

Smoking Model: Evaluating the Dynamics of Tobacco Smoking in Australia

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ABSTRACT

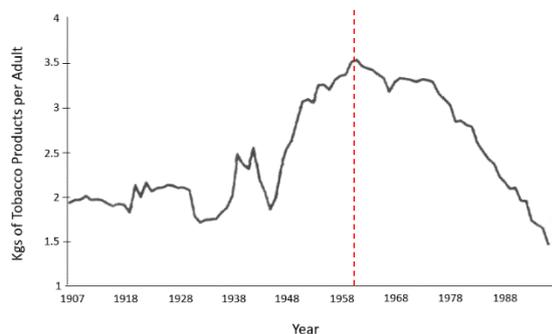
It is becoming increasingly accepted that smoking tobacco causes a wide range of deleterious health issues, including death. Awareness of these issues has resulted in a declining rate of smoking in Australia. However, the healthcare cost burden to the Australian Government remains high because of costs associated with anti-smoking campaigns coupled with the legacy effects of people who no longer smoke but still carry the health effects of when they did smoke. In this paper we present a system dynamics (SD) model (*Smoking model*) that is being developed to evaluate how tobacco smoking can be managed over time, whilst accounting for potential lag effects in the healthcare costs to Government. The model also aims to assist in estimating the impacts of certain interventions on the smoking prevalence over time to consider their effectiveness and role in policy making. The *Smoking model* is part of a teaching platform, called the UQ Cases project, which is scheduled to be completed by January 2020. This SD model is framed around the problem of the ongoing challenge of managing smoking in Australia.

Introduction

Tobacco smoking is associated with a wide variety of health problems and is responsible for the smoking-related deaths of thousands of people each year in Australia (Weiland et al., 2016).

As knowledge about the harmful health effects associated with smoking has increased, various interventions have been introduced by Governments to address the issue, starting in the 1950s. In Australia, this has led to a decline in tobacco consumption, after reaching its peak in the 1960s, as shown in Figure 1 (Bardsley and Olekalns, 1999).

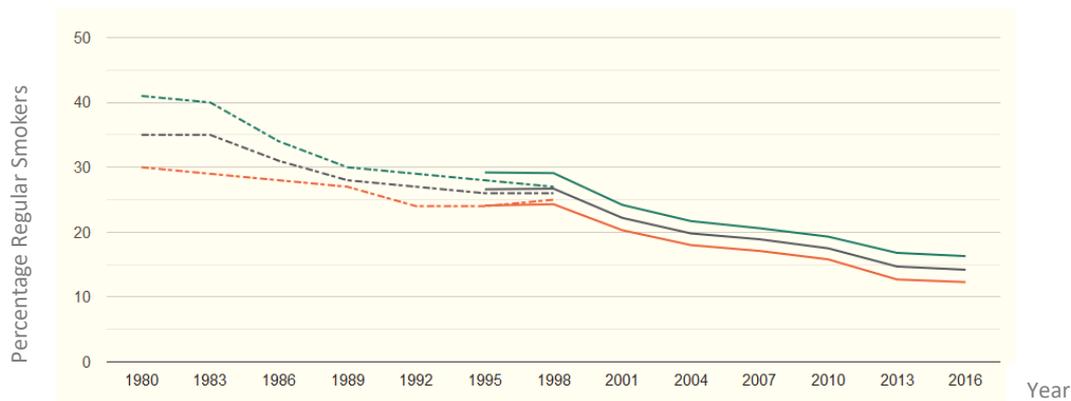
Decision-making in the model encompasses both economic (i.e. revenue from excise versus healthcare costs) and non-economic aspects (i.e. moral obligation to decrease smoking due to the deleterious health issues). A causal loop diagram (CLD) was constructed to provide the qualitative template for the SD model and featured prominent reinforcing and balancing loops that helped explain the observed behaviour from historical data. A SD model has been built from this CLD and is currently under development and testing. Preliminary testing indicates that the model captures the behaviour of the system e.g. smoking rates decline faster in response to Government interventions (tax increase, anti-smoking campaigns, plain packaging) but the cost of such interventions is not necessarily offset by reductions in healthcare recovery (from reducing smoking rates). Once the SD model testing is finalised, it will be used to evaluate the efficacy of Government interventions (policy evaluation), which will be presented at a later stage.



