
Quadratic (life expectancy $= b_0 + \{b_1\,\text{GDP}\} + \{b_2\,\text{GDP}^2\}$):	76.7%
Cubic (life expectancy $= b_0 + \{b_1\,\text{GDP}\} + \{b_2\,\text{GDP}^2\} + \{b_3\,\text{GDP}^3\}$):	82.9%
Power (life expectancy $= b_0\,\{\text{GDP}^{b_1}\}$):	80.7%
Compound (life expectancy $= b_0\,\{b_1^{\text{GDP}}\}$):	51.2%
S curve (life expectancy $= e^{b_0 + b_1/\text{GDP}}$):	72.2%
Growth (life expectancy $= e^{b_0 + b_1\,\text{GDP}}$):	51.2%
Exponential (life expectancy $= b_0\,e^{b_1\,\text{GDP}}$):	51.2%



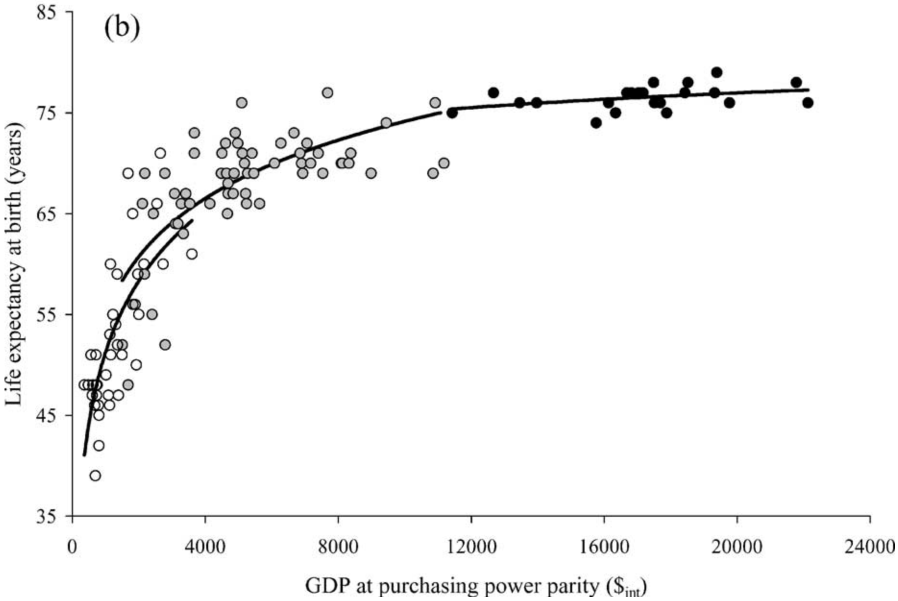


Fig. 3. Scatterplots of life expectancy at birth against GDP per capita at purchasing power parity in 1991 with zero-order Log_{10}-linear regressions superimposed thereon for (a) all 120 high-, middle- and low-income countries combined; and (b) 22 high- (●), 61 middle- (◎) and 37 low-income countries (O) separately.

countries. Assuming that the life expectancy of individuals on these lower-than-average incomes is similar to that experienced by poorer *countries* with similar (average) incomes, including population-level data from these populations should provide a clearer indication of what relationships exist between income and health at the *individual* level within high-income countries. This analysis is included in the final column of Table 2, which includes data from 22 high-income countries and 20 middle-income countries whose GDP per capita was ≥50% of the poorest high-income country (Ireland, 50% GDP = $\$_{int}5715$). Amongst these 42 countries, there was clear evidence of a statistically significant relationship between GDP and life expectancy (see Table 2), while a Log_{10}-linear regression provided a marginally better statistical fit between GDP and life expectancy (adjusted $r^2 = 64.7\%$) than a linear regression (adjusted $r^2 = 64.2\%$).

Table 2
Separate zero-order linear and Log_{10}-linear regressions between life expectancy at birth and GDP per capita in 1991 amongst 22 high-, 61 middle- and 37 low-income countries (World Bank 1993), and 42 high- and middle-income countries whose GDP $\geqslant \$_{int}5715$

	High-income	Middle-income	Low-income	GDP $\geqslant \$_{int}5715$
GDP (B(SEM)):	1.76×10^{-4}(0.00)	1.43×10^{-3}(0.00)[a]	7.57×10^{-3}(0.00)[a]	5.12×10^{-4} (0.00)[a]
Adjusted r^2:	11.3%	34.5%	54.3%	64.2%
Log_{10} GDP (B(SEM)):	6.59(3.45)	19.22(2.50)[a]	23.55(3.64)[a]	14.33(1.64)[a]
Adjusted r^2:	11.2%	49.2%	53.2%	64.7%

[a] $P<0.001$.

