# INTEGRATED SYSTEM DYNAMICS: ANALYSIS OF POLICY OPTIONS FOR TOBACCO CONTROL IN NEW ZEALAND

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## ABSTRACT

This paper provides an overview of the 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 attributable mortality. Finally areas for future model enhancement are identified.

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

## 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).

Traditional epidemiological methods (eg randomised control trials, cohort studies) help us understand the parts (eg effectiveness of nicotine replacement therapy) but not the whole. Tobacco use can be thought of as a ‘system’ containing emergent properties, complexity, and nonlinear dynamics.

Traditional epidemiological methods deal with complexity by breaking the issue down into parts simple enough to be controlled (randomised control trials ) or observed (cohort or case control study). System dynamics (SD) deals with complexity by abstracting the key elements and simulating their dynamic inter-relationships (using multiple simultaneous differential equations).

The focus of an SD model is on the behaviour of the system *as a system*. Elements are retained only if necessary, and only relevant attributes incorporated.

"*Everything should be made as simple as possible – but not simpler*"
- Albert Einstein

The specific objectives of the SD tobacco control model are:

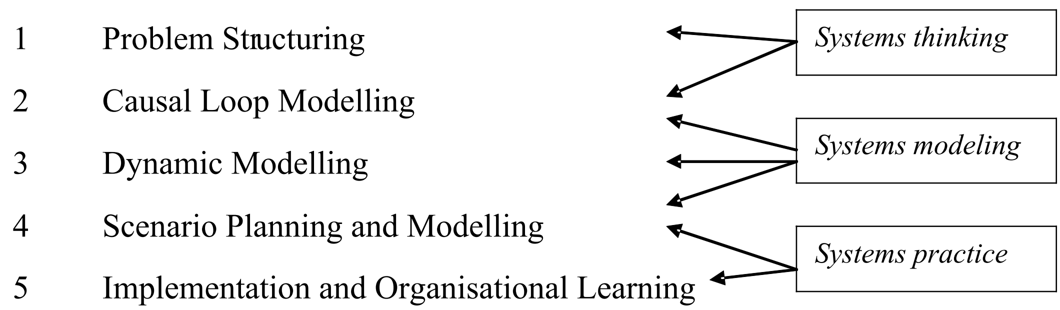
(a) to support evidence-informed tobacco control policy;
(b) to provide a decision support tool when considering strategic policy options in tobacco control; and
(c) to assess the utility of system dynamics in formulating public health policy in the NZ context.

MOH has a statutory responsibility to monitor use of, and harms caused by, tobacco products. Also this is required as signatory to the WHO Framework Convention on Tobacco Control (WHO, 2005).

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 integrated 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 & ISSS 07 conference theme *(integrated systems science)*




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

The theme of this conference is “Integrated Systems Sciences: Systems Thinking, Modeling and Practice”. ISSS (2007) defines this theme as follows: “It attempts to promote systems sciences as an approach to complexity in a broad sense, identified in organizations, communities and societies, and their environments, in such a holistic and integrated way that we draw on all of systems sciences from systems thinking and systems modeling to systems practice.” While SD does not draw on all the systems sciences, it is certainly concerned with the scope of the integrated systems sciences outlined by the ISSS conference organisers. The five phase integrated SD approach outlined in Table 1, shows the relationships to the integrated systems sciences as follows (ISSS, 2007):

