Childhood forecasting of a small segment of the population with large economic burden

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Policymakers are interested in early-years interventions to ameliorate childhood risks. They hope for improved adult outcomes in the long run that bring a return on investment. The size of the return that can be expected partly depends on how strongly childhood risks forecast adult outcomes, but there is disagreement about whether childhood determines adulthood. We integrated multiple nationwide administrative databases and electronic medical records with the four-decade-long Dunedin birth cohort study to test child-to-adult prediction in a different way, using a population-segmentation approach. A segment comprising 22% of the cohort accounted for 36% of the cohort's injury insurance claims; 40% of excess obese kilograms; 54% of cigarettes smoked; 57% of hospital nights; 66% of welfare benefits; 77% of fatherless child-rearing; 78% of prescription fills; and 81% of criminal convictions. Childhood risks, including poor brain health at three years of age, predicted this segment with large effect sizes. Early-years interventions that are effective for this population segment could yield very large returns on investment.

Around the world, the population is ageing and total fertility rates are declining. As a result, nations increasingly view children and young people as valuable resources for the economic and social well-being of whole societies. This view is accompanied by public-policy interest in early interventions to help as many children as possible achieve their full potential. A key question concerns the potential size of the impact that might be brought about by interventions in the early years of children's lives[1,2]. Research teams that have followed up on small samples of children who were enrolled in intervention experiments carried out decades ago point to reductions in school leaving, unemployment, crime, obesity and even blood pressure[3–6]. Some argue that today's better-designed interventions might achieve greater reductions in adult problems than previous efforts[7] (see also www.nuffieldfoundation.org, www.blueprintsprograms.com, http://ies.ed.gov/ncee/wwc and http://incredibleyears.com). Others assert that interventions for the youngest children will bring an even greater return on investment compared with interventions that begin when children are older[8]. However, a skeptic could point out that return on investment for society will depend not only on an intervention's capacity to ameliorate childhood risks, but also on how relevant those risks are for downstream adult functioning in the general population. Thus, to a large extent, the question of how much early-years intervention can lift health and social well-being and reduce costs depends on how strongly early-years risk factors are tied to adult outcomes in the population. Our own research and that of others suggests that while childhood risk factors do predict adult outcomes with statistical significance, the effect sizes are typically modest[9–11]. The interpretation of these modest child-to-adult effect sizes is polarizing, and has sown confusion among scientists, policy makers and the public[12–14]. On the one hand, claims are made that the 'child is father of the man', because continuity from childhood risks to adult outcomes is stronger than expected, given the long duration of follow-up.

On the other hand, on the basis of the same data, warnings are issued about the myth of early-childhood determinism and about unwarranted overemphasis on childhood.

Here, we tackled the prediction question anew in the context of the Dunedin Longitudinal Study, a population-representative 1972–1973 birth cohort of 1,037 New Zealanders assessed at ages 3, 5, 7, 9, 11, 13, 15, 18, 21, 26, 32 and 38 years and followed from birth to midlife with 95% retention (Supplementary Information). We first integrated our longitudinal survey data and clinical data with multiple nationwide government administrative databases and electronic medical records. Then, using a novel segmentation approach, we tested the hypothesis that a small segment of the adult population accounts for a large cumulative economic burden and that this segment can be predicted with good accuracy from early childhood.

Results

Throughout the cohort's childhood, during the first decade of life, we measured risk factors that are thought to augur poor adult outcomes: growing up in a socioeconomically deprived family, exposure to maltreatment, low IQ and poor self-control. We report these four risk factors here because they are proven predictors of adult health and social outcomes and are high-priority targets in many early-years intervention programmes[15–17]. A strength of this analysis is that all childhood risk predictors were measured prospectively, unbiased by participants' knowledge of their adult outcomes.

At the most recent follow-up assessment when the cohort reached 38 years of age, roughly the midpoint in the human lifespan, we drew on personal interviews and on New Zealand's multiple nationwide administrative databases and electronic medical records to ascertain the cumulative distributions of economically burdensome outcomes in eight social and health sectors. These outcomes are referred to here as economically burdensome because, in each instance, these are events, behaviours and conditions that saddle society and

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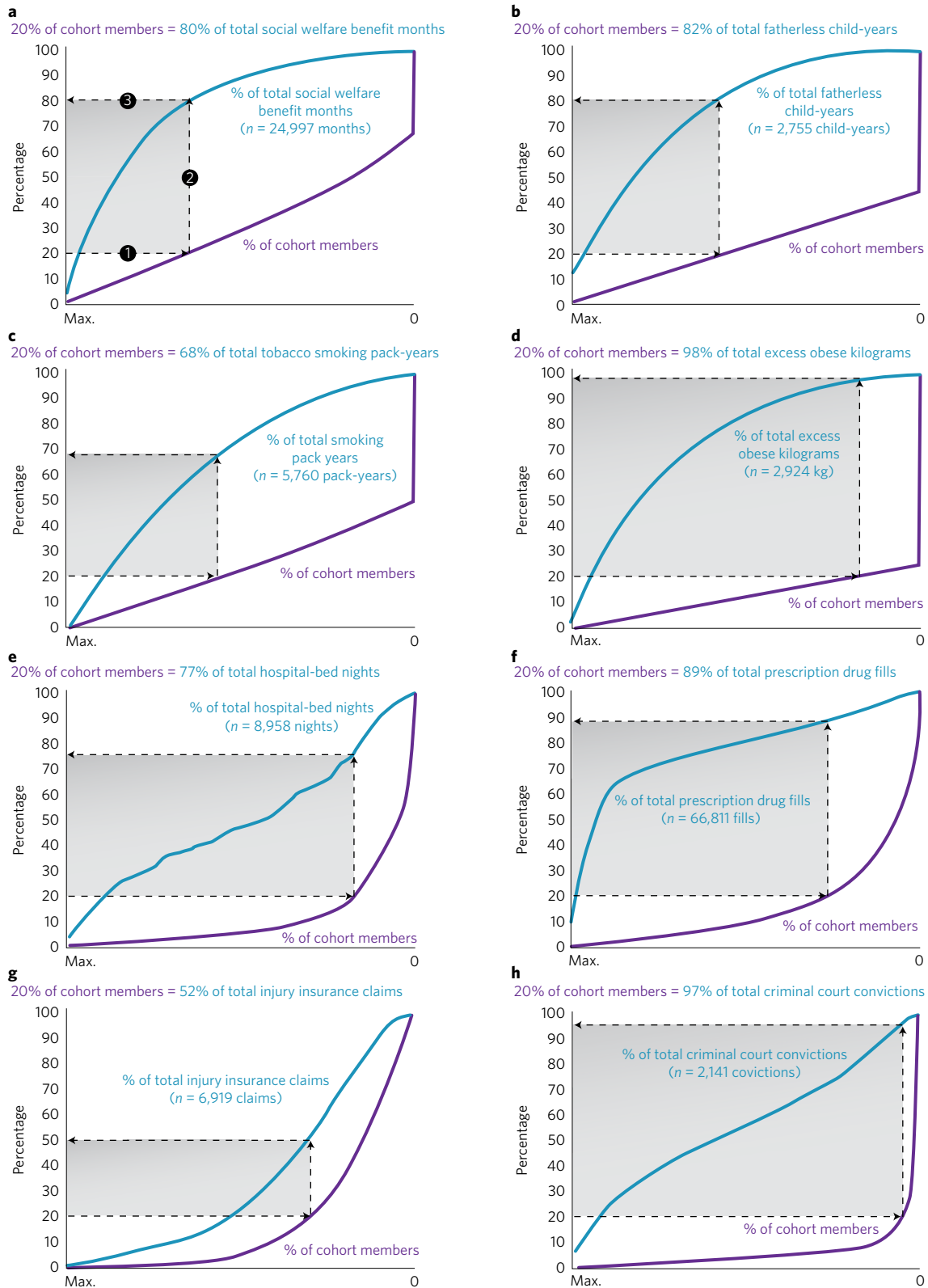
Figure 1 | Measuring the concentration of economic-burden outcomes in a birth cohort. The data represent information about 940 people who were born in one hospital in the period 1972–1973 and are lifelong participants in the Dunedin Longitudinal Study. **a**–**h**, A minority of individuals is shown to account for a majority of outcomes in a birth cohort for each of eight different social and health sectors: social welfare (**a**), fatherless children (**b**), smoking (**c**), excess obese kilograms (**d**), hospital stays (**e**), prescription fills (**f**), injury claims (**g**) and crime (**h**). Each panel displays the cumulative distribution of an outcome in the cohort. To find the proportion of each outcome that 20% of the population accounts for, start at 20% on the vertical axis and follow dashed arrow 1 to the right (to the purple line), then follow arrow 2 up to the blue line, then follow arrow 3 to the left (back to the vertical axis) to read off the corresponding proportion of the total. Each x-axis denotes the count of each respective outcome in its own units (e.g. benefit months, pack-years and so on).

