Using system dynamics to analyse policy options for tobacco control in New Zealand

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Abstract

This paper outlines a system dynamics model that has been developed to assist the Ministry of Health to evaluate the dynamic consequences of tobacco control policies in New Zealand. The model consists of 4 sectors: population; smoking prevalences; second hand smoke; and tobacco attributable deaths. The model is simulated for 20-30 years into the future. The simulation package used is *'iThink'*, and a user interface is presented for policy analysis. A range of illustrative scenarios are provided, including: business as usual; fiscal strategies involving less affordable cigarettes; harm minimisation strategies involving either less addictive cigarettes or less toxic cigarettes; and combinations of the above policies. The main output variables (performance measures) include current smoking prevalence, tobacco consumption, and tobacco attibutable mortality.

Keywords: system dynamics, tobacco policy model; New Zealand Ministry of Health; dynamic simulation; tobacco control policies.

Introduction

This paper describes a system dynamics model that has been developed to help the Ministry of Health (MOH) to evaluate the dynamic consequences of tobacco control policies in New Zealand (NZ). The MOH has a statutory responsibility to monitor use of, and harms caused by, tobacco products under the Health Act (1956). Also such monitoring is required under the WHO Framework Convention on Tobacco Control (WHO, 2005) to which NZ is a signatory.

Previous system dynamics studies related to tobacco policy includes: the DYNAMO based system dynamics modelling work at MIT in the late 1970s and early 1980s on the impacts of smoking by Roberts et al. (1982); the Markovian system dynamics computer based simulation model developed in the USA by Tengs et al. (2001a & b; 2004a & b), Ahmad (2005) and Ahmad & Billimek (2005) for analyzing tobacco related policies; the computer simulation model called SimSmoke developed by Levy et al. (2006a, & b) to assess the impacts of a broad array of public policies related to tobacco control; and the system dynamics pilot study by Cavana & Clifford (2006) at NZ Customs Service analysing the collection of tobacco excise duties and cigarette smoking in NZ.

The general approach used in this study follows the five phase approach in Table 1, as outlined by Maani and Cavana (2000, 2007), following the general approach of the system dynamics methodology (e.g. see Forrester, 1961; Coyle, 1996; Sterman, 2000):

Table 1. Systems thinking and modelling methodology

Phases	
1	Problem Structuring
2	Causal Loop Modelling
3	Dynamic Modelling
4	Scenario Planning and Modelling
5	Implementation and Organisational Learning

Source: Maani and Cavana (2000, Table 2.1, p16)

This paper outlines progress to date of the tobacco policy modelling study. The next section provides the overview causal loop diagram that provided the conceptual framework for the development of the stock flow diagrams and simulation model outlined in the following section. The main part of this paper outlines a range of scenarios that we have already explored using the tobacco policy model, briefly describing the experiments and the model performance measures for a range of tobacco control policies.

Causal loop modelling

The overall causal structure for the model is provided in Fig 1. This diagram shows the population aging chain and the various categories of smokers and non-smokers. The feedback effects of adult smokers and teen peer group smokers on initiation and on exposure to secondhand smoke can be clearly seen, and the effects of various tobacco control policies on initiation, net quitting (ie, cessation minus relapse rates), and smoking intensity can also be observed in this diagram. Changes in tobacco control policy settings are represented in the model in two ways:

- Changes in smoking behaviour, reflected in initiation and quit rates and smoking intensity.
- Changes in excess mortality risks (the relative risks of death for those exposed compared to those not exposed) for current smokers, exsmokers, and never smokers exposed to secondhand smoke, by age and duration of exposure.

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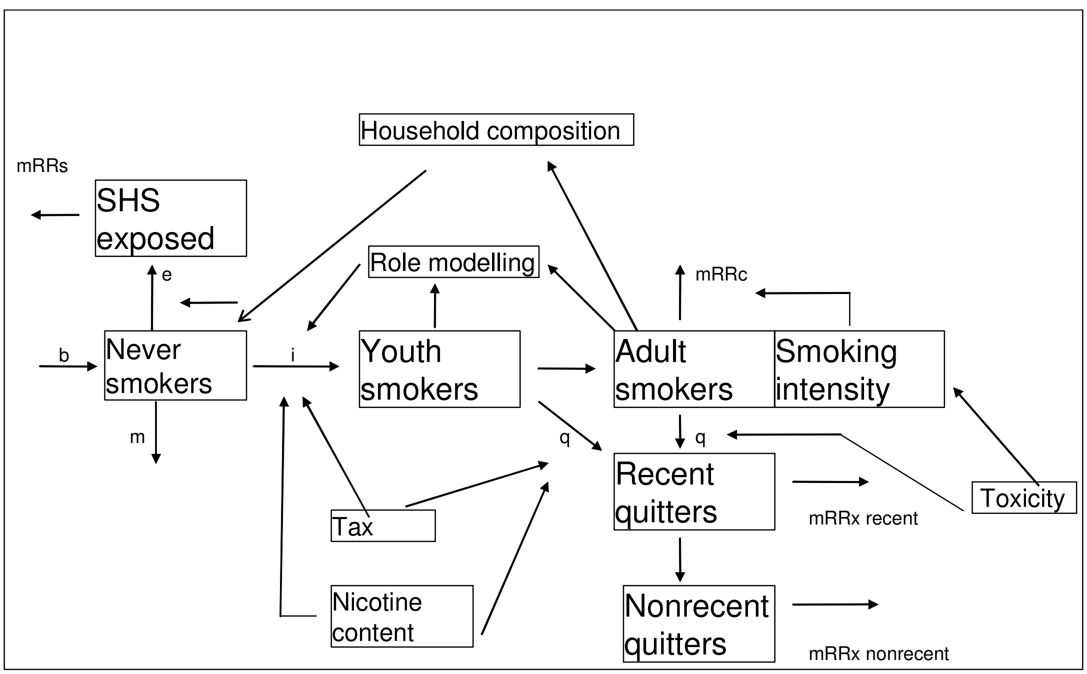
The quantitative relationship between the change in policy setting (the 'dose') and smoking behaviour or excess mortality risk (the 'response') is the hazard ratio or 'elasticity'.