Notwithstanding the assumption that individuals living on the poverty line in high-income countries have the same life expectancy as poorer *populations* with the same (average) incomes, these analyses suggest that the relationships between income and health at the individual level may also be curvilinear within high-income countries. Indeed, since the very poorest individuals in these high-income countries are likely to have incomes (and associated life expectancies) that are even lower than $\$_{int}5715$, the curvilinear relationships between income and health at an individual level within high-income countries may well be even steeper. Under these circumstances, the 'artefactual explanation' would account for at least some part of the association between income inequality and average health status across high-income countries, on which the relative income hypothesis depends.

If, however, the underlying relationships between income and health at the individual level within high-income countries *are* curvilinear, analyses of average income and average health status at the *population* level would only provide, at very best, a crude approximation of any underlying, *individual-level* relationships (see (ii) above). This is because the average health status observed at the population level would depend not only on average income, but also on income inequality within each country (compare $\bar{S}_o$ and $\bar{S}_p$ in Fig. 2). Indeed, provided the curvilinear relationships between income and health at the individual level are also asymptotic, any given level of income inequality would create steeper relationships between (average) income and (average) health status at the population level than any underlying individual-level relationships (see (ii) in the previous section). This is because the lower incomes of individuals living in poorer countries would fall further away from the asymptote of any individual-level relationships between income and health, where a steeper slope would exacerbate the impact of income inequality on average health status, causing a greater decline in average health status amongst poorer countries (compare populations B and C in Fig. 2).

In fact, amongst the 80 countries with available data, there was substantial variation in income inequality, with Gini coefficients (GINI) ranging from under 25 (in Denmark, Austria and Belarus) to more than 60 (in Brazil and Sierra Leone). There was also a tendency for income inequality to be higher in countries with lower GDP, even after controlling for the type of income/consumption distribution survey conducted (i.e. income vs. expenditure), which tends to distort the estimates of income inequality obtained (World Bank, 1997, p. 254). This tendency would further increase the slope of the curvilinear relationship between average income and average health status at the population level, over and above any disproportionate effect of income inequality on average health status in poorer countries.

To provide a more accurate picture of the underlying relationships between income and health at the individual level using population-level data, it is therefore necessary to control not only for differences in income inequality between different countries (which differentially affect their average health status), but also for the *interaction* between income inequality and average income, (since income inequality has a disproportionate impact on the average health status of poorer countries). Applying this approach to the 80 countries with available data on income inequality, Table 3 also summarises the predicted life expectancy at four levels of income ($\$_{int}500$, $\$_{int}5000$, $\$_{int}10\,000$, $\$_{int}20\,000$) across the full range of GDP, using 8 multivariate analyses each containing a different measure of income inequality. For all but one measure of income inequality (S80), there was a significant and negative independent relationship between income inequality and life expectancy, suggesting, once again, that increases in income inequality are associated with a decline in average health status. As predicted (under (ii) in the previous section), the interaction between income inequality and GDP had a significant and positive association with life expectancy, such that income inequality had a less negative effect on residual differences in average health status amongst wealthier countries. For each measure of income inequality, the difference in life expectancy predicted by Log_{10}GDP and survey type alone and that predicted by Log_{10}GDP, survey type, income inequality and the interaction (between income inequality and

Table 3

Multiple Log_{10}-linear regressions of life expectancy at birth against GDP per capita in 1991 amongst 80 high-, middle- and low-income countries, with life expectancy predicted over a range of GDP ($\$_{int}500$ to $\$_{int}20\,000$) by eight different models, each containing a different measure of income inequality, after controlling for the type of survey conducted (income vs. expenditure), income inequality and the interaction between income inequality and GDP