Table 1 | Childhood predictors of economic-burden outcomes in a birth cohort.

High cost in each sector	Univariate models				Multivariate models			
	RR	RR 95% CI	AUC	AUC 95% CI	RR	RR 95% CI	AUC	AUC 95% CI
Social welfare*							0.78	(0.74, 0.82)
Childhood low SES	**1.47**	**(1.28, 1.69)**	0.73	(0.69, 0.77)	**1.18**	**(1.02, 1.36)**		
Child maltreatment	**1.47**	**(1.33, 1.62)**	0.74	(0.70, 0.78)	**1.31**	**(1.18, 1.46)**		
Childhood low IQ	**1.50**	**(1.37, 1.65)**	0.73	(0.69, 0.77)	**1.19**	**(1.05, 1.34)**		
Childhood low self-control	**1.51**	**(1.37, 1.65)**	0.75	(0.71, 0.79)	**1.24**	**(1.10, 1.39)**		
Fatherless children							0.67	(0.62, 0.72)
Childhood low SES	**1.39**	**(1.17, 1.65)**	0.63	(0.58, 0.68)	**1.24**	**(1.03, 1.49)**		
Child maltreatment	**1.36**	**(1.19, 1.56)**	0.63	(0.58, 0.68)	**1.26**	**(1.09, 1.46)**		
Childhood low IQ	**1.26**	**(1.09, 1.47)**	0.62	(0.56, 0.67)	1.04	(0.86, 1.26)		
Childhood low self-control	**1.33**	**(1.18, 1.50)**	0.64	(0.59, 0.69)	1.15	(0.99, 1.34)		
Smoking							0.69	(0.65, 0.74)
Childhood low SES	**1.50**	**(1.30, 1.73)**	0.64	(0.60, 0.69)	**1.29**	**(1.11, 1.50)**		
Child maltreatment	**1.34**	**(1.21, 1.49)**	0.61	(0.56, 0.66)	**1.20**	**(1.06, 1.35)**		
Childhood low IQ	**1.36**	**(1.21, 1.53)**	0.64	(0.59, 0.68)	1.08	(0.93, 1.25)		
Childhood low self-control	**1.43**	**(1.30, 1.57)**	0.65	(0.60, 0.70)	**1.21**	**(1.07, 1.37)**		
Excess weight							0.61	(0.56, 0.65)
Childhood low SES	**1.26**	**(1.11, 1.43)**	0.59	(0.55, 0.64)	**1.16**	**(1.00, 1.35)**		
Child maltreatment	**1.13**	**(1.01, 1.28)**	0.56	(0.52, 0.61)	1.09	(0.96, 1.24)		
Childhood low IQ	**1.24**	**(1.10, 1.40)**	0.58	(0.53, 0.63)	1.14	(0.97, 1.34)		
Childhood low self-control	**1.18**	**(1.06, 1.32)**	0.57	(0.52, 0.62)	1.04	(0.89, 1.20)		
Hospital stays*							0.75	(0.71, 0.79)
Childhood low SES	**1.35**	**(1.18, 1.54)**	0.74	(0.70, 0.78)	**1.23**	**(1.07, 1.43)**		
Child maltreatment	**1.14**	**(1.02, 1.29)**	0.72	(0.68, 0.76)	1.06	(0.93, 1.20)		
Childhood low IQ	**1.26**	**(1.12, 1.43)**	0.73	(0.69, 0.77)	1.09	(0.95, 1.26)		
Childhood low self-control	**1.27**	**(1.14, 1.42)**	0.74	(0.70, 0.77)	**1.15**	**(1.01, 1.32)**		
Prescription fills*							0.75	(0.71, 0.78)
Childhood low SES	**1.27**	**(1.11, 1.44)**	0.73	(0.70, 0.77)	**1.18**	**(1.03, 1.37)**		
Child maltreatment	1.10	(0.98, 1.25)	0.71	(0.67, 0.74)	1.02	(0.89, 1.17)		
Childhood low IQ	**1.30**	**(1.16, 1.45)**	0.73	(0.70, 0.77)	1.14	(0.99, 1.32)		
Childhood low self-control	**1.25**	**(1.12, 1.39)**	0.73	(0.70, 0.77)	1.11	(0.98, 1.27)		
Injury claims*							0.74	(0.71, 0.78)
Childhood low SES	**1.18**	**(1.03, 1.34)**	0.74	(0.70, 0.78)	**1.19**	**(1.02, 1.38)**		
Child maltreatment	1.03	(0.92, 1.16)	0.73	(0.69, 0.77)	0.98	(0.86, 1.12)		
Childhood low IQ	1.07	(0.95, 1.20)	0.73	(0.69, 0.77)	0.95	(0.82, 1.10)		
Childhood low self-control	**1.12**	**(1.01, 1.24)**	0.74	(0.70, 0.78)	1.09	(0.95, 1.24)		
Crime*							0.77	(0.74, 0.80)
Childhood low SES	**1.36**	**(1.22, 1.52)**	0.74	(0.70, 0.77)	**1.24**	**(1.11, 1.39)**		
Child maltreatment	**1.31**	**(1.20, 1.43)**	0.73	(0.70, 0.77)	**1.18**	**(1.07, 1.30)**		
Childhood low IQ	**1.19**	**(1.08, 1.31)**	0.72	(0.68, 0.76)	0.93	(0.83, 1.04)		
Childhood low self-control	**1.35**	**(1.25, 1.46)**	0.75	(0.71, 0.79)	**1.26**	**(1.15, 1.38)**		

