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Reformulation Can Only Reach the Salt It Controls: Why the Same Sodium Policy Prevents Five Times More Disease in One Food System Than Another

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ABSTRACT

Background. Mandatory or voluntary reformulation of processed foods is the most widely recommended instrument for population sodium reduction, and its evidence base comes largely from food systems in which most salt is added during industrial processing. In many countries most salt is added by the cook or at the table, where no reformulation policy reaches. The consequence of that difference for the achievable health benefit has rarely been quantified on a common scale.

Objective. To estimate the cardiovascular events averted by reformulation, by behaviour change and by their combination across food systems differing in the discretionary share of salt intake, and to determine where reformulation alone can reach the 5 g per day target.

Methods. Four hundred thousand adults were simulated with log-normal salt intake of mean 10.0 g per day, an age distribution and a systolic blood pressure distribution. Salt was apportioned between processed and discretionary sources at discretionary shares of 25 %, 50 %, 70 % and 85 %. Reduction in salt intake was translated to a fall in systolic blood pressure using a dose–response that increases with baseline pressure and age, and blood pressure to stroke and ischaemic heart disease rates using relative risks of 0.75 and 0.80 per 10 mmHg. Four interventions were evaluated: 25 % and 50 % reformulation, a 20 % reduction in discretionary salt, and their combination.

Results. Baseline modelled burden was 487.9 stroke and ischaemic heart disease events per 100,000 per year. A 25 % reformulation averted 28.8 events per 100,000 per year where only 25 % of salt was discretionary but 5.9 where 85 % was — a 4.9-fold difference for an identical policy. The ceiling on reformulation was correspondingly bounded: removing every gram of processed-food salt averted 103.9 events (21.3 % of burden) in the processed-dominant system and 23.2 events (4.8 %) in the highly discretionary one. Reaching 5 g per day required a 50.1 % reduction in total intake, which reformulation alone could deliver only where the discretionary share was 25 % and would then require reformulating 66.7 % of processed-food salt. The combined strategy converged across food systems, averting 31.8 to 36.2 events per 100,000 per year regardless of the source split.

Conclusions. Sodium policy transferred between food systems without adjusting for where the salt is added will underdeliver by up to fivefold. A dual strategy performs almost identically everywhere and is the robust recommendation where the source split is uncertain or changing.

1. Introduction

Excess dietary sodium raises blood pressure [1], and blood pressure is the leading modifiable risk factor for stroke and ischaemic heart disease [2–4]. Population sodium reduction is accordingly one of the most widely endorsed public health interventions [5,6], and the instrument most often recommended for delivering it is reformulation: reducing the salt added to processed and packaged foods, by voluntary target, by agreement or by regulation [7,8].

Reformulation has an attractive property. It requires nothing of the consumer, it is invisible at the point of consumption, and taste acclimatisation means that gradual reduction is not detected. Where it has been implemented in food systems dominated by industrially processed food, it has produced measurable falls in population intake [9,10].

It also has a hard boundary. Reformulation reaches only the salt that industry adds. In food systems where most salt enters food in the kitchen — from the salt jar, the soy or fish sauce bottle, the seasoning cube, the

pickle — the fraction of intake within reach of a reformulation policy may be a quarter or less of the total [11,12]. The policy is not thereby useless, but its ceiling is set by a property of the food system rather than by the ambition of the target.

That property varies enormously [13] and is a food-system characteristic in the most direct sense: it reflects how much of the national diet has passed through industrial processing. This study quantifies what it implies. Three questions are addressed: how much cardiovascular disease a given reformulation policy prevents across food systems with different source splits; what the ceiling on reformulation is in each; and whether any strategy performs consistently when the source split is unknown.

2. Methods

2.1 Population and intake

Four hundred thousand adults were simulated. Salt intake was drawn from a log-normal distribution with mean 10.0 g per day and coefficient of variation 35 % [13], age from a normal distribution centred at 45 years, and baseline systolic blood pressure from a normal distribution centred at 128 mmHg. Intake was apportioned between processed-food and discretionary sources at a fixed share for each modelled food system.