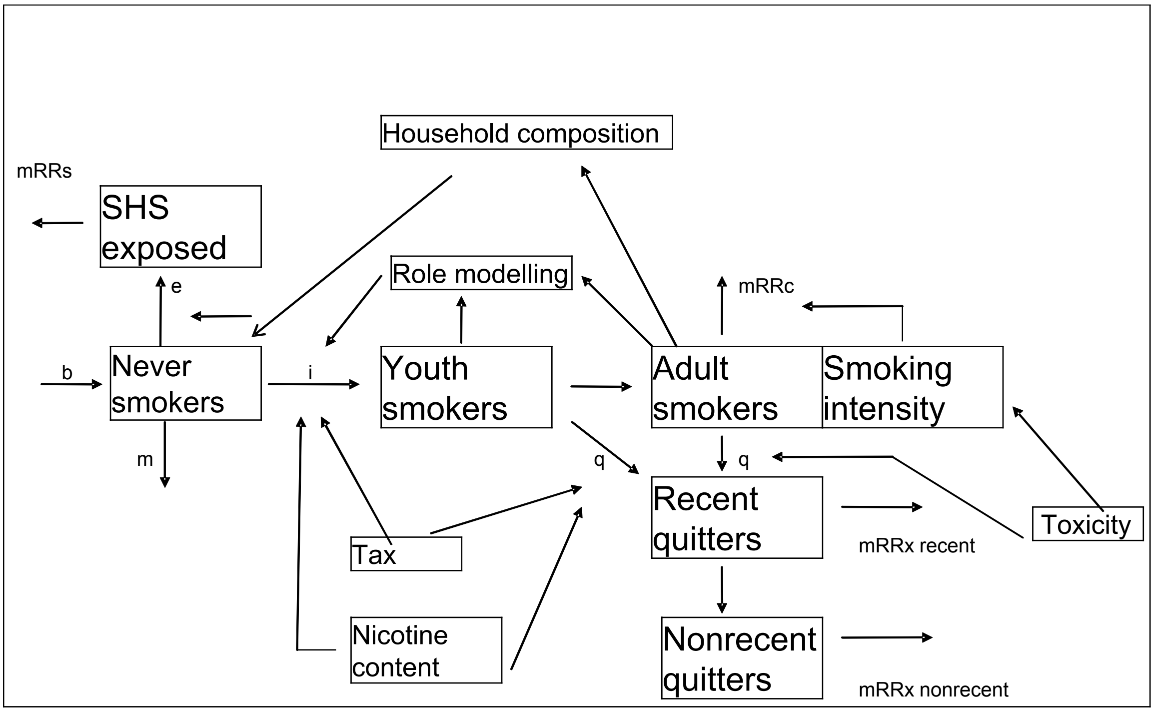
> “*Systems thinking* promotes holism as its primary intellectual strategy for handling complexity, whether the approach is hard or soft, carried out by academia or practitioners. Instead of analyzing complex systems by breaking them down into their parts, it advocates studying them as `wholes' using systems concepts…” [this relates to the problem structuring and casual loop modelling phases summarised in Table 1].
>
> “*Systems modeling* aims at describing, analyzing and prescribing a real entity or phenomenon by constructing a variety of systems models. It includes mathematical models, conceptual models, computer models and simulation tools…” [this relates to the casual loop modelling, dynamic modelling and scenario planning/modelling phases summarised in Table 1].
>
> “Finally, *systems practice*, or practical applications of systems thinking/ideas, is the greatest success of systems sciences in recent years. It has shown that systems sciences have the ability to translate theoretical notions into the practical domain through the use of systems methodologies, models and methods…” [this relates to the scenario planning/modelling and implementation/organisational learning phases summarised in Table 1].

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 with the tobacco policy model describing the experiments and the model performance measures for a range of tobacco control policies. Finally some limitations and areas for further work are outlined in the concluding section.

## CAUSAL LOOP MODELLING

The overall causal loop diagram 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 peer group smokers can be clearly seen, and the effects of various tobacco control measures on initiation rates (smoking starts), quitting smoking, and smoking intensity can also be observed in this diagram.

Figure 1: Causal Loop Diagram for the NZ Tobacco Policy Model




*Key*: i = smoking initiation rate; b = birth rate; e = exposure 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.

This diagram provides the conceptual framework for the development of the 4 sector system dynamics simulation model, briefly outlined in the following section. It must be emphasised that this model represents work in progress, and the authors are continuing to develop it along the lines outlined in the final section of this paper.

Nevertheless, the model is currently very useful for demonstrating the impact of a range of tobacco control policies. In some cases the output measures have been summarised outside the SD model. These performance metrics will ultimately be endogenised within the model.