The Table shows that children who grew up in socioeconomically deprived environments, who experienced child maltreatment, who scored more poorly on childhood IQ tests, and who exhibited less self-control were more likely to belong to a high-cost economic burden group as adults, in each of eight different sectors. Childhood socioeconomic status (SES), IQ and self-control are standardized z-scores (mean (M) = 0, s.d. = 1); childhood maltreatment is coded as 0 = none, 1 = probable, 2 = definite maltreatment. All models control for sex. The prediction was the same when men and women were analysed separately (see Supplementary Information for details). *Time spent outside New Zealand is added as a covariate in analyses that use New Zealand administrative data. AUC, area under the curve; CI, confidence interval; RR, risk ratio. RRs in bold are statistically significant at $P < 0.05$.

government with both direct and indirect costs. These are also the same outcomes that early-years interventions hope to reduce[18]. We predicted social welfare dependency, fatherless child-rearing (defined by the absence of the biological father from the households in which a cohort member's offspring live), tobacco smoking, excess body weight, admissions to taxpayer-funded national-health-service hospitals, taxpayer-funded prescription drug fills, taxpayer-funded insurance claims paid out for accidents and injuries, and convictions for crime (Fig. 1). Analyses tested how strongly childhood risks predicted these economically burdensome outcomes in this cohort.

Prospective longitudinal cohort studies have tackled the prediction question before[19]. Here, we draw attention to two infrequently tried approaches to prediction. Our first fresh approach was to predict the concentration of each economically burdensome behaviour

by focusing on its cumulative distribution across the cohort. Typically, prediction has focused on dimensional outcomes, such as the number of crime convictions accrued by a person, or nominal outcomes, such as whether the person is a convicted offender or not. Instead, we noted that most economically burdensome outcomes have a markedly skewed distribution, and accordingly defined our prediction target as the small group of cohort members who could be considered high-cost because they accounted for an excessive amount of an outcome (for example, a few individuals account for the majority of criminal convictions and are thus high-cost users of the criminal justice sector). To define this concentration, we followed the lead of Vilfredo Pareto who, over 100 years ago, observed that 80% of 'effects' emanate from 20% of 'sources'[20]. In Pareto's day, the problem definition was that 20% of families owned 80% of land in Italy. The so-called Pareto

principle is alive and useful today: for example, in software engineering, 20% of the code is said to contain 80% of the errors[21]. Here, we measured each outcome variable in units that could be meaningfully counted (for example, tobacco pack-years, hospital-bed nights, prescription fills, criminal convictions and so on). Such measures allowed us to identify the minority of individuals who accounted for the majority of each economically burdensome outcome.

Our second fresh approach was to predict the aggregation of different types of economically burdensome behavioural outcomes. Economic analyses of early-years interventions illustrate the advantages of estimating the costs associated with multiple outcomes[22]. However, typical approaches to prediction in population studies continue to predict only one outcome at a time. We noted that some cohort members appeared to be engaged in economically burdensome behaviour across multiple health and social sectors. This observation suggests that a relatively small population segment may generate a large share of societal costs. If this is true, this group would be a high-value target for prevention. We hypothesized that predicting such aggregated concentrations would yield stronger estimates of prediction from childhood to adulthood than reported in previous research. We analysed aggregation as the second step, after analysing concentration.

Adult outcomes were concentrated as anticipated from the Pareto principle (that is, the 80–20 rule). Cumulative distribution functions showed that in each of the eight social and health sectors where we collected data, 20% of the individuals consistently accounted for a disproportionate share (close to 80%) of the outcome (Fig. 1). These distributions led us to operationally define a high-cost group in each sector as the 20% of the cohort members who accounted for a disproportionate share in that sector.

We observed that members of the high-cost group in every sector could be differentiated from their peers by the same four childhood disadvantages: they tended to have grown up in more socioeconomically deprived environments; to have experienced child maltreatment; to have scored poorly on childhood IQ tests; and to have exhibited low childhood self-control (Table 1). The predictions were fairly uniform across each of the eight different social and health sectors with the exception of injury claims. In addition to being less concentrated within a high-cost group, injury claims were less strongly associated with childhood risk factors.

Figure 1 and Table 1 both focus on one sector at a time. However, a heat map (Fig. 2a) showed that high-cost group members in one sector were often significantly more likely to reappear as high-cost in other sectors too, and that the observed distribution of high-cost
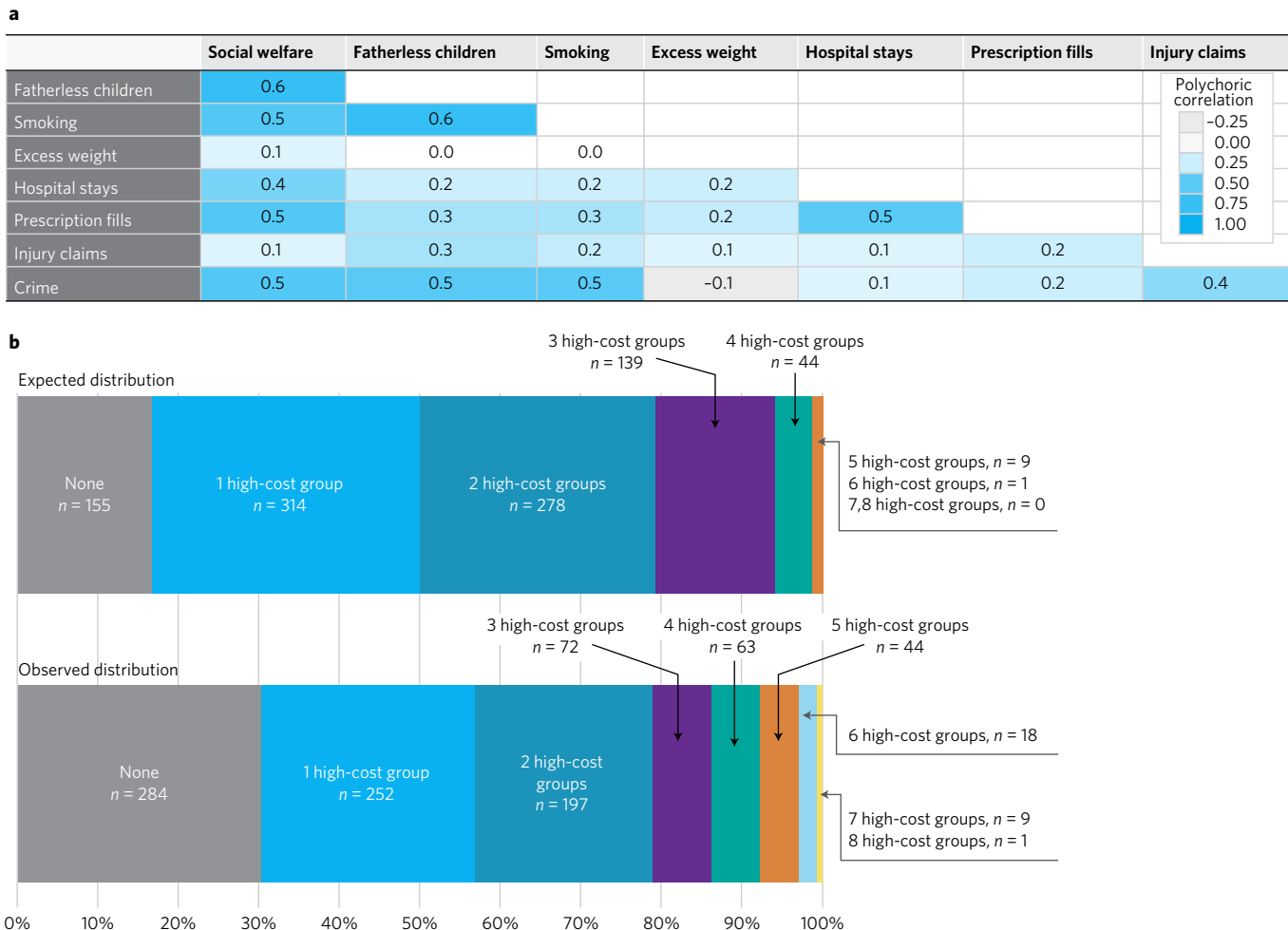
a