Source: adapted from Bardsley and Olekalns, 1999

Figure 1 – Annual Per Capita Consumption of Tobacco Products in Australia

The red line shows the timing of ‘peak’ consumption.



Source: Scollo and Winstanley, 2019

Figure 2 – Prevalence of Regular Smokers in % in Australia between 1980 and 2016

The orange line represents women, the green line indicates the men, and the purple line shows the total number of smokers. Data is collected from the Anti-Cancer Council of Victoria, representing the dotted line values, and the National Drug Strategy Household Survey, representing the normal line values.

In Figure 2, the same pattern is depicted in the behaviour of smoking prevalence for women, men, and for the total number of smokers (Scollo and Winstanley, 2019). This data shows a consistent decline in the number of male and female smokers in Australia for the period 1980–2016. It also highlights that the number of male smokers has been higher than the number of female smokers throughout this period (this aspect has not been implemented in the model).

The introduction of Government interventions and change in laws and regulations has coincided with a shift in the social acceptability of smoking that was the by-product of the decreasing smoking prevalence. Not long ago, in the 1950s, before knowledge about the harmful health effects of smoking became evident and widespread, smoking was a social norm. Everyone seemed to smoke and people were allowed to smoke in public places (Chapman and Freeman, 2008), such as restaurants, planes and even in hospitals. Nonetheless, as the scientific findings were spread out in communities, people began to understand the inherent risks of smoking. This has contributed to the decline in smoking prevalence, and led to the increasing unacceptability of being a smoker in society (Chapman and Freeman, 2008).

In addition to its rising denormalisation in society (Chapman and Freeman, 2008), smoking also has a significant health cost burden for Governments that can be of the order of magnitude of hundreds of millions of Australian dollars every year (Hurley, 2006). These costs have continued to rise despite the declining rate of smoking, indicating a delay in the associated health effects of smoking. In Australia, there was an increase of 23.5% in the overall smoking related costs in 2004-2005, based on 1998-1999 estimates, despite the decreasing pattern in smoking

prevalence in that same period (Collins and Lapsley, 2011).

This is explained by the lagged or legacy health effects associated with smoking, which continued after people have quit smoking. In other words, even if people stop smoking today, the Government will still be confronted (even if at a lower level) of the impact of previous decades of smoking, until the lagged effects work their way through the system (Collins and Lapsley, 2011).

Somewhat paradoxically, tobacco smoking is a significant source of revenue for Governments in the form of tobacco excise, which is estimated to be billions of Australian dollars a year (Commonwealth of Australia, 2010). Even after adjustments (i.e. loss of income tax due to mortality), tobacco tax revenue outweighs tobacco-related costs (Commonwealth of Australia, 2010). Given this tension between economics and social expectations, decision makers in the Government need to consider both economic and moral obligations when forming policy for tobacco smoking.

The Australian Government has increasingly adopted an active role in introducing new tools and strategies for tobacco smoking. Its focus has not solely been on the health effects of smoking, but also on denormalisation strategies that are accompanied by the increasing unacceptability and stigma (Hefler and Carter, 2017). The common strategies used are:

- Tobacco tax and pricing
- Plain packaging and pictorial warnings
- Anti-smoking campaigns.