	Income inequality measure[a]								
B(SEM)	None	1/S10	1/S20	1/S40	1/S60	1/S80	TOP20	TOP10	GINI
Survey type: (income vs. expenditure)[b]	3.30(1.28)[c]	3.35(1.21)[d]	3.21(1.23)[c]	3.13(1.23)[c]	3.19(1.23)[c]	3.18(1.28)[c]	3.32(1.22)[d]	3.27(1.23)[d]	3.38(1.22)[d]
Log_{10}GDP:	18.24(1.52)[e]	13.01(1.86)[e]	13.14(1.99)[e]	12.40(2.45)[e]	−2.22(6.63)	5.60(17.22)	−2.08(6.51)	4.42(4.89)	4.57(4.43)
Inequality: (income or expenditure)	—	−34.77(8.97)[e]	−98.57(29.20)[d]	−211.78(75.81)[d]	−1114.43(353.37)[d]	−849.51(1346.07)	−1.64(0.51)[d]	−1.73(0.58)[d]	−1.32(0.40)[d]
Interaction: (Log_{10}GDP × inequality)	—	9.76(2.68)[e]	28.40(8.98)[d]	64.08(24.56)[c]	318.10(99.85)[d]	292.39(380.25)	0.46(0.14)[d]	0.49(0.16)[d]	0.37(0.11)[d]
Adjusted r^2:	82.1%	85.1%	84.4%	83.7%	83.8%	82.2%	83.9%	83.7%	84.0%
Life expectancy predicted at									
GDP = $\$_{int}500$:	48.7	49.1	48.7	48.3	48.0	47.8	47.8	47.9	48.2
GDP = $\$_{int}5000$:	66.9	67.4	67.4	67.5	67.7	67.1	67.2	67.6	67.5
GDP = $\$_{int}10\,000$:	72.4	72.9	73.1	73.3	73.6	72.9	73.0	73.6	73.3
GDP = $\$_{int}20\,000$:	77.9	78.5	78.7	79.0	79.6	78.7	78.8	79.5	79.1

[a] For the 80 countries included in these analyses S10, S20, S40, S60 and S80 were all inversely related to income inequality, while TOP20, TOP10 and GINI were all directly related to income inequality. To facilitate the interpretation of any relationships between different measures of income inequality and average health status, the first five measures were transformed by calculating their reciprocal values (i.e. 1/S10, 1/S20, 1/S40, 1/S60 and 1/S80) prior to analysis.

[b] A dummy variable for survey type (income = 1, expenditure = 0) was included to control for systematic differences in estimates of income inequality calculated from surveys of income and those calculated from surveys of expenditure (see World Bank, 1997, pp. 254).

[c] $P < 0.05$.

[d] $P < 0.01$.

[e] $P < 0.001$.

$Log_{10}GDP$), *increased* as GDP rose from $\$_{int}500$, through $\$_{int}5000$ and $\$_{int}10\,000$ to $\$_{int}20\,000$ (see Table 3). Controlling for income inequality as well as the interaction between income inequality and average income, therefore *increased* the slope of the residual curvilinear relationship between GDP and life expectancy. Together, these findings suggest that the underlying relationships between income and health at the *individual* level are not only curvilinear and asymptotic, but also steeper than that observed in Fig. 3 at the *population* level. If so, the 'artefactual explanation' would account for an even greater part of the association between income inequality and average health status at the population level, since a steeper curvilinear relationship between income and health at the individual level would accentuate the ('artefactual') association between income inequality and average health status at the population level (compare populations B and C in Fig. 2, and see also point (ii) in the section *Does the 'artefactual explanation' necessarily invalidate the relative income hypothesis?* below).

To recap each of the points made above, Wilkinson's (1996; Fig. 3.1, p. 34) use of population-level data to falsify the 'artefactual explanation' for the association between income inequality and average health status at the population level amongst high-income countries is flawed on two counts:

(i) By analysing data from high-, middle- and low-income countries separately, the analyses presented in Table 2 and summarised in Fig. 3(b) also found little evidence of a statistical relationship between average income and average health status amongst high-income countries. However, assuming that the life expectancy of individuals on lower-than-average incomes within these high-income countries is similar to that experienced by poorer *populations* (such as those in middle-income countries) with similar (average) incomes, the analysis presented in the final column of Table 2 suggests that even population-level data provide evidence of statistically significant curvilinear relationships at the individual level *within* high-income countries.