Table 1. Model inputs

Input	Value	Basis
Salt intake	Log-normal, mean 10.0 g/day, CV 35 %	Above the target in most surveyed populations
Age	Normal, mean 45 years, SD 16, truncated 20–90	Adult population
Baseline systolic blood pressure	Normal, mean 128 mmHg, SD 18, truncated 90–210	Adult population
Discretionary share of salt	25 %, 50 %, 70 %, 85 %	Spans processed-food-dominant to kitchen-dominant systems
Blood pressure response	1.0 mmHg per g salt/day in normotensive adults, rising with pressure and age	Greater responsiveness in hypertensive and older adults
Stroke relative risk	0.75 per 10 mmHg lower systolic pressure	Conventional epidemiological gradient
Ischaemic heart disease relative risk	0.80 per 10 mmHg lower	Conventional epidemiological gradient
Baseline event rates at 128 mmHg	180 stroke, 260 ischaemic heart disease per 100,000/year	Representative middle-income rates

Note. *All values are representative assumptions for modelling [1,2] and are not estimates for any country. Absolute event counts are indicative; the comparisons between food systems follow from the structure of the model.*

2.2 Causal chain

Each intervention reduces salt from one source. The resulting reduction in intake produces a fall in systolic blood pressure [1],

$$\Delta SBP = \Delta salt \times k \times f\left(SBP_0\right) \times g\left(age\right) \tag{1}$$

where the two modifying functions increase the response in those with higher baseline pressure and greater age, reflecting the well-documented greater salt sensitivity of hypertensive and older adults [1,14]. Event rates then follow from the shifted blood pressure distribution through the relative risks in Table 1 [2].

The modelling choice that carries the paper is that reformulation acts only on the processed component and behaviour change only on the discretionary component. That is the point at issue and it is a simplification in one respect noted in Section 4.3: some discretionary salt is itself an industrially produced condiment, which blurs the boundary in a direction that favours reformulation.

2.3 Interventions

Table 2. Interventions modelled

Intervention	Acts on	Assumed effect	Policy instrument
Reformulation 25 %	Processed-food salt	25 % reduction	Voluntary or mandatory targets
Reformulation 50 %	Processed-food salt	50 % reduction	Sustained mandatory programme
Behaviour change 20 %	Discretionary salt	20 % reduction	Mass media, labelling, low-sodium substitutes, cooking guidance
Combined	Both	25 % and 20 % respectively	Dual strategy

3. Results

3.1 Baseline

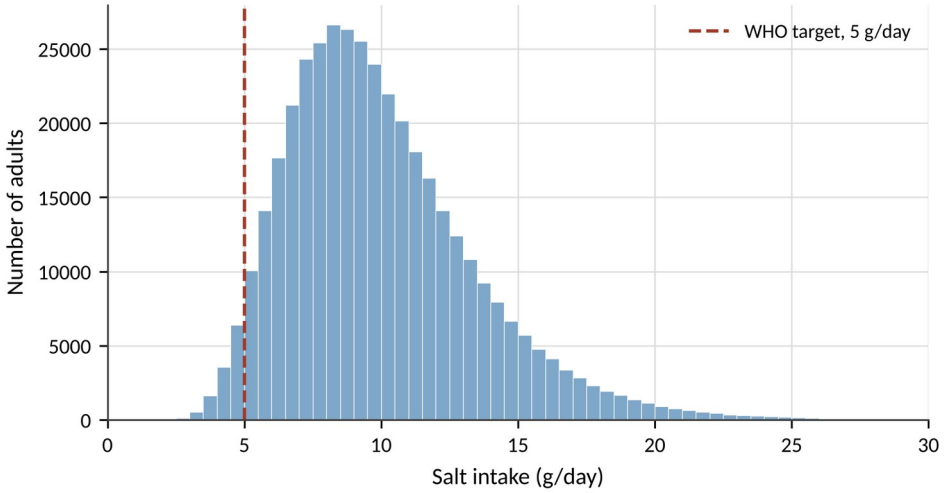


Figure 1. Simulated distribution of salt intake against the 5 g per day target.