Figure 1: Systems Diagram for the NZ Tobacco Policy Model



Key: i = smoking initiation rate; b = birth rate; e = proportion exposed to second hand smoke; q = net quit rate; m = never smoker mortality rate; RR = relative risks of mortality; c = current smokers; s = second hand smoke; x = ex-smokers.

Dynamic modelling

Overview of the simulation model

The system dynamics simulation model consists of 4 sectors: population; smoking prevalences; second hand smoke; and tobacco attributable deaths.

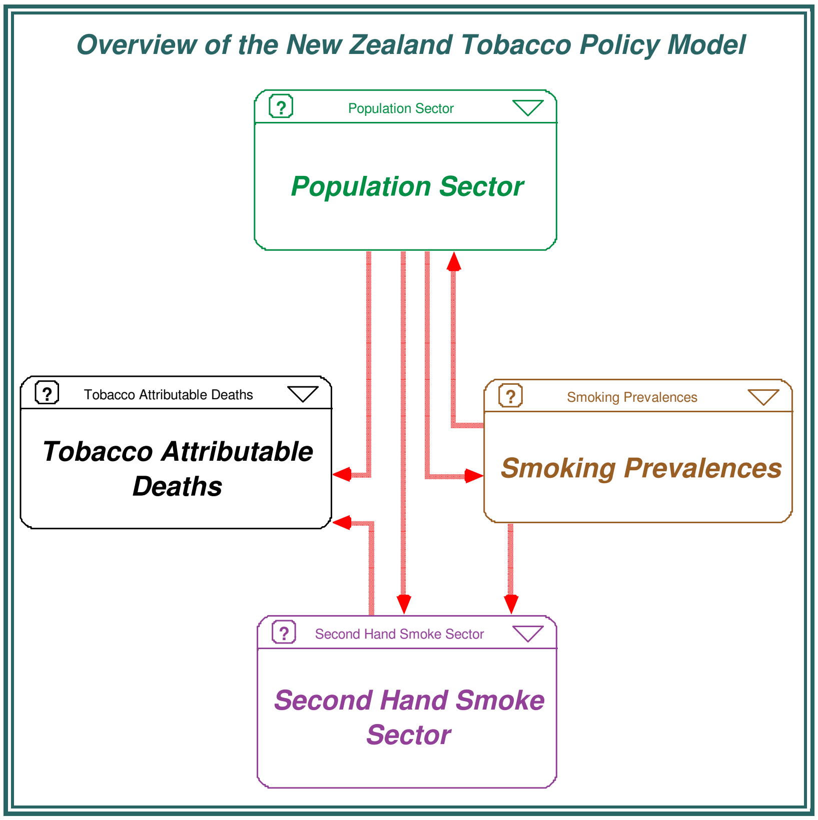


Fig. 2. Overview of the MOH tobacco policy model

The tobacco sector consists of population aging chains broken down into 10 year age groups representing stocks of 'never smokers', current smokers', 'recent ex-smokers', and 'non recent ex-smokers'. Flows are provided for births, aging between cohorts, initiation and net-quitting smoking, and mortality associated with smoking & ex-smoking related risks. The prevalences sector calculates ratios for each of the stocks or combination of age related stocks in the population sector. The second hand smoke sector calculates the exposure and mortality associated with second hand (passive) smoking by age group in NZ. Finally the tobacco attributable mortality (TAM) sector summarises the mortality associated with smoking and second hand smoke by age cohort in NZ.

Only the simplified stock flow diagram for the population sector will be provided in this paper (see Figure 3). The variable names are classified as acronyms, *where for example*:

- 10G = age group from 10 to 19 years old
- NS = never smokers
- CS = current smokers
- XSR = recent ex-smokers
- XSNR = non recent ex-smokers
- Births = annual births
- D = annual deaths
- NSD 70G = annual deaths of never smokers in the 70 plus age group
- NS to 10G = annual aging into the age group starting at age 10 (flow - aging between the 1st two age cohorts)
- q = annual net-quit rate (ie rate of quitting smoking less restarting smoking)
- m = mortality rate
- ir = initiation rate
- RR CS30T69G = relative risk of mortality of current smokers in the 30 to 69 year old age group

The model is developed using the ***iThink*** v9.01 dynamic simulation software package (iSee systems, 2005). The sources for the data used to initialise the model are summarised in Table 2 below. The model will be available from the authors when the project is completed. The model can be simulated for 50 years, although the focus is on the medium term, 20-30 years into the future.