(ii) By adjusting for income inequality and the interaction between income inequality and average income, the analyses presented in Table 3 provide a better indication of any underlying relationships between income and health at the individual level than the zero-order associations between GDP and life expectancy presented in Tables 1 and 2. These multivariate analyses suggest that the individual-level relationships are likely to be curvilinear and asymptotic, and appear to be even steeper than that observed between average income and average health status at the population level (i.e. Fig. 3).

If these analyses of population-level data better reflect the true shape of the individual-level relationships between income and health within high-income countries, it is possible that the 'artefactual explanation' might wholly account for the statistical association between income inequality and average health status at the population level, on which the relative income hypothesis depends.

Does the 'artefactual explanation' necessarily invalidate the relative income hypothesis?

Where do the analyses presented in the previous sections leave the relative income hypothesis? Might there be more to the statistical association between income inequality and average health status at the population level than simply a statistical artefact? Given the empirical evidence of curvilinear relationships between income and health at the individual level in a variety of high-income countries (Backlund et al., 1996; Ecob & Davey Smith, 1999; Ellison, 1999b; Wolfson et al., 1999), Gravelle's (1998) 'artefactual explanation' would surely account for at least some part of the statistical associations between income inequality and average health status at the population level, amongst these (if not all) high-income countries. However, the 'artefactual explanation' does not rule out the possibility that income inequality *also* has an independent effect on individual health (and thereby average health status at the population level), just as the relative income hypothesis suggests. Indeed, there are three possible scenarios under which the relative income hypothesis might be partly or wholly responsible for the statistical association between income inequality and average health status at the population level:

(i) If income inequality at the population level has a deleterious effect on the health of either rich and/or poor individuals, then the average height of any relationships (curvilinear or otherwise) between income and health at the individual level would be lower in less egalitarian populations.

(ii) If income inequality at the population level has a deleterious effect on the health of poor individuals, with or without a beneficial effect on the health of rich individuals, then the curvilinear relationships between income and health at the individual level would be steeper in less egalitarian populations.

(iii) If income inequality at the population level has an increasingly deleterious effect on the health of poor individuals, such that their health gets progressively worse as income declines, then the curvilinearity of individual-level relationships between income and health would be more pronounced in less egalitarian populations.

The important distinction between these three possible scenarios is that under the first, income inequality at the population level would have an independent effect on individual *and* population health, whatever the shape of the relationships between income and health at the individual level. Under the second, income inequality would accentuate the ('artefactual') effect of existing curvilinear relationships between income and health at the individual level on the association between income inequality and health at the population level. Under the third, income inequality at the population level might ultimately be responsible for the curvilinear nature of the relationships between income and health at the individual level, and thereby the ('artefactual') statistical association between income inequality and average health status at the population level.

Evidence that one or more of these three scenarios are partly responsible for the association between income inequality and average health status at the population level might take the form of associations between income inequality (at the population level) and the average height, slope and/or curvilinearity of relationships between income and health (at the individual level). Indeed, if any of these associations predicted maximal, flat and/or (*non*-curvi)linear relationships between income and health in absolutely egalitarian populations (i.e. those with no inequalities in income), it would suggest that the scenarios concerned were wholly responsible for the ('artefactual') association between income inequality and average health status at the population level. However, even if there were no associations between income inequality at the population level and the average height, slope and/or curvilinearity of the relationship between income and health at the individual level, it would still be possible for the third scenario to be wholly responsible for the association between income inequality and average health status at the population level. This possibility would arise if *any* level of income inequality (other than absolute equality) imposed *exactly the same* curvilinear relationship between income and health at the individual level (along the lines of those in Figs. 1 or 2) on each population. In this instance, the curvilinearity of the (identical) relationships between income and health at the individual level would be sufficient to create an (ostensibly 'artefactual') association between income inequality and average health status at the population level (as demonstrated by populations A and B in Fig. 2).