Mean intake was 10.01 g per day, with 97.0 % of the population above the 5 g target and a 90th percentile of 14.59 g (Figure 1). The modelled baseline burden was 205.9 strokes and 282.0 ischaemic heart disease events per 100,000 per year, a total of 487.9.

The distribution matters for what follows. Because the blood pressure response is greater in those with higher baseline pressure, the same proportional reduction in intake produces a larger absolute benefit in the part of the population at highest risk, which is the mechanism by which a small mean shift can avert a non-trivial number of events [14].

3.2 The same policy in four food systems

Table 3. Events averted per 100,000 per year, by intervention and food system

Intervention	25 % discretionary	50 % discretionary	70 % discretionary	85 % discretionary
Reformulation 25 %	28.8	19.5	11.8	5.9
Reformulation 50 %	55.7	38.0	23.2	11.8
Behaviour change 20 %	7.9	15.6	21.7	26.2
Combined	36.2	34.4	32.9	31.8

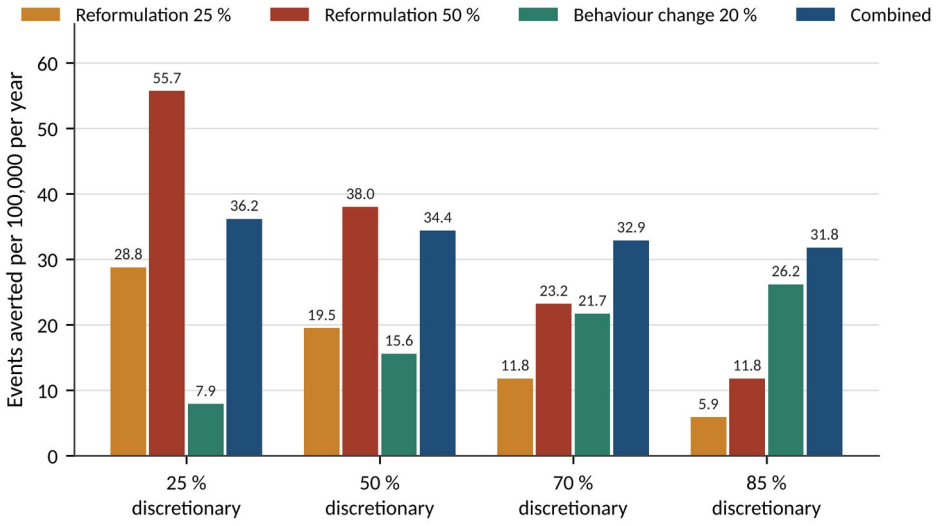


Figure 2. Events averted by each intervention across four food systems.

The first row of Table 3 is the finding. An identical reformulation policy — a 25 % reduction in the salt content of processed foods, the kind of target a national programme might set for a five-year period [7] — averts 28.8 cardiovascular events per 100,000 per year in a food system where a quarter of salt is discretionary, and 5.9 where 85 % is. The policy has not changed; the food system has.

The third row runs the other way, as it must. Behaviour change directed at discretionary salt averts 7.9 events where there is little discretionary salt to address and 26.2 where it dominates. The two instruments are close to mirror images, and each is at its weakest exactly where the other is at its strongest.