	Social welfare	Fatherless children	Smoking	Excess weight	Hospital stays	Prescription fills	Injury claims
Fatherless children	0.6						
Smoking	0.5	0.6					
Excess weight	0.1	0.0	0.0				
Hospital stays	0.4	0.2	0.2	0.2			
Prescription fills	0.5	0.3	0.3	0.2	0.5		
Injury claims	0.1	0.3	0.2	0.1	0.1	0.2	
Crime	0.5	0.5	0.5	−0.1	0.1	0.2	0.4

Polychoric correlation
-0.25
0.00
0.25
0.50
0.75
1.00

b

Figure 2 | The aggregation of adult economic-burden outcomes. a, The polychoric correlations show that high-cost group members in one sector were significantly more likely to reappear as high cost in other sectors. **b**, The distribution of high-cost individuals across multiple sectors deviated from the expectation of a random distribution, $\chi^2 (7, n = 940) = 2103.44$, $P < 0.001$, with excesses at the two tails (that is, there are more people than expected who do not belong to any high-cost group and there are more people than expected who belong to multiple high-cost groups). The expected distribution is based on the assumption that the high-cost groups were independent and did not overlap beyond chance. The observed/expected ratios in each of the nine cells are: 1.83, 0.80, 0.71, 0.52, 1.45, 5.09, 16.89, 120.53, 439.47.
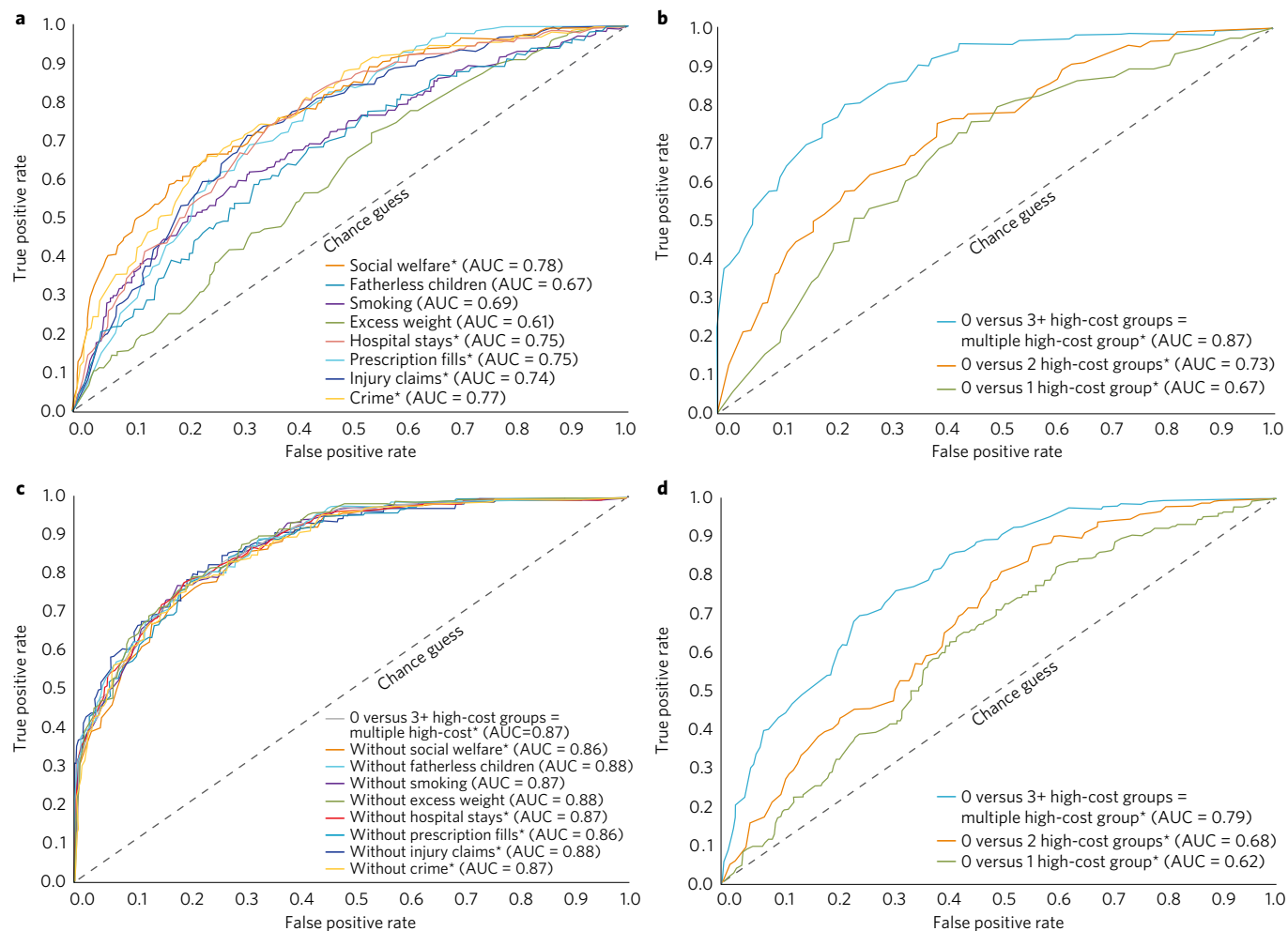
Figure 3 | Predicting the probability of economic-burden outcomes. **a**–**c**, We tested the predictive performance of a model that included information about four childhood risk factors. We assessed discrimination (that is, the model's ability to classify correctly) using the AUC. The diagonal line in each panel indicates random classification. Points above the diagonal represent good (better than random) classification results. **a**, Childhood factors only modestly predicted which cohort members belonged to any particular single high-cost group. **b**, Classification improved when predicting who belonged to multiple high-cost groups. **c**, Results of a leave-one-out analysis documenting that accurate prediction was not simply an artifact of predicting one high-cost group well. **d**, Reaching back to early childhood, brain health at three years of age predicted which cohort members belonged to multiple high-cost groups. All models controlled for sex. Models in **a**–**c** included childhood socioeconomic status (SES), childhood maltreatment, IQ and self-control. *Time spent outside New Zealand is added as a covariate in analyses that use New Zealand administrative data.