Tobacco Tax and Pricing

The tax on tobacco is passed on to consumers in the form of increased cigarette prices and it is known to increase the rate of quitting and decrease the rate of uptake (Hirono and Smith, 2018). Hence, an increase in tax is aimed at reducing the number of people smoking. The effect of tax increase on Government revenue (excise) then depends on whether the increase in price offsets the loss in tobacco sales or not (Ekpu and Brown, 2015). The Australian Government has a track record of raising the excise tax of cigarettes to the point, where prices in Australia are currently the highest in the world (AUD \$30.00 per 25-pack of Marlboro cigarettes) (Numbeo, 2019). By 2020, this price is projected to reach AUD \$40.00 per packet based on the Government's 12.5% annual increase in tobacco excise from 2016 (Hirono and Smith, 2018). Although these price increases work effectively and it is proven to reduce smoking rates among the general community, they have a diminishing effect on the most vulnerable members of the community. It is likely to create a greater disadvantage for them, both financially and socially (Hirono and Smith, 2018).

Plain Packaging and Pictorial Warnings

Australia has passed the legislation requiring the mandatory plain packaging for tobacco products in 2011 (Jarman, 2013). This meant the removal of logos, colours and brand images. All tobacco products are now presented with standard colour and font and pictorial warnings of the health effects (Jarman, 2013). Although found to be effective in reducing the smoking rate, its impact cannot be separated from the staged excise rate increases together with the price increases in the past years (O'Bannon and Clark, 2019).

Anti-smoking Campaigns

Mass media campaigns have long been a core strategy in tobacco control, aiming to expose messages about the negative health effects and the denormalisation of smoking (Borland and Balmford, 2003). Not only do they directly influence the wide community, they indirectly contribute to the denormalisation of smoking by influencing social norms, and encourage discussion about the detrimental effects of smoking among family and friends (Purcell, 2015).

In Australia, there was an evident increase in campaigning in 1997 as part of the National Tobacco Campaign (Hill and Carroll, 2003). It is important to note that advertising should continue to have a high exposure level to maintain its effect (Borland and Balmford, 2003). However, greater exposure also means greater investment expenditure to the Government, hence it becomes dependent on the availability of financial resources.

METHODOLOGY

The aim of this paper is to present a system dynamics model (*Smoking model*) that is being developed to explore and evaluate how tobacco smoking can be managed whilst accounting for potential lag effects in the healthcare costs to Government. The problem of managing tobacco smoking, the efficacy of interventions and the results are all presented in the system dynamics methodological framework modelling (Maani and Cavana, 2007).

Accordingly, the development of the *Smoking model* follows the four-step process of (i) problem structuring, (ii) causal loop modelling, (iii) dynamic modelling and (iv) scenario planning and modelling (Maani and Cavana, 2007).

The *Smoking model* is currently at step (iii) of the development process and therefore this paper does not include details on the scenario planning and modelling step, which is still to be completed.

Development of this *Smoking model* is based upon a desktop study and consultation with experts from the field of study of public health. Therefore, the model development is based on continuous parameterisation of the model variables, which comprises updating the model variables as new information becomes available i.e. through literature and expert elicitation. Consequently, this process follows an iterative approach as consistent with systems theory (Sterman, 2000).

The *Smoking model* is also part of a teaching platform, called the UQ Cases project, which is scheduled to be completed by January 2020. The UQ Cases project uses system dynamics modelling as a platform for teaching and learning purposes at the University of Queensland.

RESULTS AND DISCUSSION

Problem Structuring (i)

The focus of the study is Australia and therefore interventions are assumed to be those undertaken by the Australian Federal Government.

The time horizon for the system dynamics model (Sterman, 2000) is 80 years, encompassing the period 1980–2060. The time horizon period includes looking at the past 40 years (1980–2019), incorporating historical trends of smoking (increasing and peaking). This can be used to evaluate the plausibility of the model outputs.

This involves looking at the changing smoking prevalence, the revenue of Government and the health costs related to smoking, for example. Changes to these model outputs are analysed in the ‘projection period’, which is looking at 40 years into the future, (2020–2060). Therefore, during this projection period, the future impacts of the presented ‘smoking interventions’ by the Government can be considered and evaluated.