This possibility aside, none of the three scenarios are necessarily mutually exclusive and all are capable of turning the 'artefactual explanation' on its head. They are all circumstances in which the average height, slope and/or curvilinearity of the relationships between income and health at the individual level would be, either partly or wholly, an 'artefact' of income inequality at the population level. To illustrate this, the six models ((a)–(f)) in Fig. 4 demonstrate how differences in income inequality between two hypothetical populations (A and B) affect the average height ((a)–(c) and (f)), slope ((c), (d) and (f)) and curvilinearity ((e) and (f)) of the relationships between income and health at the individual level. In (a)–(c), the curvilinearity of these individual-level relationships is the same for both population A and B, while the average height of the relationship decreases with increasing inequality (from A to B) as a result of a decline in the health of both rich and poor individuals (a) or rich (b) and poor (c) individuals alone (i.e. scenario (i) above). In (c) and (d) the curvilinearity of these individual-level relationships is also the same for both populations, while their slope increases with increasing inequality (from A to B) as a result of a deleterious effect of inequality on the health of poor individuals with (d), or without (c), a beneficial effect on the health of rich individuals (i.e. scenario (ii) above). In (e), the curvilinearity of the relationship between income and health at the individual level increases with increasing inequality (from A to B; as in scenario (i) above). Finally, (f) demonstrates a combination of these effects with a decrease in the average height, an increase in the slope and an increase in the curvilinearity of the relationship between income and health at the individual level as income inequality increases (from A to B). In each model, income inequality is associated with changes in the average height ((a)–(c) and (f)), slope ((c), (d) and (f)) and/or curvilinearity ((e) and (f)), of the individual-level relationships between income and health in such a way that leads to a decline in average health status along the lines suggested in each of the scenarios (above):

(i) By decreasing the average height of the individual-level relationships between income and health in (a)–(c) and (f), an increase in income inequality reduces the health of all (bar the poorest (b) or richest (c)) individuals in population B;
(ii) By increasing the slope of the individual-level relationships between income and health in (c), (d) and (f), an increase in income inequality further accentuates the disproportionate impact of poverty on the health of the poorest individuals in population B.
(iii) By increasing the curvilinearity of the individual-level relationships between income and health in (e) and (f), an increase in income inequality exacerbates the effect of disparities in income between rich and poor on the average health status of population B.

Is there any empirical evidence for the type of effects described in Fig. 4? Population-level analyses provide some grounds for speculation. For example, Wolfson et al. (1999) found a strong residual association between income inequality and average health status amongst 50 US States, even after controlling for the 'artefactual'