individuals across multiple sectors deviated from the distribution that would be expected if the high-cost groups were independent, χ^2 (7, $n = 940$) = 2103.44, $P < 0.001$ (Fig. 2b). The fact that membership in one high-cost group is associated with greater likelihood of membership in other high-cost groups re-framed the prediction question: how well could childhood risks predict the number of high-cost groups to which an individual belonged?

At a population level, each of the childhood factors was a statistically significant predictor of risk for belonging to more high-cost groups (Table 2). Prediction was the same when men and women were analysed separately (Supplementary Information). However, this population-level analysis did not answer the question of whether childhood factors were useful in predicting the outcome for an individual child[23]. We evaluated the accuracy of individual predictions by applying a receiver operating characteristic (ROC) curve analysis. An ROC curve plots the sensitivity and specificity of prediction at various thresholds and yields a metric indexing predictive accuracy: the area under the curve (AUC)[24]. The AUC reflects the probability of correctly classifying any randomly selected pair of cohort members in which one person belongs to

a high-cost group and the other does not. It can take on any value between 0.50 (indicating chance prediction) and 1.00 (indicating perfect prediction). Some pundits grade the values as: worthless (0.5–0.6), poor (0.6–0.7), fair (0.7–0.8), good (0.8–0.9) and excellent (0.9–1.0). Behavioural scientists note that AUC values of 0.54, 0.64 and 0.71 correspond to Cohen's d values of 0.20, 0.50 and 0.80, which are regarded as small, medium and large effects, respectively[25]. Using the standards of medical research, values approaching 0.8 suggest adequate discrimination for consideration in decision-making about intervention[26].

The four childhood risks predicted which cohort members belonged to any particular single high-cost group with poor-to-fair accuracy (Fig. 3a). However, as hypothesized, prediction improved when we turned to predicting who belonged to multiple high-cost groups (Fig. 3b). Individuals who belonged to three or more high-cost outcome groups are hereafter referred to as the multiple-high-cost population segment. The multiple-high-cost segment comprised 22% of the Dunedin cohort ($n = 207$ of 940 cohort members). Childhood socioeconomic deprivation, maltreatment, low IQ and poor self-control predicted these multiple-high-cost adults

Table 2 | Childhood predictors of economic-burden outcomes in a birth cohort.

	Univariate models				Multivariate models			
	IRR	**IRR 95% CI**			**IRR**	**IRR 95% CI**		
(a) Predicting the number of high-cost groups (range 0–8)								
Number of high-cost groups*								
Childhood low SES	**1.33**	**(1.25, 1.42)**			**1.21**	**(1.13, 1.29)**		
Child maltreatment	**1.23**	**(1.17, 1.30)**			**1.13**	**(1.07, 1.20)**		
Childhood low IQ	**1.26**	**(1.18, 1.34)**			1.05	(0.98, 1.13)		
Childhood low self-control	**1.32**	**(1.25, 1.40)**			**1.18**	**(1.11, 1.26)**		
	Univariate models				**Multivariate models**			
	RR	**RR 95% CI**	**AUC**	**AUC 95% CI**	**RR**	**RR 95% CI**	**AUC**	**AUC 95% CI**
(b) Predicting the multiple-high-cost group								
0 versus 1 high-cost group*							0.67	(0.62, 0.72)
Childhood low SES	**1.20**	**(1.08, 1.32)**	0.66	(0.61, 0.71)	**1.17**	**(1.06, 1.30)**		
Child maltreatment	**1.12**	**(1.02, 1.22)**	0.64	(0.59, 0.69)	1.08	(0.98, 1.18)		
Childhood low IQ	1.07	(0.97, 1.18)	0.62	(0.57, 0.67)	0.97	(0.88, 1.08)		
Childhood low self-control	**1.16**	**(1.06, 1.27)**	0.65	(0.60, 0.70)	1.10	(0.99, 1.21)		
0 versus 2 high-cost groups*							0.73	(0.69, 0.78)
Childhood low SES	**1.23**	**(1.10, 1.37)**	0.69	(0.64, 0.74)	1.12	(1.00, 1.26)		
Child maltreatment	1.07	(0.96, 1.19)	0.66	(0.61, 0.71)	1.00	(0.89, 1.12)		
Childhood low IQ	**1.33**	**(1.20, 1.48)**	0.71	(0.67, 0.76)	**1.16**	**(1.01, 1.32)**		
Childhood low self-control	**1.29**	**(1.19, 1.39)**	0.72	(0.68, 0.77)	**1.19**	**(1.07, 1.31)**		
0 versus 3+ high-cost groups = multiple-high-cost*							0.87	(0.84, 0.90)
Childhood low SES	**1.49**	**(1.35, 1.64)**	0.83	(0.79, 0.86)	**1.31**	**(1.18, 1.45)**		
Child maltreatment	**1.28**	**(1.19, 1.37)**	0.80	(0.76, 0.84)	**1.14**	**(1.05, 1.23)**		
Childhood low IQ	**1.35**	**(1.24, 1.47)**	0.81	(0.77, 0.85)	1.08	(0.98, 1.20)		
Childhood low self-control	**1.38**	**(1.27, 1.49)**	0.84	(0.80, 0.87)	**1.17**	**(1.07, 1.29)**		

Section (a) shows that children who grew up in socioeconomically deprived environments, who experienced child maltreatment, who scored more poorly on childhood IQ tests and who exhibited less self-control were more likely to belong to more high-cost economic-burden groups in adulthood (ranging from 0–8). Section (b) shows that these childhood factors differentiated a group of cohort members who became, as adults, members of the multiple-high-cost segment of their society. Incidence rate ratios (IRRs) in bold are statistically significant at $P < 0.05$. All other details are as for Table 1.

with considerable accuracy, as indicated by an AUC value of 0.87 (approaching excellent). To answer the question of whether accurate prediction of the multiple-high-cost segment capitalized on the fact that high-cost membership in one particular sector (for example, the crime sector, welfare sector and so on) could be predicted well, sensitivity analyses were undertaken in which each high-cost group was left out one sector at a time, in turn. Results showed that accurate prediction was not simply an artifact of predicting well in any one sector (Fig. 3c).