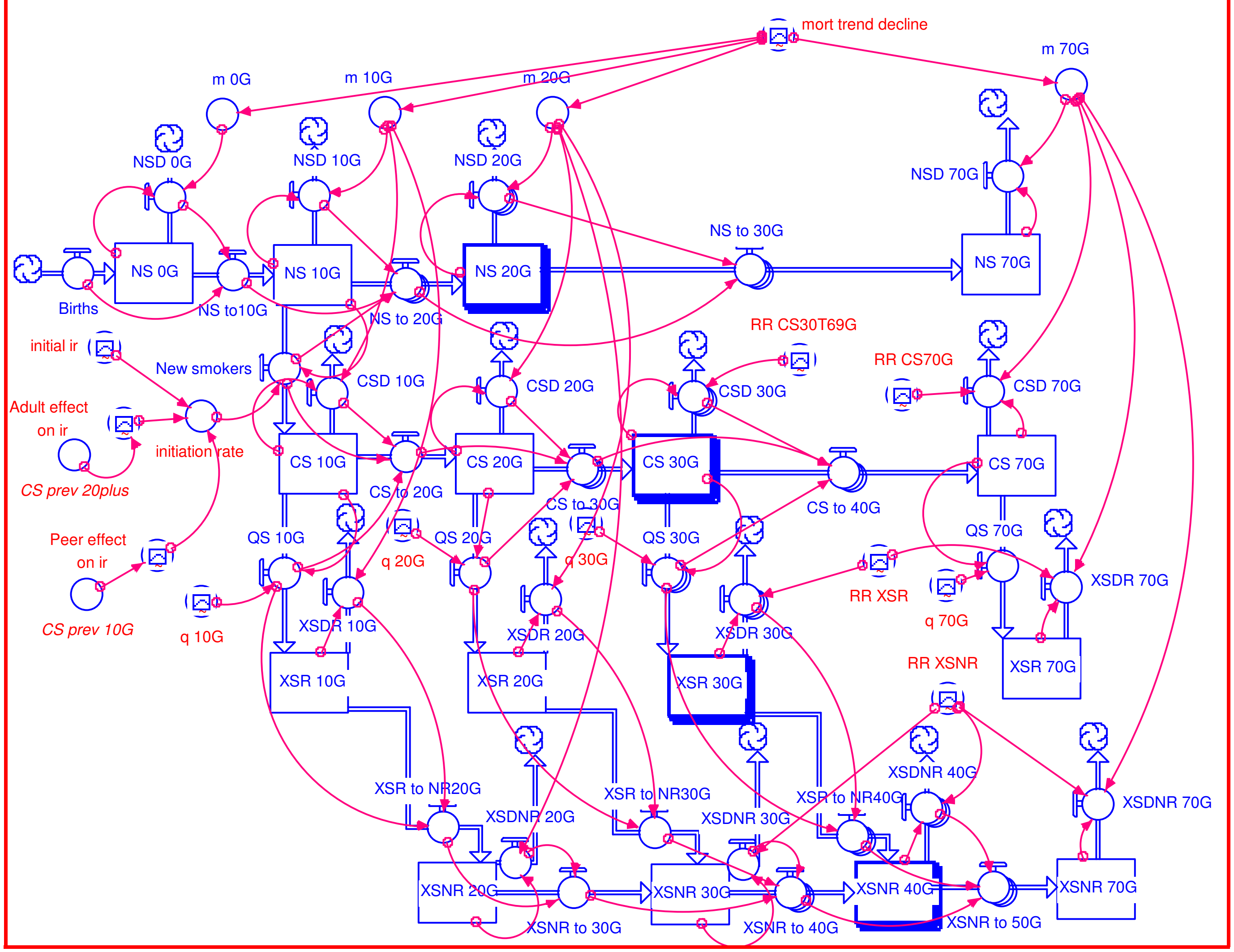
Table 2. Initialising the Tobacco Policy Model

Prevalence (current, ex-smoking)	NZHS 02/03
Initiation rate (and responsiveness to parental and peer role modelling)	NZTUS 06
Net quit rates	NZTUS 06
Smoking intensity distribution	NZTUS 06
Never smoker mortality rates	$m_o = m / [p_c(RRc - 1) + p_x (RRx - 1) + 1]$
RR current smokers (by duration and intensity)	CPS II (duration = age –15)
RR ex-smokers (by duration)	CPS II
RR SHS exposure	NZCMS
Never smokers exposed to SHS	NZHS 02/03
Population estimates and projections (including mortality trend)	SNZ

NZHS 02/03 = 2002/03 New Zealand Health Survey
NZTUS 06 = 2006 New Zealand Tobacco Use Survey
CPS I I = American Cancer Society Cancer Prevention Study II
NZCMS = New Zealand Census Mortality Study
SNZ = Statistics New Zealand

Simpliified Population Sector

Fig. 3. Stock flow diagram for the population sector



Calibrating and testing the model

The model was subjected to a number of verification and validation tests. Firstly, we calibrated the model by checking that the base case reproduced current prevalence, consumption and tobacco attributable mortality (TAM) by age – this involved minor tweaking of initiation and quit rates. Secondly, we carried out 'validation' experiments including:

- Business as usual (BAU) scenario reproduces recent trend in prevalence
- Prevalence increases if never smoker mortality decreases or relative risk (RR) related to smoking decreases
- Prevalence, consumption and TAM behave appropriately if initiation and quit rates change
- Youth smoking prevalence changes appropriately if parental / peer feedbacks change
- Second hand or passive smoking (SHS)–attributable mortality changes appropriately if living arrangements change.

Scenario Planning and Modelling

The user interface for the model is provided in Figure 4. This shows the parameters that can be adjusted readily by the public health physicians, policy analysts, managers, or others experimenting with the model (for example, carrying out 'what if' or scenario analyses, or sensitivity analyses).