The associated health care costs will also be identified and analysed in these future projections, in comparison with the prevalence of smoking, to see the correlations and the plausibility of lagged effects in the system.

Causal Loop Modelling (ii)

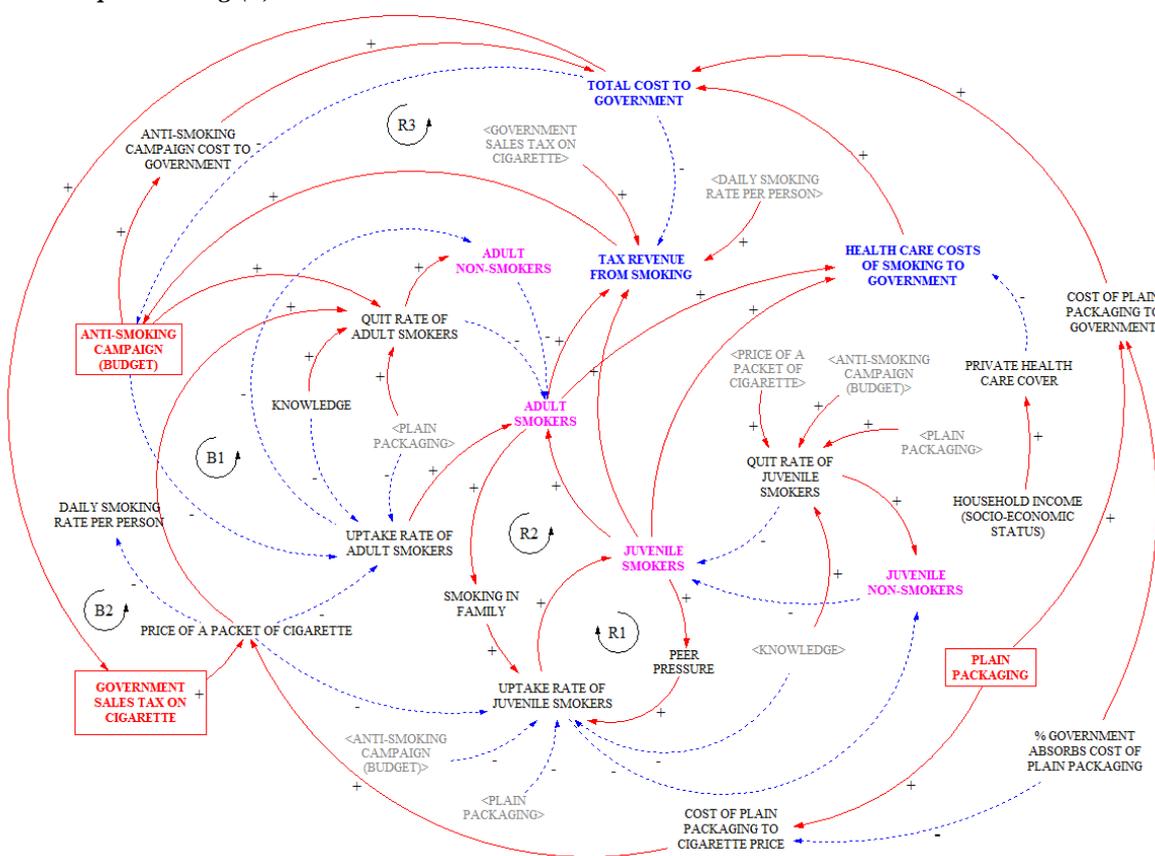


Figure 3 – Causal Loop Diagram of the Smoking Model

The red lines represent the connections with ‘plus’ polarities, and the blue dotted lines show the connections with ‘minus’ polarities – polarities indicate the direction of correlation between two connected variables.