Our prediction was based on risk measures (familial socioeconomic characteristics, maltreatment, IQ and self-control) that we constructed using repeated measurements collected across the first decade of children's lives. However, multi-wave risk measurement is not a realistic standard that can be achieved by many other studies, nor implemented by policy analysts. Moreover, multi-wave measures from birth to 11 years of age did not address the possible importance of early-childhood interventions that target preschoolers. As such, we asked: how well could outcomes be predicted from a single brief evaluation of each child, using a standard paediatric assessment during the preschool years?

At 3 years of age, each child in the cohort participated in a 45 minute examination that included assessments of neurological soft signs, intelligence, receptive language and motor skills. The examiners (having no previous knowledge of the child) then rated each child's frustration tolerance, resistance, restlessness, impulsivity and lack of persistence in reaching goals. This examination yielded a summary index that we have termed brain health, a global index of the neurocognitive status of three-year-old children[27] (Supplementary Information). Variation in brain health at three years of age significantly predicted economically burdensome outcomes in each sector, except injury claims (Table 3). Moreover, variation in cohort

members' brain health at three years of age predicted with considerable accuracy which individuals would be members of the multiple-high cost segment 35 years later, with an AUC value of 0.79 (Fig. 3d).

Is this multiple-high-cost population segment a priority prevention target? They made up only 22% of their age cohort born in one year in one city. However, they left a big footprint on costs of service delivery (Fig. 4a). By age 38 years they used 66% of the birth cohort's welfare benefits; accounted for 77% of fatherless child-years in the next generation; smoked 54% of the cohort's tobacco cigarettes; carried 40% of the cohort's kilograms of excess weight; occupied 57% of their cohort's hospital-bed nights; filled 78% of all prescriptions; were convicted for 81% of the crimes charged to the cohort; and even made a disproportionate number (36%) of injury claims. In contrast, the data also reveal a substantial segment of the cohort (30%) who did not belong to the high-cost group in any sector. Figure 4b shows that this group has left an unusually small footprint on their society so far.

Discussion

This research yielded two results. First, the study uncovered a population segment that featured as high cost across multiple health and social sectors. This illustrates the potential discovery value offered by integrating the data of multiple longitudinal administrative databases and electronic health records. Without such data, this population segment would have remained hidden. Second, by linking administrative data with individual-level longitudinal data, the study provides the strongest effect sizes yet, measuring the connection between an at-risk childhood and costly adult outcomes in the population. The prediction was excellent when it relied on multiple risk factors measured during the first decade of children's lives, and was still good when it relied on information derived from a relatively

Table 3 | Variation in children's brain health at 3 years of age predicted which children belonged to high-cost economic-burden groups 35 years later.

	RR	RR 95% CI	AUC	AUC 95% CI
(a) High cost in each sector				
Social welfare*	**1.38**	**(1.25, 1.53)**	0.73	(0.69, 0.77)
Fatherless children	**1.22**	**(1.07, 1.38)**	0.61	(0.56, 0.66)
Smoking	**1.25**	**(1.12, 1.40)**	0.60	(0.55, 0.64)
Excess weight	**1.15**	**(1.02, 1.29)**	0.56	(0.52, 0.61)
Hospital stays*	**1.18**	**(1.05, 1.34)**	0.72	(0.68, 0.76)
Prescription fills*	**1.23**	**(1.10, 1.38)**	0.73	(0.69, 0.76)
Injury claims*	1.10	(0.99, 1.23)	0.74	(0.70, 0.77)
Crime*	**1.19**	**(1.09, 1.29)**	0.72	(0.68, 0.75)
(b) Number of groups	**IRR**	**IRR 95% CI**		
Number of high-cost groups*	**1.20**	**(1.13, 1.27)**		
(c) Multiple-high-cost groups	**RR**	**RR 95% CI**	**AUC**	**AUC 95% CI**
0 versus 1 high-cost group*	1.03	(0.94, 1.14)	0.62	(0.57, 0.67)
0 versus 2 high-cost groups*	**1.17**	**(1.07, 1.28)**	0.68	(0.63, 0.73)
0 versus 3+ high-cost groups*	**1.26**	**(1.17, 1.36)**	0.79	(0.75, 0.83)

Section (a) shows that variation in brain health at 3 years of age predicted who was more likely to belong to a high-cost group in adulthood, in each of eight different sectors. Section (b) shows that brain health at 3 years of age predicted the number of high-cost groups (ranging from 0–8) to which each cohort member belonged. Section (c) shows that brain health at 3 years of age differentiated cohort members who became, as adults, members of the multiple-high-cost segment of their society. All models control for sex. The prediction was the same when men and women were analysed separately (see Supplementary Information for details). *Time spent outside New Zealand is added as a covariate in analyses that use New Zealand administrative data. AUC, area under the curve; CI, confidence interval; IRR, incidence rate ratio; RR, risk ratio. RR's and IRR's in bold are statistically significant at P < 0.05.

brief assessment of brain health when the children were three years old. Given two three-year-old children (one who grew up to belong to multiple high-cost groups and one who grew up to belong to none), the model was able to classify them accurately 80% of the time. If this pattern of findings is replicated elsewhere, it will imply that early-years interventions, if efficient and effective with this population segment, could make very large reductions in economic burden. The amount that this economic burden can be reduced by remains an empirical question at present, but historical interventions that have targeted children on the basis of low IQ have proven effective with a good rate of return, giving cause for optimism[28].