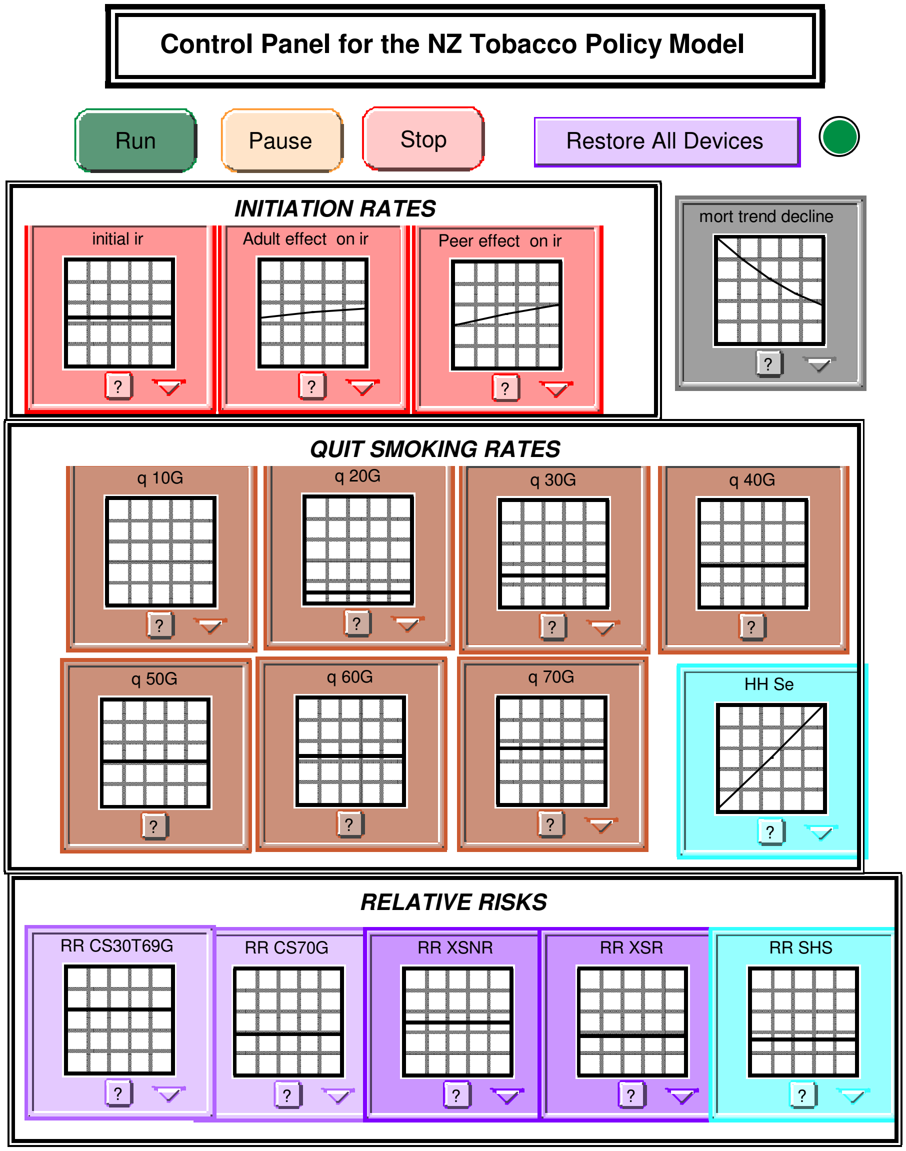


Fig 4. User interface for the tobacco policy model

A range of scenarios have been run to explore various policy options, including:

- business as usual;
- fiscal strategies involving less affordable cigarettes (through raising the excise tax rate on tobacco products);
- harm minimisation strategies involving either less addictive cigarettes or less toxic cigarettes; and
- combinations of the above policies.

Table 3 shows the elasticities used in the scenarios to be presented. For example, a 1% decrease in affordability will reduce the relative risk of mortality for current smokers (compared to never smokers) by 0.5%. In most scenarios, elasticities are assumed to be the same for all age groups, but this is not a necessary constraint.

Table 3. Elasticities (hazard ratios) for the experiments

Exposure	Outcome	Elasticity	Source
Affordability	RR Initiation rate Net quit rate	- 0.50 - 0.50 + 0.50	Chaloupka 2002 Nicolas 2002 Forster 2000
Addictiveness	RR Initiation rate Net quit rate	+ 0.10 - 0.50 + 0.67	Tengs 2005 Henningfield 2004 Gray 2005
Toxicity	RR Initiation rate Net quit rate	-0.80 +0.08 -0.33	Tengs 2004 Gray 2006

Elasticity = percentage change in outcome for a one percent change in exposure

The main output variables are current smoking prevalence (rate and count), tobacco consumption (per capita and total), and tobacco attributable mortality (rate and count).

Business as usual (BAU) scenario

The key model output for the business as usual (BAU) scenario (or base case) is provided in Table 4.

Table 4. Major performance measures for BAU scenario

	Prevalence		Consumption		TAM	
	Rate	Count	Pc	Total	Rate	Count
2011	22.3	761	977	3328	124	4921
2021	21.6	769	946	3372	120	4963
2031	21.0	775	920	3400	115	4887
Change	1.3	(14)	57	(72)	9	34

Key: Prevalence rate = rate per 100; per capita tobacco consumption in cigarette equivalents; total consumption in metric tonnes; TAM (tobacco attributable mortality) rate = rate per 100 000

The BAU scenario is required not only as the counterfactual against which all intervention scenarios must be compared, but has also been found useful in assisting the MOH to set outcome targets for the tobacco control programme.

Note that model predicts a very slow rate of decline in prevalence – 1.3 percentage points over 20 years or less than 0.1 percentage point per year. Per capita consumption falls from approximately 1000 CE/yr[1] today to about 900 CE/yr. Attributable mortality rate falls by less than 0.5% per year while count remains essentially stable (reflecting demographic trends).

Less affordable cigarette scenario

Scenario: 20% reduction in affordability from 2006, real value maintained thereafter.

Parameters: Relative risk (RR) current smoking 10% decrease; initiation rate 10% decrease & net quit rates 10% increase.

Generally for this type of scenario, econometric modelling is better than SD modelling (since NZ has long time series for price, tax, costliness and consumption). Nevertheless, SD has some advantages especially in linkage to health impacts.

This scenario is based on the recent history of price increases in NZ: 1991 (21%), 1998 (15%), 2000 (23%) – so a 20% reduction in affordability (increase in costliness) is realistic (also discussed in Cavana & Clifford, 2006).

This scenario involves a step change in affordability in 2006, sustained thereafter (in terms of minutes of labour at the average wage rate required to purchase a standard pack of cigarettes or quantity of loose tobacco) by annual adjustments for inflation and increase in real incomes.