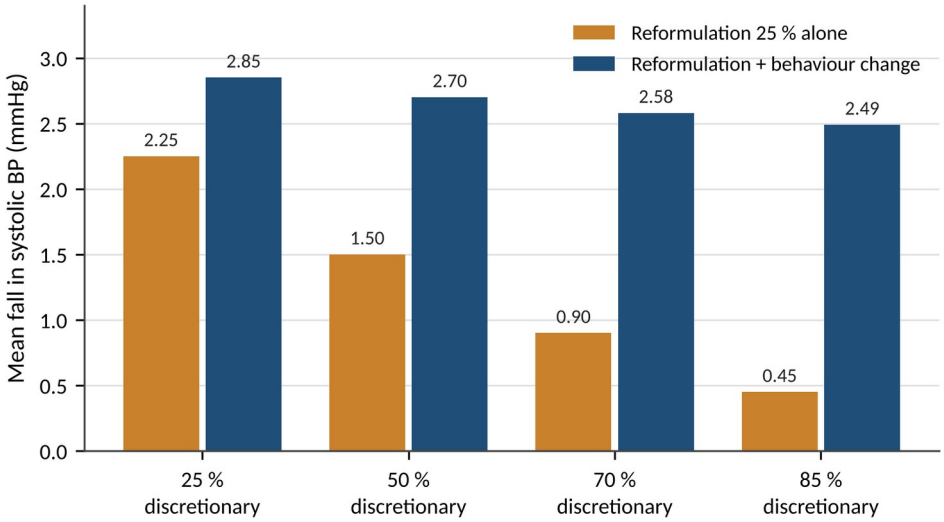


Figure 3. Mean fall in systolic blood pressure under reformulation alone and under the dual strategy.

Expressed as blood pressure, the shifts are small in absolute terms — under 3 mmHg in every case (Figure 3) — which is characteristic of population-wide risk-factor interventions and is why they are evaluated on events rather than on individual benefit [14,15]. A shift of this size changes almost nothing for any one person and moves several hundred events per million.

3.3 The ceiling on reformulation

Table 4. Maximum achievable by reformulation alone

Discretionary share	Salt within reach of reformulation	Events averted if all of it were removed	Share of burden averted
25 %	7.5 g/day	103.9	21.3 %
50 %	5.0 g/day	72.5	14.9 %
70 %	3.0 g/day	45.2	9.3 %
85 %	1.5 g/day	23.2	4.8 %

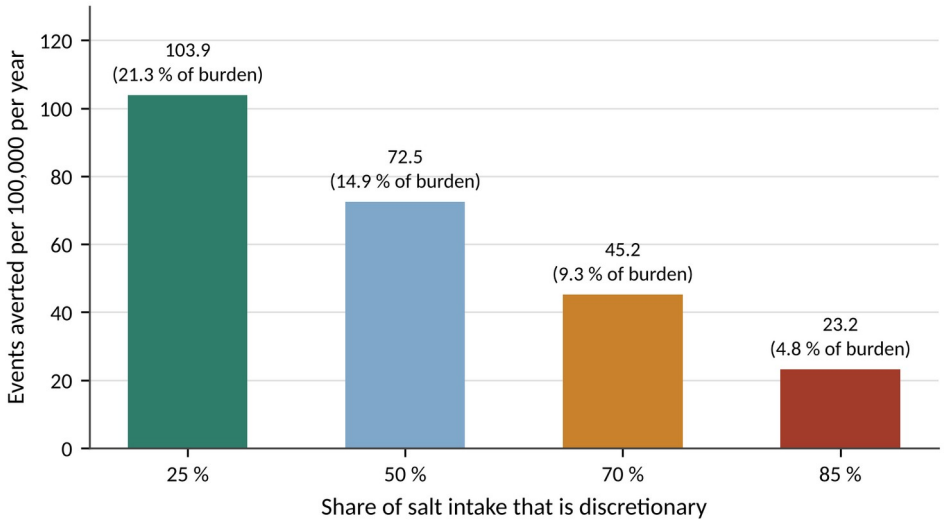


Figure 4. Events averted if every gram of processed-food salt were eliminated.

Table 4 removes the question of how ambitious a reformulation target is and asks what the instrument could achieve at its theoretical limit. Even eliminating processed-food salt entirely — which no programme has approached and which would be technologically and commercially impossible — averts 4.8 % of the modelled burden in the highly discretionary food system against 21.3 % in the processed-dominant one.