This research has limitations. First, the results reflect one geographic location and a specific historical period. New Zealand is a useful laboratory because it suffers income inequalities similar to the United States and the United Kingdom (after-tax Gini coefficient: NZ = 0.33, UK = 0.35, US = 0.39)[29], spends a comparable amount on health care (NZ = 10%, UK = 9%, US = 17% of GDP)[30], has a national health care system and has a generous social safety net. Nevertheless, geographical and generational variations require investigation. Second, using 20% to identify a vital proportion of the population may seem arbitrary, but rather than choosing a sample-specific operant, we chose the Pareto principle a priori as a useful rule-of-thumb because it is familiar to researchers, policymakers and the public. Third, the data were right-hand censored at age 38 years, and we could not test how well early-childhood risks predict economically burdensome outcomes across the full life course. This is an important question because the health-care burden of developed societies concentrates in older age groups. To the extent that factors such as smoking, excess weight and health problems during midlife foretell health-care burden and social dependency, findings here should extend to later life (keeping in mind that midlife smoking, weight problems and health problems also forecast premature mortality). Fourth, we address the strength of prediction only; we did not address the causal mechanisms behind the predictive associations reported here. Whether the risk factors studied here are causal, or whether they mediate other prior causal influences, the finding that economically burdensome adult outcomes are predictable from these early-life factors with moderate to strong effects suggests that these risk factors are not unreasonable targets for randomized experimental intervention trials. Moreover, many interventions have treated risk factors that are not root causes, and improved outcome nevertheless. Fifth, we are unable to directly compare costs across sectors because we did not monetize outcomes within each sector. Although the multiple-high-cost group is clearly 'expensive', we did not convert each of our outcomes (for example, pack-years of smoking, criminal convictions,
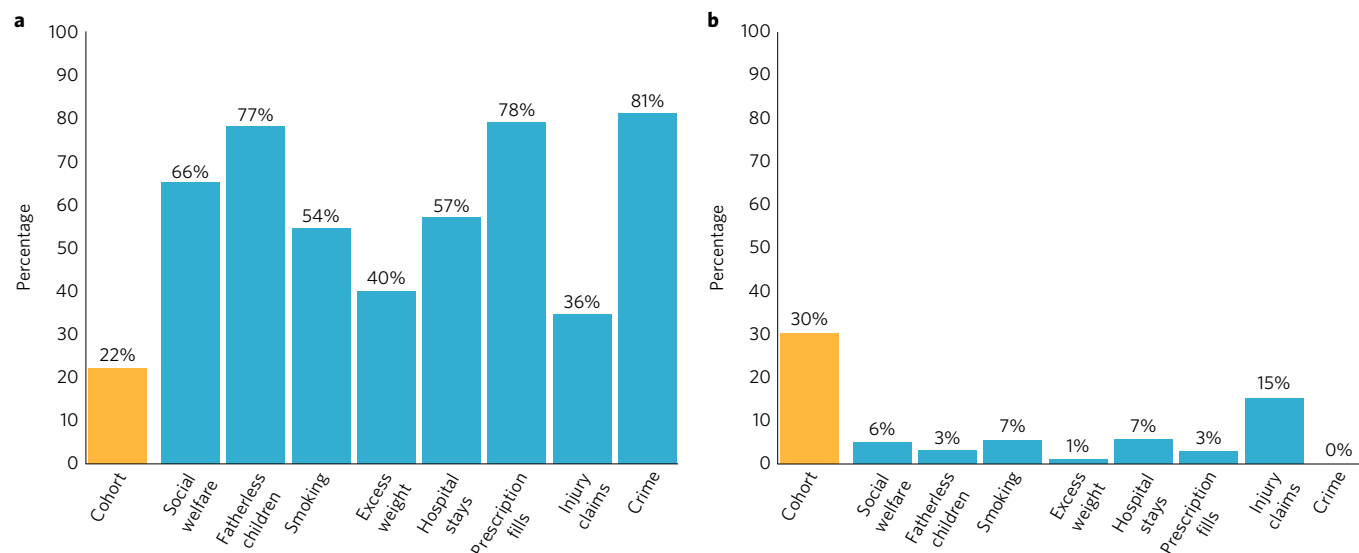

Figure 4 | The big footprint of multiple-high-cost users. a, Costs to society of multiple-high-cost users. Although the multiple-high-cost group made up only 22% of the cohort (n = 207), it accounted for a disproportionate share of economic-burden outcomes across all eight health and social sectors that we examined. **b**, In contrast, a substantial segment of the cohort did not belong to any high-cost group (30%; n = 289) and left an unusually light footprint on society.

injury insurance claims) to (New Zealand) dollars, for the following three reasons: monetizing outcomes is informative when evaluating return on investment of an intervention of known cost, but we did not study an intervention[22]; monetizing costs is not without assumptions, and estimates are time- and place-specific; compared with New-Zealand-specific monetized estimates the concentration metric reported here will be a more feasible target for replication and extension studies. The concentration metric can be used, for example, to ask whether high-cost groups aggregate to the same extent in different times and places, whether the same risk factors predict a multiple-high-cost group across time and place, and how historical events such as economic recessions or immigration affect high-cost distributions.

As a final limitation, we are aware that from a different perspective, the economically burdensome behaviours we have studied can be considered economically generative, or at least neutral. Smokers fuel the tobacco industry; crime provides jobs in policing, courts and corrections; hospital admissions, prescription fills and injury insurance claims animate the health care and pharmaceutical industries. Such cost–benefit analyses were beyond our scope. Moreover, it is not we who designated these outcomes as burdensome; rather, we selected them because they are oft-cited long-term targets of early-years intervention policy[18,31].

This research revealed a predictable aggregation of different economically burdensome adult outcomes in the same multiple-high-cost segment of the population. This aggregation has implications for methodology, prevention science and human rights. Methodologically, the finding illustrates that social science research on risk prediction can benefit from considering the accumulation of outcomes within a lifetime. Social scientists have observed that failure to aggregate information about risk predictors results in small or null effects in prediction[32,33], but the recommendation to aggregate has typically been applied only to predictor variables, such as when studying cumulative disadvantage or adverse childhood experiences[34,35]. We turned this recommendation on its head by showing how aggregating outcome variables, not just predictors, can improve effect sizes in longitudinal prediction research. Such aggregation has been used in medical epidemiology, to index the cumulative deficits associated with ageing[36] for example, but it is rarely used in the social and behavioural sciences. Treatment studies, as well as observational studies, can make use of this principle to more comprehensively evaluate impact. Moreover, health, social and justice sectors might benefit from understanding that the bulk of their services are going to the same clients.

The finding also has implications for early-years prevention science[2,37–39]. We sought to inform a question that nags at the behavioural and social sciences, and that has strategic consequences for national policy on children: how strong is the connection between childhood risk and future costly life-course outcomes? Results reported here suggest that the importance of childhood risks for poor adult outcomes has generally been underestimated. It is not news to service-delivery professionals that some individuals use more than their share of services. What is new is that individuals feature in multiple service sectors and they can be identified as children with reasonable accuracy. The question for intervention science becomes not just 'what works?' but 'what works for this multiple-high-cost population segment of children?'

Finally, the finding has implications for human rights. We aimed to test whether population segmentation could give a more accurate evidence base to clarify the need for early-years intervention. We are aware of the potential for misuse; population segments are often stigmatized and stereotyped. However, the predictions reported here make clear that the most costly adults in our cohort started the race of life from a starting block somewhere behind the rest, and while carrying a heavy handicap in brain health. Such a disadvantaged citizen is unlikely to be able to cover his or her share of health

and social costs, but there is no merit in blaming the victim for economic burden following from childhood disadvantage. Instead, ameliorating the effects of childhood disadvantage is an important aim[40,41] and achieving this through early-years support for families and children could benefit all members of a society.

Methods
A more detailed report of the study design, measurement and statistical analysis is provided in the Supplementary Information.

Dunedin study sample. Participants are members of the Dunedin Multidisciplinary Health and Development Study, which tracks the development of 1,037 individuals born in the period 1972–1973 in Dunedin, New Zealand[42].