Assumptions:

- no price manipulation by tobacco companies
- improvement in access to cessation services accompanies tax increases
- minimal increase in brand switching, switching from manufactured cigarettes to RYO, smuggling and home growing of tobacco
- tobacco products removed from CPI

What will be the impact on smoking behaviours?

Tobacco economists talk about 3 elasticities:

- total price elasticity of demand (consumption elasticity)
- prevalence elasticity (we need to decompose this into 'quitting elasticity' and 'initiation elasticity')
- conditional demand elasticity (reduction in cigarettes/day among continuing smokers - intensity elasticity)

[1] 1 cigarette equivalent = 1 manufactured cigarette or 1 gram of 'roll your own' (RYO) tobacco.

An estimate for short run consumption elasticity of –0.5 is provided by a meta – analysis (Chaloupka, 2002), with long run elasticity about twice this. About half comes from prevalence reduction and about half from cutting down, so intensity elasticity and hence impact on the relative risk of mortality (ie, the RRs) is also approximately - 0.5. Sophisticated duration analyses (eg Nicolas (2002) for Spain; Forster & Jones (2000) for Britain) show that a permanent 10% increase in costliness will reduce duration of smoking by about 10%. This translates into an increase in the probability of quitting of about 5% so quitting elasticity is about +0.5. Unfortunately the few direct studies of price impact on youth initiation probability have given conflicting results. However, since changes in youth smoking prevalence largely reflect changes in initiation, we can conclude that initiation elasticity = prevalence elasticity for youth. So initiation elasticity is about – 0.5 (consistent with estimates from Nicolas (2002) and Forster & Jones (2000) analyses)

We of course have an inbuilt check on the validity of these elasticity estimates: running the model for the long term (say 20 yrs), our scenario of 20% affordability reduction should generate about 20% reduction in consumption (long term consumption elasticity of –1.0) and about 10% reduction in prevalence (long term prevalence elasticity of –0.5). The key model output is summarised in table 5.

Table 5. Model output for the less affordable cigarette scenario

		Prevalence		Consumption		TAM	
		Rate	Count	Pc	Total	Rate	Count
2011	base	22.3	761	977	3328	124	4921
	expt	21.9	747	863	2941	116	4596
	diff	0.4	14	114	387	8	325
	% diff	1.8		11.6		6.5	
2021	base	21.6	769	946	3372	120	4963
	expt	20.3	726	800	2853	112	4616
	diff	1.3	43	146	519	8	347
	% diff	6.0		15.4		6.6	
2031	base	21.0	775	920	3400	115	4887
	expt	19.1	706	753	2781	106	4497
	diff	1.9	69	167	619	9	390
	% diff	9.0		18.2		7.8	

The first point to note is that the long term consumption reduction is close to the 20% expected, and long term prevalence reduction is close to the 10% expected (slightly more if compared to the 2006 base rather than to the BAU scenario – but the latter is the correct counterfactual).

Interestingly, this produces a slightly lower attributable mortality reduction of about 8%, but this does increase to around 10% if reductions in RRx and RRshs are modelled as well as RRc. (relative risks – ex-smokers, second hand smokers, and current smokers respectively).

Note that there is a substantial short term drop in consumption – largely due to cutting down. Longer term, about half the drop in consumption is due to cutting down and half to prevalence reduction (mainly quitting).

In summary, the model demonstrates that a feasible increase in costliness, if sustained over the long term, could produce major health gain. Specifically, a sustained 20% increase in costliness could yield 9% greater reduction in prevalence, 18% greater reduction in consumption, and most importantly, at least 8% greater reduction in attributable mortality than would otherwise be the case.

While not without political and other risks, there is some evidence that these risks could be managed. This is not the case for the harm minimisation examples we turn to now.

Harm minimisation scenario

Harm minimisation (HM) is the new frontier in tobacco control. However, any HM strategy would be superimposed on existing tobacco control strategies and would not operate in isolation from efforts to reduce youth initiation into tobacco use, provide cessation services for addicted smokers, or protect non-smokers from exposure to SHS. Despite this, HM has serious risks – as shown by the experience in the 1970s, when marketing of so-called safer cigarettes led to expansion of the tobacco market and net harm at the population level.

In reality, accurate and independent measurement and monitoring of addictiveness and toxicity of tobacco smoke is an essential precondition to any regulation of product modification – and it is not at all clear that such testing is technically possible at the present time. Hence our simulations are purely illustrative. We do not consider the potential introduction of smokeless tobacco products such as Swedish snus; such tobacco products are not used in New Zealand at present, nor is there any significant history of their use in this country.

Less Addictive Cigarette (RNC) Scenario

Scenario: 30% reduction in nicotine content implemented progressively from 2006 to 2011

Parameters: RR current smoking 3% increase; initiation rate 15% decrease; and net quit rates 20% increase.

The scenario involves a 30% reduction in addictiveness, assuming that there was a valid and reliable way to measure this. (A 30% reduction in nicotine content of tobacco is technically perfectly feasible). 30% is chosen so as not to deny NZ smokers their nicotine fix, but merely to remove the ‘excess’ nicotine in NZ cigarettes.

Although this is represented as a reduced nicotine content cigarette, addictiveness could be decreased by changing the content of additives such as acetaldehyde and ammonia (which affects the ratio of freebase to ionised nicotine by altering smoke pH) instead.

Note that we are not simulating the “Benningfield approach” (Henningfield et al 2004) – denicotinisation – which is probably unacceptable to smokers and politically unrealistic at the present time. Instead, the scenario aims only to reduce the excess nicotine in NZ cigarettes so that smokers in the future will experience, on average, a less fierce addiction or level of tobacco dependence than is currently the case.