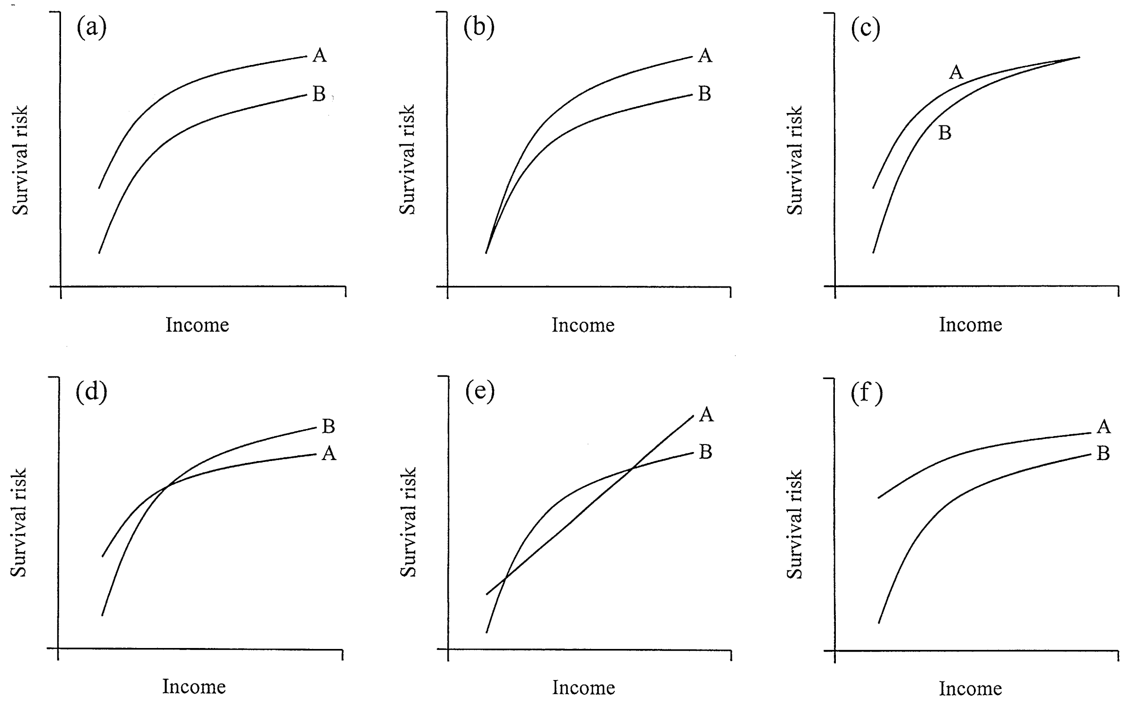


Fig. 4. Hypothetical scenarios in which an increase in income inequality at the population level (from population A to population B) is associated with a decrease in the average height ((a)–(c)), an increase in the slope ((c) and (d)) and an increase in the curvilinearity ((e)) of their individual-level relationships between income and health. A combination of these effects can be observed in (f), with a decrease in the average height, an increase in the slope and an increase in the curvilinearity of the relationship between income and health at the individual level as income inequality increases (from A to B).

effect of the curvilinear relationship between income and health at the individual level across the US as a whole. This could be interpreted as evidence that the average height, slope and/or curvilinearity of the individual-level relationships between income and health vary from one State to the next, in such a way that create and/or accentuate the ('artefactual') association between income inequality and average health status across different States. A similar interpretation could be applied to variation in the strength of the association between different measures of income inequality and average health status across different US States (Kawachi & Kennedy, 1997; Daly et al., 1998) and different high-income countries (Saunders, 1996; Ellison, 1998; Judge, 1995; Judge et al., 1998). Since different measures of income inequality are sensitive to different characteristics of the relationships between income and health at the individual level (Kawachi & Kennedy, 1997; Daly et al., 1998), variation in the strength of the population-level association between average health status and different measures of income inequality could reflect variation in the individual-level relationships between income and health. This seems to run contrary to Gravelle's (1998) assertion that the 'artefactual explanation' should not "depend on the shapes of the income distributions or on using a particular measure of income distribution" (p. 383). Yet this assertion was based on a mathematical demonstration which assumed (for simplicity's sake) that improvements in health continued to decline at a similar rate across the full range of income (i.e. a quadratic function), and that the same curvilinear relationship (between income and health at the individual level) applied across all populations. Neither of these assumptions are necessarily valid, and variation in the nature of the individual-level relationships between income and health within different populations might explain why the strength of population-level associations between income inequality and average health status depend on the measure of income inequality used.

Such speculation is as far as population-level data can take the debate (Gravelle, 1999). Firm evidence that income inequality is associated with changes in the average height, slope and/or curvilinearity of the relationships between income and health at the individual level (along the lines suggested in scenarios (i), (ii) and/or (iii)) requires cross-sectional analyses of individual-level data from populations with different levels of income inequality or, better still, longitudinal analyses of individual-level data from populations experiencing changes in income inequality over time. This is no easy task, given the paucity of comprehensive or representative surveys with comparable data on income and health at the individual level in high-income countries. Indeed, the lower and shallower relationships between occupational class and mortality in ('egalitarian') Sweden compared to those in ('unequal') Britain, described by Vagerö and Lundberg (1989) and Leon et al. (1992), may simply reflect the differential exclusion of economically inactive individuals from each population (Martikainen & Valkonen, 1999). Nevertheless, broadly representative samples from high-income countries do suggest that the height, slope and/or curvilinearity of the relationship between income and health at the individual level depend not only on the measures of 'income' and 'health' used (compare Backlund et al. (1996) with Wolfson et al. (1999), and Ecob and Davey Smith (1999) with Der et al. (1999)), but also on the population(s) examined (Ellison, 1999c). It remains to be seen whether income inequality is responsible for changes in the nature of this relationship that lead to, and/or accentuate, the ('artefactual') association between income inequality and average health status at the population level. If it does, the 'artefactual explanation' might simply be a 'statistical artefact' of the relative income hypothesis.

Summary

Provided the cost–benefit ratio of health-enhancing goods and services vary, the law of diminishing returns should create curvilinear asymptotic relationships between income and health at the individual level, in which improvements in health decline as incomes increase. Under these circumstances, the ill-effects of lower-than-average incomes would outweigh the comparatively modest benefits of higher-than-average incomes. Disparities in income between rich and poor (i.e. income inequality) would therefore lead to a decline in average health status and an ('artefactual') association between income inequality and average health status at the population level. This 'artefactual explanation' for the association between income inequality and average health status at the population level poses a serious challenge to the relative income hypothesis, which interprets the association as evidence that income inequality has a deleterious psychosocial effect on individual health.