## 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.

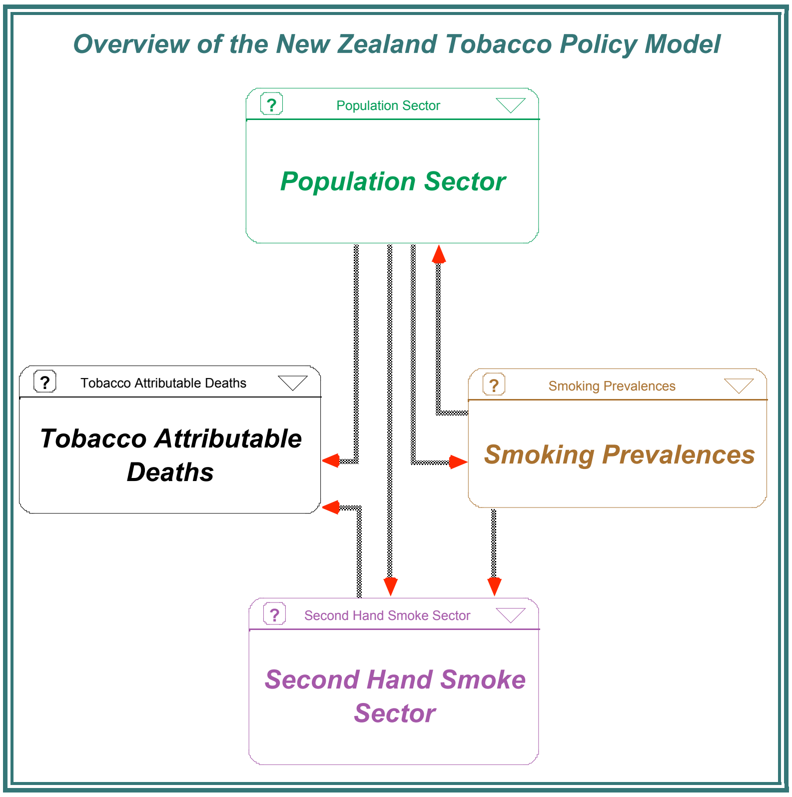



Figure 2: Overview of the MOH tobacco policy model

The tobacco sector consists of population aging chains broken down into approximately 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 deaths 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)

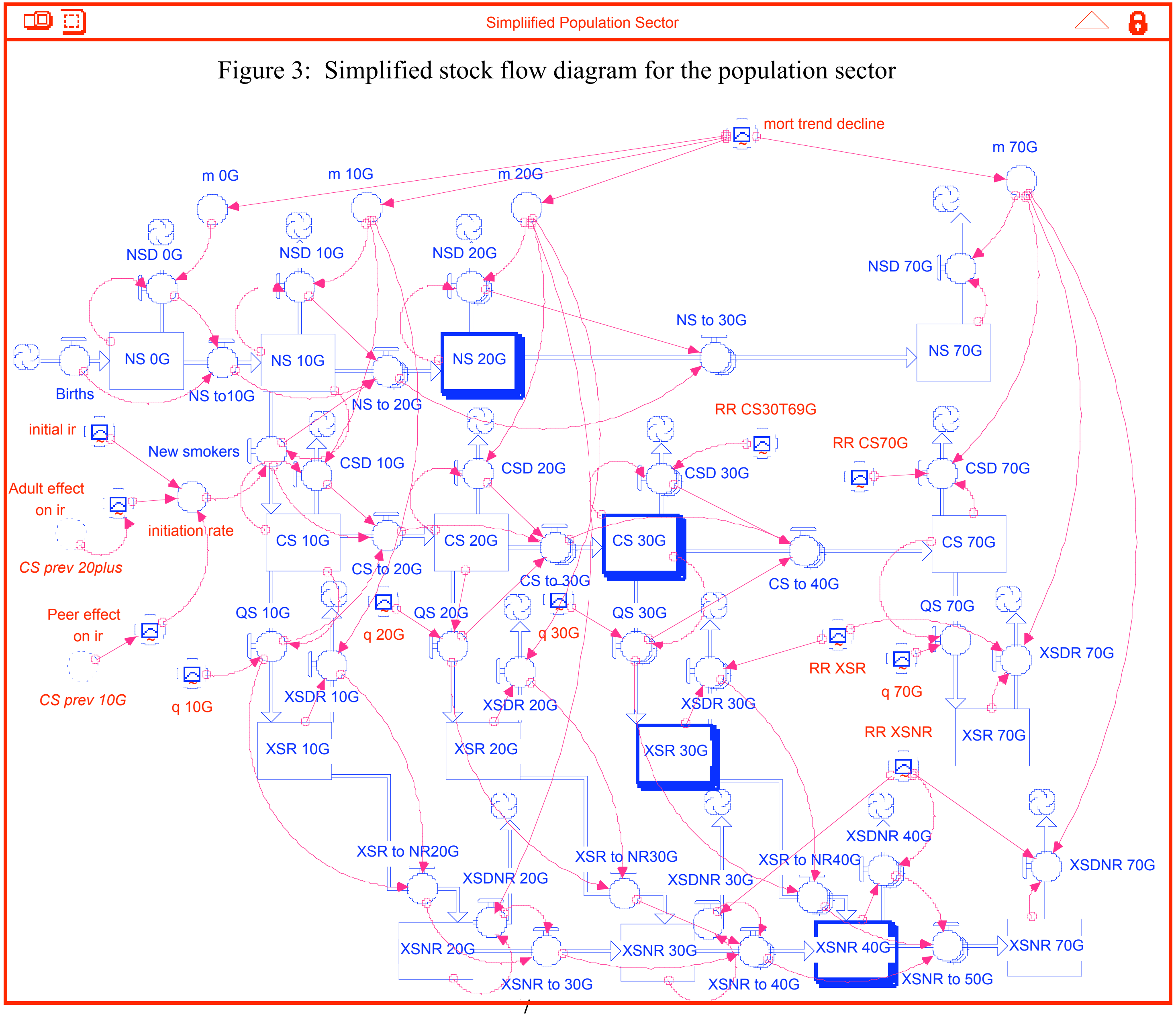
- m = mortality rate
- ir = initiation rate
- RR CS30T69G = relative risk of mortality of current smokers in the 30 to 69 year old age group