Measuring economic-burden outcomes. We drew on personal interviews and on New Zealand's multiple nationwide administrative databases and electronic medical records to ascertain the cumulative distributions of eight economically burdensome outcomes (Fig. 1).

Social welfare benefit months. Using record linkage, we collected information about social welfare benefits received from the New Zealand Ministry of Social Development (Fig. 1a). The cohort accumulated 24,997 months of welfare payments between January 1993 and March 2012 (approximately age 21–38 years). The cumulative distribution of benefit months revealed that 20% of the cohort accounted for 80% of the months of social welfare benefits received by the cohort. These individuals constituted a high-cost group in the social welfare sector.

Fatherless child-years. Fatherless child-years (Fig. 1b) are defined by the absence of the biological father from the households in which a cohort member's offspring live. Using life history calendars, we recorded information about childbirths and the living arrangements of all cohort members' offspring (until each reached 18 years of age). In the cohort, 669 parents produced 1,418 live births. These offspring lived a total of 10,946 child-years of which 25% (2,755 child-years) were spent in households without their biological fathers. Twenty per cent of the cohort accounted for 82% of their offsprings' fatherless years. These individuals constituted a high-cost group in the fatherless-children sector.

Tobacco smoking pack-years. In repeated personal interviews, we gathered details about tobacco smoking and calculated the number of pack-years smoked (Fig. 1c), where pack-years = ((number of cigarettes smoked per day × number of years smoked)/20); 1 pack-year = 7,305 cigarettes. The cohort smoked 5,760 pack-years, the equivalent of 42,076,800 cigarettes. Twenty per cent of the cohort accounted for 68% of the pack-years smoked. These individuals constituted a high-cost group in the smoking sector.

Excess obese kilograms. We measured height and weight during anthropometric assessments (Fig. 1d). By early midlife, the cohort had put on 2,924 kg of excess weight, defined as the total number of kilograms beyond a BMI of 30, the recognized cut-off for obesity; thus, a person with a BMI ≤ 30 carries 0 excess obese kilograms, whereas the excess weight of a person with a BMI > 30 is their actual weight minus the weight predicted for a BMI of 30 based on their height. Twenty per cent of the cohort accounted for 98% of excess weight in the cohort. These individuals constituted a high-cost group in the excess-weight sector.

Hospital-bed nights. We obtained details of admission events to public hospitals from Ministry of Health records (Fig. 1e). The cohort accumulated 8,958 nights in the hospital from January 1988 to March 2012. Twenty per cent of the cohort accounted for 77% of hospital-bed nights in the cohort. These individuals constituted a high-cost group in the hospital-stay sector.
Prescription drug fills. We obtained information about prescription drugs filled by pharmacists, as indicated on the nationwide Pharmaceutical Management Agency database (Fig. 1f). The cohort filled 66,811 prescriptions between January 2006 and March 2012. Twenty per cent of the cohort accounted for 89% of prescriptions. These individuals constituted a high-cost group in the prescription-fill sector.

Injury insurance claims. We obtained records of insurance claims for accidents and injuries from the Accident Compensation Corporation, the national provider of comprehensive, no-fault personal injury cover for New Zealanders (Fig. 1g). The cohort made 6,919 claims between January 1993 and March 2012. The concentration was not as pronounced for this outcome as for others, perhaps owing to the random nature of many accidents and injuries. Nevertheless, 20% of the cohort accounted for 52% of injury claims in the cohort. These individuals constituted a high-cost group in the injury-claim sector.

Convictions for crime. We obtained information about criminal convictions by searching the records available to the New Zealand Police (Fig. 1h). The cohort had 2,141 convictions for adult crimes (excluding routine traffic offenses), beginning at age 15. The concentration was more pronounced

for this outcome than for others: 20% of the cohort accounted for 97% of convictions in the cohort. These individuals constituted a high-cost group in the crime sector.

Measuring childhood risk factors. We measured risk factors that are thought to augur poor adult outcomes. All risk factor measures have been described in previous reports about this cohort.

Childhood socioeconomic status[43] was defined as the average of the highest occupational status of either parent across study assessments from the cohort member's birth through 11 years (1 = unskilled labourer; 6 = professional), on New Zealand's occupational rating of the 1970s.

Childhood maltreatment[44] includes evidence of: (1) maternal rejection assessed at 3 years of age by observational ratings of mothers' interaction with the study children, (2) harsh discipline assessed at ages 7 and 9 years by parental report of disciplinary behaviours, (3) two or more changes in the child's primary caregiver, and (4) physical abuse and (5) sexual abuse reported by study members once they reached adulthood. For each child, our cumulative index counts the number of maltreatment indicators during the first decade of life; 63.7% of children experienced no maltreatment, 26.7% experienced one indicator of maltreatment (hereinafter 'probable' maltreatment), and 9.6% experienced two or more indicators of maltreatment ('definite' maltreatment).

Childhood intelligence[9] was measured as IQ with the Wechsler Intelligence Scale for Children – Revised (WISC-R) administered at ages 7, 9 and 11 years. IQ scores for the three ages were averaged and standardized.

Childhood self-control[9] during the first decade of life was measured using nine measures of self-control: observational ratings of children's lack of control (ages 3 and 5 years) and parent, teacher and self-reports of hyperactivity, lack of persistence, inattention, impulsive aggression and impulsivity (ages 5, 7, 9 and 11 years). The nine measures were positively and significantly correlated. Based on principal components analysis, the standardized measures were averaged into a single composite comprising multiple ages and informants, with strong internal reliability $\alpha = 0.86$.

Brain health at three years of age. Using the information from the child examination and subsequent behaviour ratings completed when study participants were three years old, we created a summary factor score via confirmatory factor analysis which we termed brain health, a global index of the child's early-neurocognitive status[27].

Statistical analysis. We began our work by examining the cumulative distributions of each of the eight outcomes (Fig. 1).

We tested the associations between childhood risk factors and growing up to be a member of a high-cost group using modified Poisson regression models to estimate risk ratios (RRs). We then added up (0–8) the number of high-cost groups to which each individual belonged and used negative binomial regressions to model incident rate ratios (IRRs). We followed up on this analysis to test the associations between childhood risk factors and membership in the multiple-high-cost sector. We evaluated predictive accuracy using ROC curve analysis to estimate each individual's probability of belonging to a high-cost group in society based on their childhood risks.

Data availability. Dunedin Study data are available from the authors on reasonable request. A managed-access process ensures that approval is granted to research that comes under the terms of participant consent and privacy (see Supplementary Information for data-sharing details).

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Author contributions

A.C., R.P. and T.E.M. designed the research, and A.C., R.M.H. and T.E.M. wrote the manuscript. A.C., S.H., S.R., R.P. and T.E.M. collected the data, and it was analysed by A.C., R.M.H. and H.H. All authors reviewed drafts, provided critical feedback and approved the final manuscript.

Additional information

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Competing interests

The authors declare no competing interests.