Assumptions:

- tobacco dependence is not a threshold (all-or-nothing) phenomenon, but displays a continuous dose-response relationship (i.e. there is gradation in the level of tobacco dependence).
- reduction in addictiveness of cigarettes (manufactured cigarettes and RYO) will be accompanied by further improvements in access to NRT eg patches and gum.
- since smokers will still be able to get their 'nicotine fix' there will be minimal increase in contraband or home grown tobacco use.
- for similar reason, there will be at most partial compensatory smoking
- ventilated filters will be banned (such filters facilitate compensatory smoking)

There are few studies to go on in the literature, and it is important to note that this approach has never actually been implemented anywhere.

Our hazard functions (elasticities) are based on a paper by Tengs et al. (2004b), from which we estimate that a 30% reduction in nicotine content may reduce smoking prevalence by about 15% i.e. a prevalence elasticity of about -0.5.

According to Tengs and other workers, the effect of a less fierce addiction will be greater on quitting than on initiation.

We translate this into a quitting elasticity of about +0.67 and an initiation elasticity of about -0.5 (which jointly should yield about the expected prevalence elasticity).

The literature is inconsistent as to the extent of compensatory smoking to be expected. Since we are removing only 'excess' nicotine, we assume that most smokers will not need to smoke more intensely or efficiently to get their required nicotine dose, but will adapt with little difficulty to the lower dose.

Based on Tengs et al., we consider compensatory over smoking will be only partial, corresponding to an RRc elasticity of about +0.1. (Note that if this was mediated entirely though intensity, it would be equivalent to an increase in mean cigarettes per day from 12.0 to 13.2).

Unlike the affordability elasticity estimates, we acknowledge that the evidence base for these 'RNC' (reduced nicotine content) hazard function estimates is poorly developed and there is a much greater need for sensitivity analysis in this scenario. The key model output is summarised in table 6.

Table 6. Model output for less addictive cigarette (RNC) scenario

		Prevalence		Consumption		TAM	
		Rate	Count	Pc	Total	Rate	Count
2011	base	22.3	761	977	3328	124	4921
	expt	22.0	749	989	3368	125	4962
	diff	0.3	12	(12)	(40)	(1)	(41)
	% diff	1.3		(1.2)		(0.8)	
2021	base	21.6	769	946	3372	120	4963
	expt	19.9	709	895	3190	118	4854
	diff	1.7	60	51	182	2	109
	% diff	7.9		5.4		1.7	
2031	base	21.0	775	920	3400	115	4887
	expt	18.2	673	818	3025	109	4646
	diff	2.8	102	102	375	6	241
	% diff	13.3		11.1		5.2	

Given that we are modelling a gradual and progressive reduction in nicotine content from 2006 to 2011, we would not expect much difference between the intervention and BAU scenarios by 2011, and indeed this is confirmed. Prevalence drops marginally more than would otherwise have been the case, but consumption is slightly up because of compensatory smoking and attributable mortality is essentially unchanged.

Over the next 20 years, however, the less fierce addiction enhances quit rates and also has some effect on initiation, so prevalence drops quite steeply – reaching about 13% less than the BAU counterfactual (close to the 15% we would expect given the elasticities used).

However, consumption falls slightly less than this and attributable mortality falls very much less (about 5% less than expected after 20 yrs) reflecting partial compensation. Nevertheless, this still amounts to over 200 fewer attributable deaths per year than would otherwise have been the case.

Interestingly, in terms of sensitivity analysis, doubling the relative risks (RRc) elasticity from +0.1 to +0.2 (i.e. twice the extent of compensatory smoking previously modelled) completely wipes out the health gain from a 30% reduction in nicotine content.

If we equate compensation with increased intensity of smoking, this corresponds to an increase in mean cigarettes per day from 12.0 to 14.4 instead of 13.2.

In summary then, removal of ‘excess nicotine’ could have a substantial impact on prevalence but a lesser although still important impact on attributable mortality in the medium to long term – provided that smuggling and compensatory smoking could be severely limited.

Less toxic cigarette scenario

Scenario: 30% reduction in toxicity implemented progressively from 2006 to 2011.
Parameters: Relative risk (RR) current smoking 25% decrease; initiation rate 2.5% increase; and net quit rates 10% decrease.

It is an open question whether a less toxic cigarette could be manufactured, especially with respect to cardiovascular toxicity.

Purely for the purposes of illustration, we will assume that a 30% reduction in overall toxicity is possible, whether through changes to the tobacco, the additives, or other dimensions of cigarette design. 30% has been claimed by some authors to be feasible (e.g. through the use of activated charcoal filters).

We further assume that regulation of marketing will be sufficient to prevent the tobacco companies' making inflated claims as to the 'safety' of the new products.

Tengs et al. (2004a & b) has modelled a 'less toxic' scenario using SD modelling and hazard functions are taken from her paper along with other intimations from the literature.

In essence, a 30% reduction in toxicity will not produce a 30% reduction in RR, for at least two reasons:

- some smokers will increase their consumption, or at least not cut down to the extent they might otherwise have done;
- if less toxic product is also less acceptable (e.g. due to differences in taste), some switching to (more toxic) home grown or contraband tobacco will occur.

So we modelled an RR (relative risk) elasticity of –0.8 rather than –1.0.

The risk with a less toxic cigarette is, of course, expansion of the tobacco market (due to fewer current smokers quitting and more ex-smokers relapsing – and teenagers would also have one less reason not to experiment, so slightly increasing initiation rates).

Benefits at the individual level will not translate into benefit at the population level if prevalence and consumption increase. We call this the 'reverse prevention paradox' (the prevention paradox refers to the more usual situation where public health interventions produce substantial benefits at the population level but little benefit to most individuals – a good example being seat belts) **.**

The literature is sparse as to the extent of behavioural effects that might be seen – much will depend on how the 'less toxic' tobacco products are marketed. What is clear is that the greater effect will be on quitting rather than initiation. Based on very limited guidance in the literature, we model a quit elasticity of –0.33 and an initiation elasticity of +0.08.