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) | Clements (modelled from Aus and NZ data 1990s) |
| Net quit rates | Clements (as above) |
| Smoking intensity distribution | NZHS 02/03 |
| 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) | Clements |
| RR SHS exposure | NZCMS (Ministry of Health 2005) |
| Never smokers exposed to SHS | NZHS 02/03 (Ministry of Health 2004) |
| Population estimates and projections (including mortality trend) | SNZ |

Figure 3: Simplified 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 by age, consumption and tobacco attributable mortality (TAM) – this involved minor tweaking of initiation and quit rates. The 'validation' experiments included:

- Base case reproduces observed prevalence, consumption, TAM
- 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 (or management flight simulator) 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. Also sensitivity analysis and scenario analysis can be undertaken by undertaking 'what if' experiments with the user interface ( e.g. changing the assumptions regarding adult and peer group effects on the smoking initiation rates, and the relative risks of mortality associated with current smokers, ex-smokers and second hand smoking).

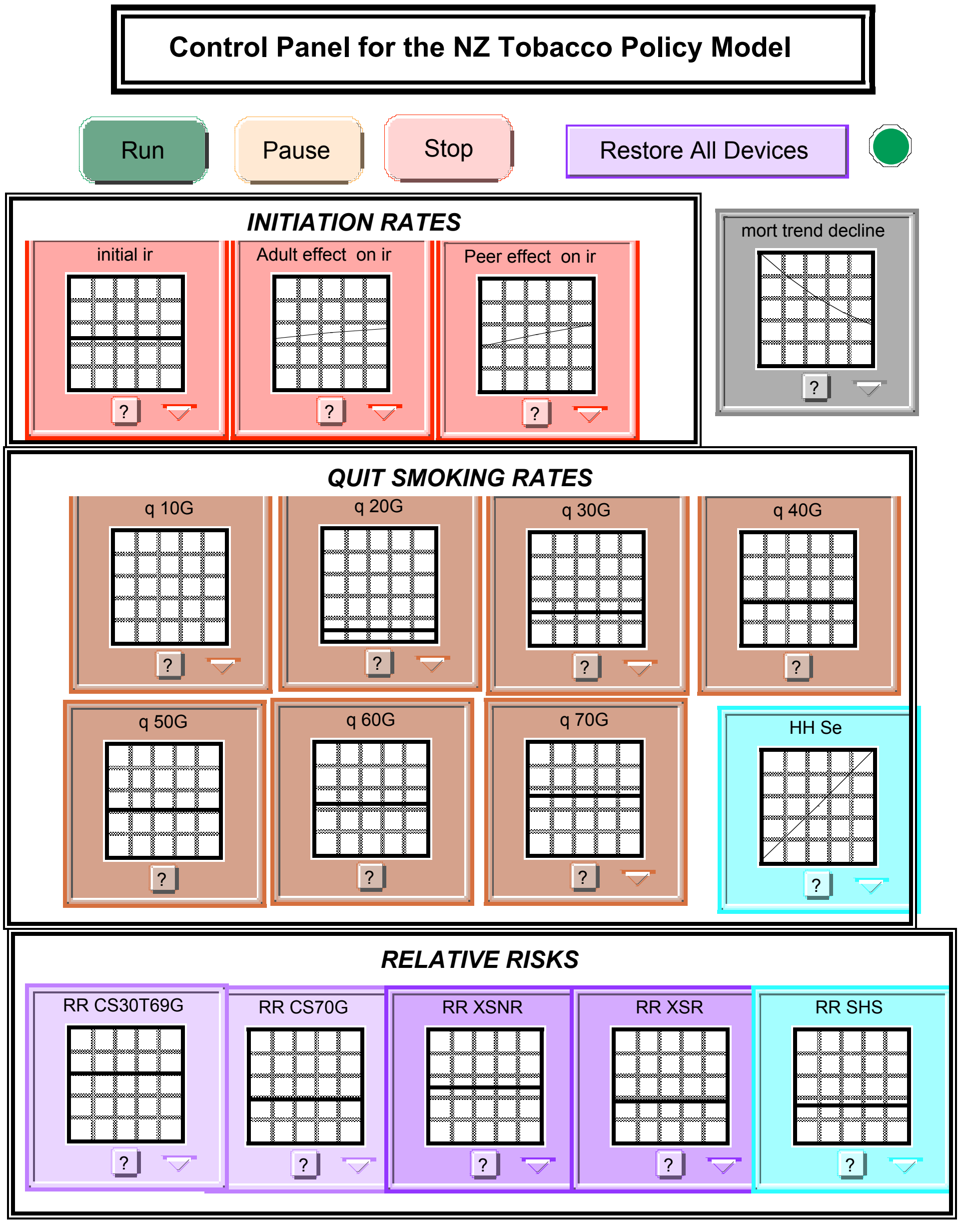



Figure 4: User interface for the tobacco policy model

A range of illustrative scenarios are provided, 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 contains the elasticities and sources for the major scenarios with the model. The main output variables (performance measures) include current smoking prevalence (rate and count), tobacco consumption (per capita and total NZ), and tobacco attributable mortality (rate and count).

Table 3: Elasticities (hazard functions) for the experiments

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

**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 |

The BAU scenario is of interest for 2 reasons:

- Target setting