This is the sense in which a reformulation-only sodium strategy in a kitchen-salt food system is not merely under-ambitious but structurally limited. The gap between what the policy can deliver and what the problem requires is not closed by tightening the target, because the target applies to a small share of the intake.

3.4 Reaching the target

Table 5. Attainability of the 5 g per day target

Discretionary share	Reduction required in total intake	Maximum reformulation can deliver	Reformulation of processed salt needed	Attainable by reformulation alone?
25 %	50.1 %	75 %	66.7 %	Yes, with a very demanding target
50 %	50.1 %	50 %	More than 100 %	No
70 %	50.1 %	30 %	More than 100 %	No
85 %	50.1 %	15 %	More than 100 %	No

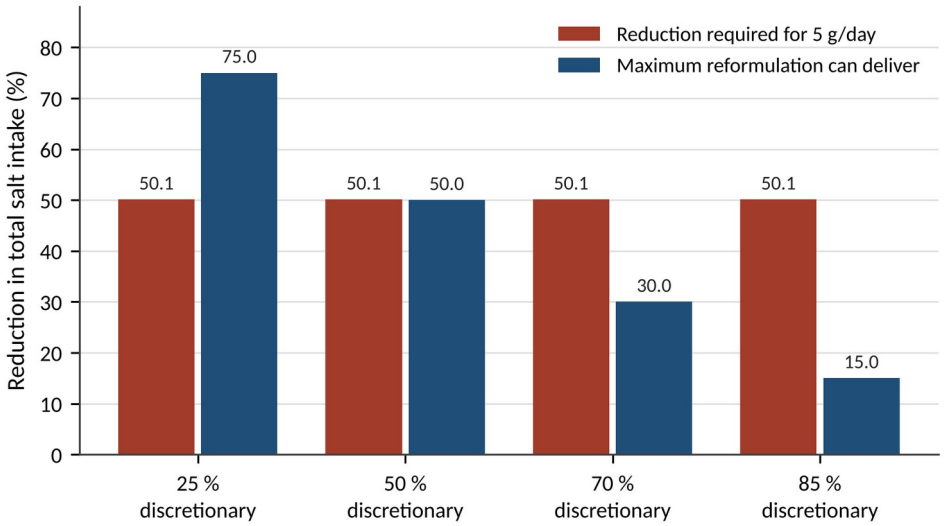


Figure 5. Reduction required for the 5 g target against the maximum reformulation can deliver.

Halving intake from 10.0 to 5.0 g per day requires a 50.1 % reduction in total salt [5]. In the processed-dominant system that is arithmetically possible through reformulation, but only by reformulating two thirds of all processed-food salt, which is beyond any programme achieved to date [8,16]. In the other three systems it is not arithmetically possible at all: the entire processed-food contribution is smaller than the reduction required.

A national programme in such a setting that adopts the 5 g target and a reformulation strategy has committed to an outcome its chosen instrument cannot produce. That is worth stating plainly, because the combination of an internationally recommended target with an internationally recommended instrument is a natural one to assemble, and the incompatibility is invisible unless the source split is examined.