Given major uncertainty about these hazard functions, sensitivity analysis is very important for this scenario. Key model output is summarised in table 7.

Table 7. Model output for the less toxic cigarette scenario

		Prevalence		Consumption		TAM	
		Rate	Count	Pc	Total	Rate	Count
2011	base	22.3	761	977	3328	124	4921
	expt	22.4	765	981	3342	119	4730
	diff	(0.1)	(4)	(4)	(14)	5	191
	% diff	(0.4)		(0.4)		3.9	
2021	base	21.6	769	946	3372	120	4963
	expt	22.1	787	968	3450	110	4521
	diff	(0.5)	18	(22)	(78)	10	442
	% diff	(2.3)		(2.3)		8.9	
2031	base	21.0	775	920	3400	115	4887
	expt	21.8	805	955	3529	107	4555
	diff	(0.8)	(30)	(35)	(129)	8	332
	% diff	(3.8)		(3.8)		6.8	

Even if toxicity could actually be reduced by 30%, and even assuming relatively limited behavioural effects leading to minimal expansion of the tobacco market (2% in 10 years and 4% in 20 years), the impact on attributable mortality is only moderate.

Note that this impact peaks in the medium term (at about 9% greater reduction than the BAU after a decade) then falls back to around 7% after a further decade – although this still amounts to over 300 deaths avoided per year.

Sensitivity analysis around the ‘risk / use equilibrium’ shows that were there no behavioural effects, the health gain would be about 50% greater than shown (i.e. around 10% reduction in attributable mortality in the long term). On the other hand, if behavioural effects are twice as great as shown (i.e. a 5% increase in initiation rates and a 20% decrease in net quit rates) the model estimates that there would be no net population health gain at all.

In summary, the population health benefits of a reduced toxicity cigarette may not be as great as might be naively expected, mainly because of behavioural effects leading to expansion of the tobacco market (increased prevalence and consumption). Nevertheless, a good case can be made that continuing smokers should not be denied access to less hazardous products, provided these can be shown to be genuinely less toxic, and this can be robustly measured and monitored.

Summary of separate scenarios

The less affordable cigarette scenario involves changes in the three key ‘policy sensitive’ variables that are all in the ‘healthward’ direction. By contrast, this is not so for the less addictive and less toxic scenarios, which turn out to be exact opposites of each other (table 8).

Thus the less addictive cigarette increases RR through compensatory over smoking, while the less toxic cigarette directly reduces it. The less addictive cigarette slows the transition from experimentation to 'hooked on nicotine' regular use, while a less toxic cigarette gives adolescents one less reason not to smoke.

A less fierce addiction of course makes it easier for current smokers, most of whom would like to quit, to actually do so - while a belief that cigarettes are now less toxic provides the addicted smoker with an excuse not to make the quit attempt.

Table 8. Summary of scenario assumptions

	RR	Initiation	Quitting
Reduced affordability	↓	↓	↑
Reduced addictiveness	↑	↓	↑
Reduced toxicity	↓	↑	↓

The interesting question is whether, in a combined scenario, the reduction in addictiveness and the reduction in toxicity will simply cancel each other out, and we will be left with an outcome no different from that achievable via a less affordable cigarette on its own. In which case it would seem not worthwhile to bother with harm reduction strategies at all.

Combined scenario

Scenario: 20% reduction in affordability; 30% reduction in nicotine content; 30% reduction in toxicity from 2006 / progressively 2006/11.

Parameters: RR current smoking 30% decrease; initiation rate 20% decrease; net quit rates 20% increase.

The joint elasticities are derived essentially by summing the separate scenarios, with some modification for plausibility. Since these are not based directly on empirical data, sensitivity analysis is especially important for this scenario. At the same time, it is precisely the ability to simulate such multiple policy enhancements simultaneously that is the strength of the SD approach. Key model output for the combined scenario is summarised in table 9.

Table 9. Model output for the combined scenario

		Prevalence		Consumption		TAM	
		Rate	Count	Pc	Total	Rate	Count
2011	base	22.3	761	977	3328	124	4921
	expt	22.0	748	898	3062	114	4527
	diff	0.3	13	79	266	10	394
	% diff	1.7		8.0		8.0	
2021	base	21.6	769	946	3372	120	4963
	expt	19.7	704	775	2765	101	4190
	diff	1.9	65	171	607	19	773
	% diff	8.8		18.0		15.8	
2031	base	21.0	775	920	3400	115	4887
	expt	17.9	662	708	2618	95	4083
	diff	3.1	113	212	782	20	804
	% diff	14.8		23.0		17.4	

In brief, using the assumptions already discussed, the combined scenario shows greater benefits than any of the separate scenarios on their own. The combined scenario achieves a current smoking prevalence of about 18% by 2031, one percentage point lower than the affordability scenario and slightly better than the addictiveness scenario. The combined scenario also achieves a lower per capita consumption than the affordability scenario could do by itself, at around 700 CE/y. And most importantly, it achieves a 10% lower attributable mortality than the affordability or toxicity scenarios on their own.

Thus the model reinforces the need for comprehensive tobacco control policies that simultaneously address multiple dimensions of the ‘tobacco system’.