- Counterfactual against which all intervention scenarios must be compared (it is invalid to compare the outcome of intervention in the future with the situation today – the only valid evaluation is to compare the BAU and intervention trajectories over an appropriate time span)

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. Other features are:

- 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).

Note that these estimates are oversimplified, because the model as currently constructed does not age standardise rates, nor does it allow for changes in fertility and net migration. Therefore it underestimates population growth and fails to fully reflect changes in population age structure (and doesn't capture changes in population ethnic composition at all).

**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')

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

- conditional demand elasticity (reduction in cigarettes/day among continuing smokers - intensity elasticity)

Meta –analysis (Chaloupka, 2002):

- short term consumption elasticity – 0.4 more recent studies suggest – 0.5
- long term about twice this i.e. – 0.8 to – 1.0
- about half comes from prevalence reduction and about half from cutting down
- so intensity elasticity and hence impact on RRc (and consequently also RRx and RRs) about - 0.5 (only interested in long term).

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).

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).

Overall summary is 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**

- Compatible with other national drugs policies
- "The present situation in which the most toxic form of nicotine delivery is the least regulated, is unacceptable from a public health perspective" (WHO, 2002)
- Serious risks – expansion of the tobacco or nicotine markets, compensatory smoking, gaming by industry, inability to audit (inadequate testing standards)

Harm minimisation (HM) is the new frontier in tobacco control. Keep in mind that 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, which no-one would like to repeat.