3.5 The robust strategy

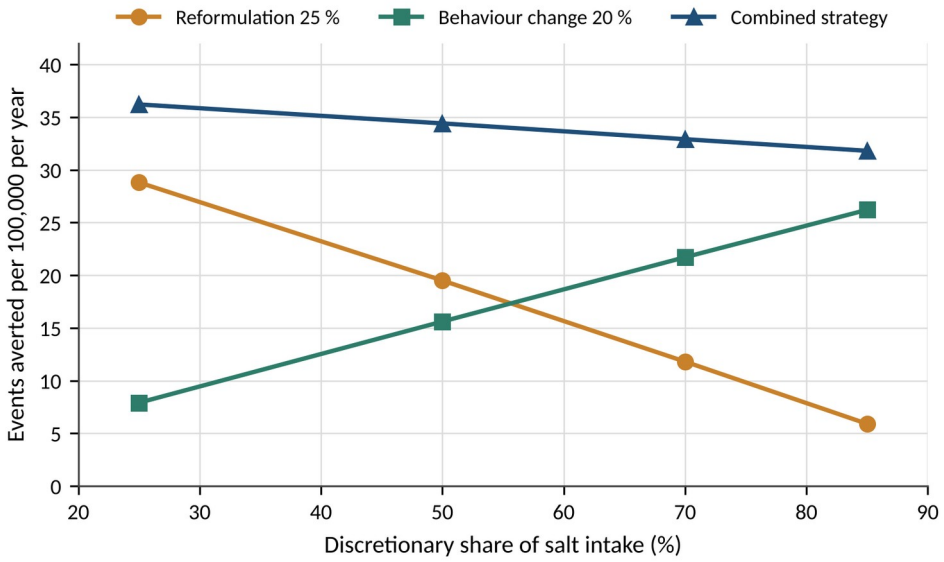


Figure 6. Events averted by each strategy across the range of discretionary shares.

The combined row of Table 3 is remarkably flat: 36.2, 34.4, 32.9 and 31.8 events averted across food systems ranging from 25 % to 85 % discretionary. A modest reformulation target paired with a modest behaviour change effort delivers almost the same benefit regardless of where the salt comes from.

The reason is straightforward and is visible in Figure 6. The two single instruments have opposite slopes, so combining them cancels the dependence on the source split. Neither is optimal in the food system that suits it — 50 % reformulation beats the combination in the processed-dominant case, at 55.7 against 36.2 — but the combination is never poor, whereas each single instrument is poor in half the range.

This is a useful property where the source split is unknown, contested or changing. It is changing almost everywhere: as food systems industrialise, the discretionary share falls and the processed share rises [6,13], which means a strategy calibrated to today's split is miscalibrated to tomorrow's. A dual strategy is robust to that transition in a way that either instrument alone is not.

4. Discussion

4.1 Principal findings

Four results follow. An identical 25 % reformulation policy averted 28.8 events per 100,000 per year in a processed-food-dominant system and 5.9 in a kitchen-salt-dominant one, a 4.9-fold difference attributable entirely to the food system. The ceiling on reformulation — eliminating processed-food salt altogether — ranged from 21.3 % of burden to 4.8 %. The 5 g per day target is unreachable by reformulation alone wherever the discretionary share exceeds about half. And a combined strategy averted 31.8 to 36.2 events in every food system modelled, making it the robust choice under uncertainty about the split.

4.2 Implications for policy

Table 6. Implications

Finding	Implication	Recommendation
Identical policy differs 4.9-fold by food system	Sodium policy does not transfer between countries	Measure the source split before adopting an instrument
Reformulation ceiling is 4.8 % of burden at 85 % discretionary	Tightening the target cannot close the gap	Do not rely on reformulation alone in kitchen-salt systems
5 g target unreachable by reformulation above 50 % discretionary	Target and instrument can be mutually incompatible	Check that the chosen instrument can arithmetically deliver the target
Behaviour change is strongest where reformulation is weakest	The instruments are complements, not rivals	Stop framing the choice as reformulation versus education
Combined strategy flat across all splits	It is robust to an unknown or changing split	Default to a dual strategy where the split is uncertain
Source split shifts as food systems industrialise	Today's calibration will be wrong tomorrow	Re-measure the split periodically, not once
Response is larger in hypertensive and older adults	Benefit concentrates in those at highest risk	Report events averted, not only mean intake change

The first row is the paper's central practical message and it concerns the transfer of policy rather than its design. Reformulation programmes are recommended internationally on the strength of experience in food systems where the great majority of salt is industrial [9,11]. That experience is sound and it is not portable: applied unchanged where salt is added in the kitchen, the same programme delivers a fifth of the benefit, and the shortfall will be attributed to weak implementation rather than to the arithmetic.