Summary of results

Table 10. Summary of results - 2031

	Prevalence	Consumption	TAM
Current (2006)	23.3	1020	4330
BAU	21.0	775	4890
Less affordable	19.1	755	4500
Less addictive	18.2	820	4650
Less toxic	21.8	955	4550
Combined	17.9	710	4080

Key: Prevalence = rate per 100 (of smokers of population 10 years and above);
Tobacco Consumption = metric tonnes per year
TAM (tobacco attributable mortality) = number of deaths from tobacco causes per year

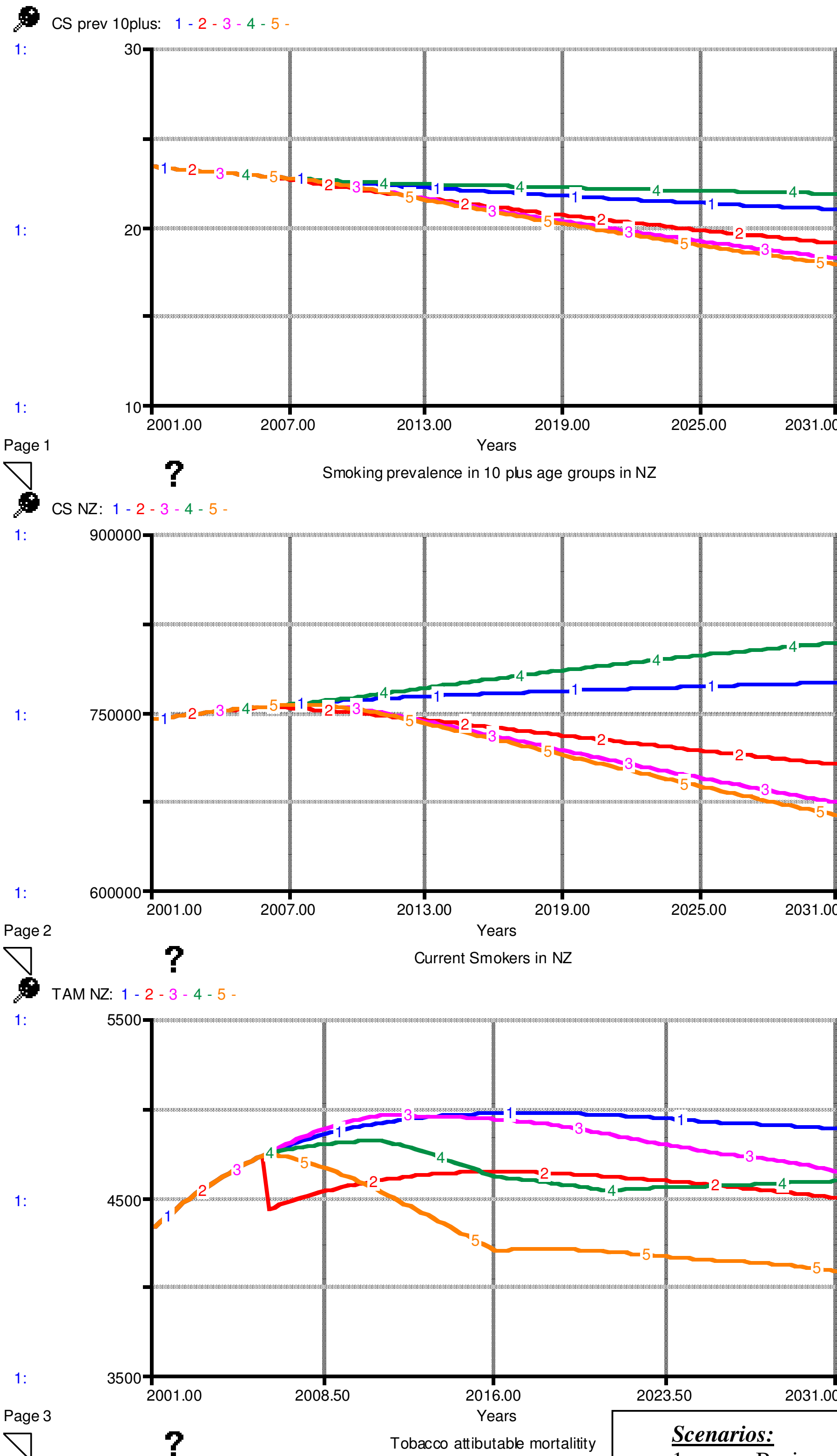
The different scenarios are compared in Table 10, using the key indicators in 2031 as the outcome measure.

The combined scenario achieves a prevalence of about 18%, one percentage point lower than the affordability scenario and slightly better than the next best scenario with respect to prevalence i.e. the addictiveness scenario.

The combined scenario also achieves a lower per capita consumption than the affordability scenario could do by itself, at around 700 CE/y. And most importantly, it achieves a 10% lower attributable mortality than the affordability or toxicity scenarios on their own.

The dynamic behaviour of the model for each of the 5 scenarios discussed in this paper is summarised in Figure 5. The main outcome indicators are smoking prevalence rates and counts and tobacco attributable mortality burden (count). Trends in these variables are shown for the 2001-2006 period, followed by the model projections to 2031.

Fig. 5. Comparison of scenarios – main performance measures



Scenarios:

1. Business as usual
2. Less affordable cigarette
3. Less addictive cigarette
4. Less toxic cigarette
5. Combined scenario

Implementation and Organisational Learning

A number of different scenarios have so far been analysed with the system dynamics model. From the results obtained to date, it would seem there may be some merit in seriously considering tobacco product modification or harm reduction regulations. However, the model supports the notions that this would only be the case if compensatory smoking and tobacco market expansion could be severely limited, and if such product regulation was combined both with effective marketing regulation and with sustained tax increases.

It is important to emphasise that this modelling has been done for illustrative purposes only. In reality, tobacco product regulation is problematic so long as we lack robust testing methods and full disclosure provisions. However, the model can also be used to explore a range of other tobacco control scenarios, including: a snus (Swedish snuff) scenario, in which switching occurs from use of smoked tobacco to smokeless tobacco products; a Tobacco Authority (regulated market model) scenario; and a nicotine market regulation scenario.

In the meantime, the SD model is available for policy analysts and tobacco researchers in New Zealand:

- to provide a joint learning experience with respect to SD modelling and tobacco control;
- to frame policy questions and assess suitability of the model for exploring them; and
- to obtain the necessary empirical data to run the model and agree plausible ranges for sensitivity analysis.

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