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.

We must emphasise that our objective with this paper is merely to illustrate what can be simulated with the SD model – policy decisions regarding harm minimisation strategies would need to take other factors into account as noted above.

## 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 "Henningfield approach" (Henningfield et al 2004) – denicotinisation – which is probably unacceptable to smokers and politically unrealistic at the present time. Instead, we are aiming 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.

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.

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 and initiate).

Benefits at the individual level will not translate into benefit at the population level if prevalence and consumption increases. We call this the 'reverse prevention paradox'.

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.

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 scenarios

Table 8: Summary of scenario assumptions

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

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.

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.

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.

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 much greater benefits than the affordability scenario on its own.

Substantial impacts on attributable mortality and consumption, but not prevalence, are seen with little delay. These increase steadily in the mid term and a substantial effect on prevalence emerges. And in the long term we see reductions of 15% or more in prevalence, consumption and most importantly, attributable mortality.

## Summary of results

Table 10. Summary of results - 2031

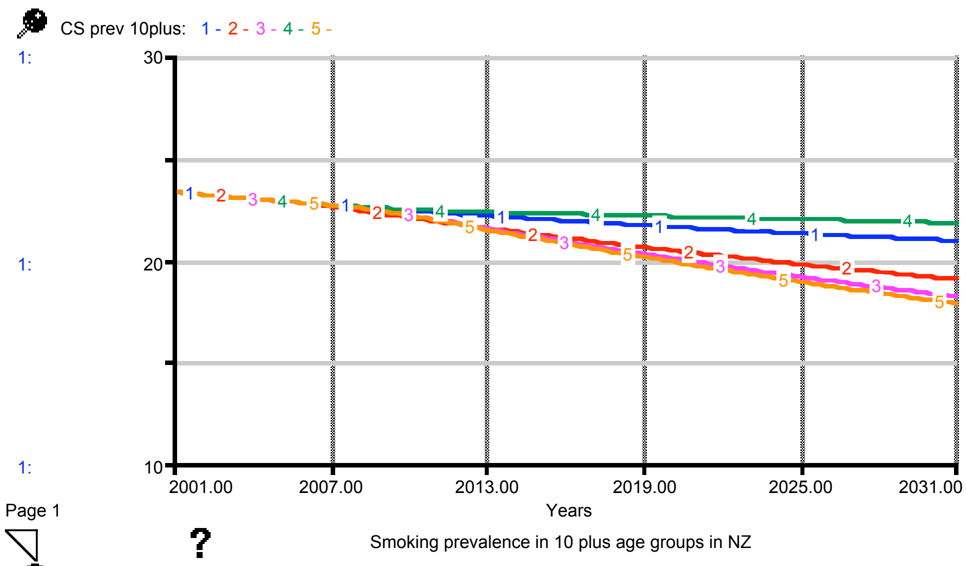
| | Prevalence | Consumption | TAM |
|---|---|---|---|
| Current (2006) | 23.3 | 1020 | 4330 |
| BAU | 21.0 | 775 | 4890 |
| Less affordable | 19.1 | 755 | 4500 |
| Less addictive | 18.2 | 820 | 4650 |
| Less toxic | 21.8 | 955 | 4550 |
| Combined | 17.9 | 710 | 4080 |