However, proponents of the relative income hypothesis argue that a curvilinear asymptotic relationship between income and health at the individual level could not be responsible for creating an entirely 'artefactual' association between income inequality and average health status at the population level amongst those high-income populations whose individual incomes fall on the shallowest part of the curve, close to the asymptote, where income inequality should have little, if any, 'artefactual' effect on average health status. Indeed, at the population level, there is no evidence of a statistically significant relationship (curvilinear or otherwise) between average income and average health status amongst high-income countries. Yet the absence of a population-level relationship between average income and average health status amongst high-income countries does not necessarily mean that there are no underlying curvilinear relationships between income and health at the individual level therein. Even if the average incomes of high-income countries do fall close to the asymptote, on the shallowest part of any relationships between income and health at the individual level, a substantial proportion of their populations live below the official poverty line, with incomes less than half the average. Provided the income of at least some of these individuals falls further away from the asymptote, on a steeper part of the individual-level curvilinear relationships between income and health, their disproportionately poorer health would lead to a decline in average health status and an ('artefactual') association between income inequality and average health status at the population level. This is evident from population-level analyses that combine data from high-income countries with those from selected middle-income countries, whose average incomes are equivalent to the incomes of individuals living on or below the poverty line in high-income countries. These analyses suggest that a significant curvilinear relationship does exist between income and health across the wider range of incomes found *within* high-income countries. Furthermore, controlling for the ('artefactual') effect of income inequality on average health status at the population level suggests that the underlying relationships between income and health at the individual level are steeper than that observed between average income and average health status at the population level. If these population-level analyses accurately reflect the individual-level relationships between income and health within high-income populations, the 'artefactual explanation' would be responsible for at least some part of the statistical association between income inequality and average health status at the population level, on which the relative income hypothesis depends.

Nevertheless, the 'artefactual explanation' for the association between income inequality and average health status at the population level may not be incompatible with the explanation(s) offered by the relative income hypothesis. If disparities in income between rich and poor are somehow responsible for creating curvilinear relationships between income and health at the individual level, and/or altering the nature of these relationships in such a way that income inequality has an independent effect on individual health, the 'artefactual explanation' would simply describe the underlying *mechanism* behind the relative income hypothesis. There is certainly ample evidence that the height, slope and curvilinearity of the individual-level relationship between income and health varies from one high-income country to the next. It remains to be seen whether income inequality is responsible for changes in the nature of these relationships that lead to, and/or accentuate, the ('artefactual') association between income inequality and average health status at the population level.

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Appendix

Suppose that the individual-level relationship between income and survival risk is denoted by $S(I)$ and the average population income is denoted by $\imath$. If a constant a were subtracted from the income of *all* individuals, it would shift the distribution of income to the left without altering the absolute difference in income between rich and poor, or the nature of the individual-level relationship between income and survival risk. Under these circumstances, the survival risk of any individual(s) with an average income would be $S(\imath - a)$, while the average survival risk of the population would be $ES(I - a)$, where E is the expectation operator. Let $S'(I - a)$ be the first derivative of S with respect to income, so that the decrease in average survival risk caused by a decrease in income of a would be $ES'(I - a)$, while the equivalent decrease in the survival risk of any individual(s) with an average income would be $S'(\imath - a)$. Provided the relationship between income and survival risk at the individual level is monotonically increasing and asymptotic (as in the curvilinear asymptotic model proposed in Fig. 1 and that based on the population-level relationships observed by Wilkinson, 1996; Fig. 3.1, p. 34), the third derivative (S''') would be positive. The decline in average survival risk (at the population level, $ES'(I - a)$) would therefore exceed that observed amongst any individual(s) with an average income ($S'(\imath - a)$). If, however, the individual-level relationships are *not* monotonically increasing nor asymptotic, (as in, for example, the quadratic model Gravelle (1998) used to illustrate the 'artefactual explanation'), S''' could be (either positive or) negative, in which case the population-level relationship between (average) survival risk and (average) income would have a similar slope to that at the individual level.

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