The sixth row deserves more weight than it usually receives in national planning. The discretionary share is not a fixed national characteristic but a moving one, falling as packaged and prepared foods take a larger share of the diet. A country in the middle of that transition should expect reformulation to become progressively more effective and discretionary-salt measures progressively less so, and a strategy fixed at the outset of a ten-year plan will be misallocated by its end.

4.3 Limitations

The clean separation between processed and discretionary salt is the principal simplification. Much discretionary salt is added through industrially manufactured condiments — soy sauce, fish sauce, bouillon cubes, seasoning mixes [11] — which are in principle reformulable even though the consumer adds them at home. Including those products within the reformulation instrument would raise its ceiling substantially in precisely the food systems where this analysis finds it lowest, and identifying that boundary empirically is the most useful extension of this work.

The dose–response chain is built from conventional epidemiological gradients applied to a simulated population rather than from trial data, and each link carries uncertainty. The blood pressure response to salt

reduction varies with individual salt sensitivity, potassium intake and baseline diet in ways not modelled; the relative risks per 10 mmHg are age-dependent in reality [2] and are applied here as constants; and compensatory behaviour — adding salt at the table to reformulated food — is not represented and would reduce the modelled reformulation benefit.

Potassium is omitted entirely, which understates the value of one specific intervention. Potassium-enriched salt substitutes act on discretionary salt and additionally raise potassium intake, which lowers blood pressure through a second mechanism [17,18]; a model counting only sodium therefore understates their benefit and, since they act on the discretionary fraction, understates the achievable benefit in exactly the food systems identified here as hardest to address.

All parameter values are representative assumptions. Baseline intake, the blood pressure distribution, the event rates and the assumed intervention effect sizes would all differ between real populations [15], and absolute event counts should not be quoted for any country. Only stroke and ischaemic heart disease are counted; sodium is also implicated in gastric cancer and renal outcomes [3], so the total benefit is understated.

5. Conclusion

A 25 % reduction in the salt content of processed foods averted 28.8 cardiovascular events per 100,000 per year in a food system where a quarter of salt is discretionary and 5.9 where 85 % is. The policy is the same in both; what differs is how much of the salt it can reach. Even eliminating processed-food salt entirely would avert 4.8 % of the modelled burden in the kitchen-salt system against 21.3 % in the industrial one, and the 5 g per day target is arithmetically unreachable by reformulation alone wherever the discretionary share exceeds about half.

The recommendation is not to abandon reformulation, which remains the instrument of choice where industry adds the salt and which becomes more powerful as food systems industrialise. It is that the source split is a food-system measurement on which sodium policy depends, that it should be taken before an instrument is chosen and re-taken as the food system changes, and that where it is unknown the dual strategy is the safe default: in this model it averted between 31.8 and 36.2 events per 100,000 per year in every food system examined, which is never the best available result and is never a poor one.

Declarations

Ethical approval. Not applicable. This is a modelling study using simulated individuals and published risk relationships; no human participants, dietary survey data or identifiable information were involved.

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Conflicts of interest. The author declares no conflicts of interest, financial or non-financial, and no relationship with food manufacturers, salt producers or salt-substitute manufacturers in relation to the subject matter of this manuscript.

Scope disclaimer. No country, national programme, company or product is evaluated. Intake distributions, source splits, effect sizes and event rates are representative assumptions; absolute event counts are indicative and must not be cited as estimates for any population.

Public health disclaimer. Nothing here constitutes dietary guidance for individuals or a recommendation to alter any national target. The analysis compares policy instruments on modelled outcomes and does not address implementation cost, industry feasibility or legal instruments.

Data and code availability. No survey or surveillance data were used in this study. All results were generated by the model described in Section 2 using the parameters listed in Table 1. The simulation code, run with a fixed random seed, reproduces every reported value and is available from the corresponding author upon reasonable request.

Author contributions. Methaq Hadi Lafta is the sole author of this work and was responsible for the conception and design of the study, development of the population sodium model, analysis and interpretation of the results, preparation of the figures and tables, and drafting, revision and final approval of the manuscript. The author is accountable for all aspects of the work.

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