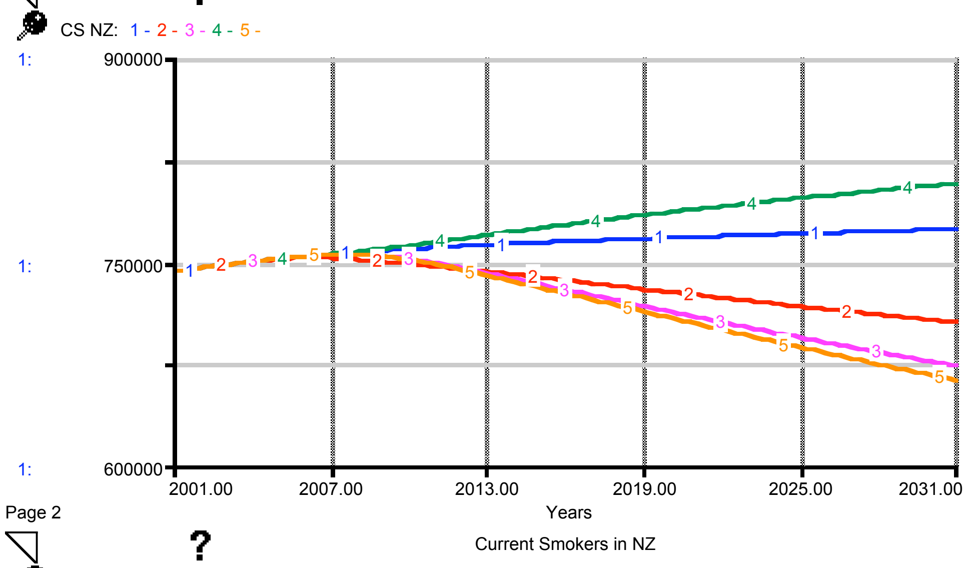
The different scenarios are compared here, using the key indicators in 2031 as the outcome measure.
The combined scenario achieves a prevalence of about 18%, one percentage point lower than the affordability scenario and slightly better than the next best scenario with respect to prevalence i.e. the addictiveness scenario.

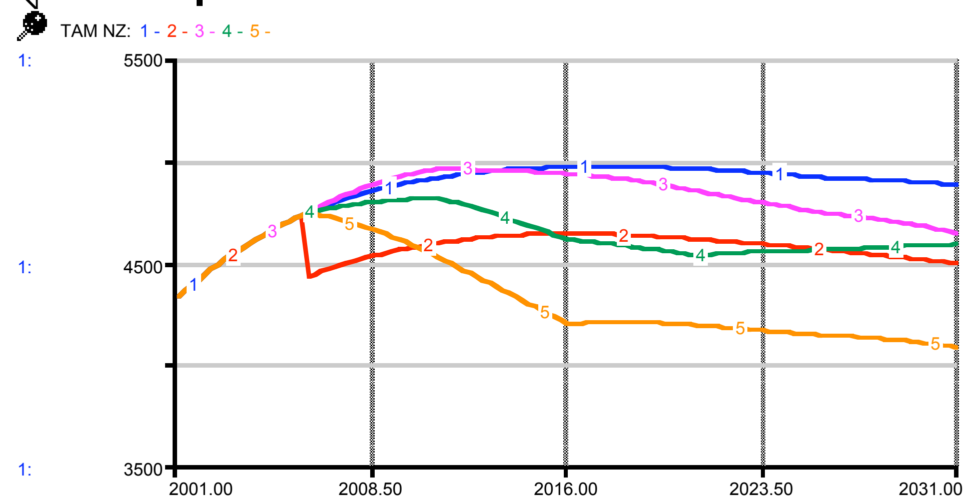
The combined scenario also achieves a lower per capita consumption than the affordability scenario could do by itself, at around 700 CE/y. And most importantly, it achieves a 10% lower attributable mortality than the affordability or toxicity scenarios on their own.

The dynamic behaviour of the main variables for each of the 5 scenarios discussed in this paper are summarised in Figure 5. The main performance measures include smoking prevalences, the number of current smokers and the annual mortality figures associated with tobacco smoking in New Zealand. Historical figures are shown for the period from 2001 to 2006, and the scenarios are provided for the period from 2006 to 2031.

Figure 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 been analysed with the system dynamics model developed for tobacco control in New Zealand. However, the model can also be used as the basis for examining a range of other tobacco control scenarios. These include: a Snus scenario (Swedish snuff); a Tobacco Authority (regulated market model) scenario; and a nicotine market regulation scenario.

From the results outlined, 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.

Once again, let us 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.

Also, there are some limitations to the tobacco control model as it currently stands. These include:

- The model is age structured but not differentiated by sex, ethnicity or economic/social grouping.
- Demographic trends (fertility, migration) are not fully captured, so population growth is under-estimated.
- Health effects are captured only by mortality, not morbidity.
- Some relevant dimensions of industry behaviour and tobacco control captured only crudely, if at all.

These limitations will be addressed by further development of this model. In the meantime, the system dynamics model is available for stakeholders in New Zealand:

- to provide a joint learning experience with respect to system dynamics 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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