The causal loop diagram (CLD) of the *Smoking model* is shown in Figure 3. It was developed using the Vensim software (<https://vensim.com/>). This qualitative model helps to explain the observed trends of the ‘smoking population’ (i.e. Figure 2). This CLD includes both balancing (B) and reinforcing (R) loops, which are shown in Figure 3 and summarized in Table 1 below.

The two balancing loops (B1, B2) reflect how the cost of anti-smoking campaigns (B1) and the loss of revenue (B2) can be an inhibition on the ongoing use of these interventions. Reinforcing loops R1 and R2 reflect how family history of smoking and peer-group pressure can drive further smoking in a ‘vicious cycle’. The role of family and peer-group smoking have been shown to be key determinants of higher smoking rates in Australia (Kelly, et al., 2010).

Reinforcing loop R3 reflects the effectiveness of anti-smoking campaigns. Although a decision to reduce campaign budget would reduce the government expenses at first, campaigns being a key determinant in the uptake rate of smoking, if the number of smokers and their health care costs increase, it could lead to further increase in total government cost.

The CLD also includes the three main intervention strategies highlighted in the *Introduction* (i.e. tobacco tax, plain packaging, and anti-smoking campaign), and these are denoted in the CLD by red text in boxes. Further discussion of these interventions is provided in the following *Dynamic Modelling* section.

Although not directly linked to in the CLD (and therefore not part of feedback loops), the key determinants of these intervention points are presumed to include economic (i.e. health care costs of smoking) as well as non-economic factors (i.e. moral obligation to reduce the smoking prevalence).

To align with the pedagogical focus of the *Smoking model* (teaching tool as part of the UQ Cases project), the premise is that the ‘decision makers’ (i.e. the model operator) will draw upon these economic and non-economic model outputs in selecting their interventions to address the problem of smoking rates and the associated healthcare cost burden.

Table 1 – Summary of Feedback Loops from the Dynamic Hypothesis

Loop Type	Variables
B1	Anti-smoking campaign (budget) → Uptake rate of adult smokers → Adult smokers → Health care costs of smoking to government → Total cost to government → Anti-smoking campaign (budget)
B2	Total cost to government → Government sales tax on cigarette → Price of a packet of cigarette → Uptake rate of adult smokers → Adult smokers → Health care costs of smoking to government → Total cost to government
R1	Juvenile smokers → Peer pressure → Uptake rate of juvenile smokers → Juvenile smokers
R2	Juvenile smokers → Adult smokers → Smoking in family → Uptake rate of juvenile smokers → Juvenile smokers
R3	Total cost to government → Anti-smoking campaign (budget) → Uptake rate of adult smokers → Adult smokers → Health care costs of smoking to government → Total cost to government

Dynamic Modelling (iii)

The aim of the dynamic modelling process is to test the dynamic hypothesis (Sterman, 2000) that is represented by the CLD and analyse the behaviour the model produces for plausibility.

The *Smoking model* was developed from the CLD presented in the previous section and the Stella Architect software (<https://www.iseesystems.com/>) was used to create this model. The model uses the default, Euler integration method and the time step DT is set to 0.125. The simulation time is specified to 80 years, with start and stop times of 1980 and 2060 accordingly.

The simulation model is separated into six main modules (Figure 4), detailed below.

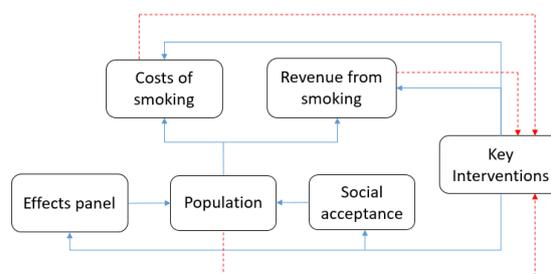


Figure 4 – Architecture of the Smoking Model

The blue solid lines represent actual connections in the model and the red dotted lines represent information that the model operator uses to base their decisions (interventions) on.

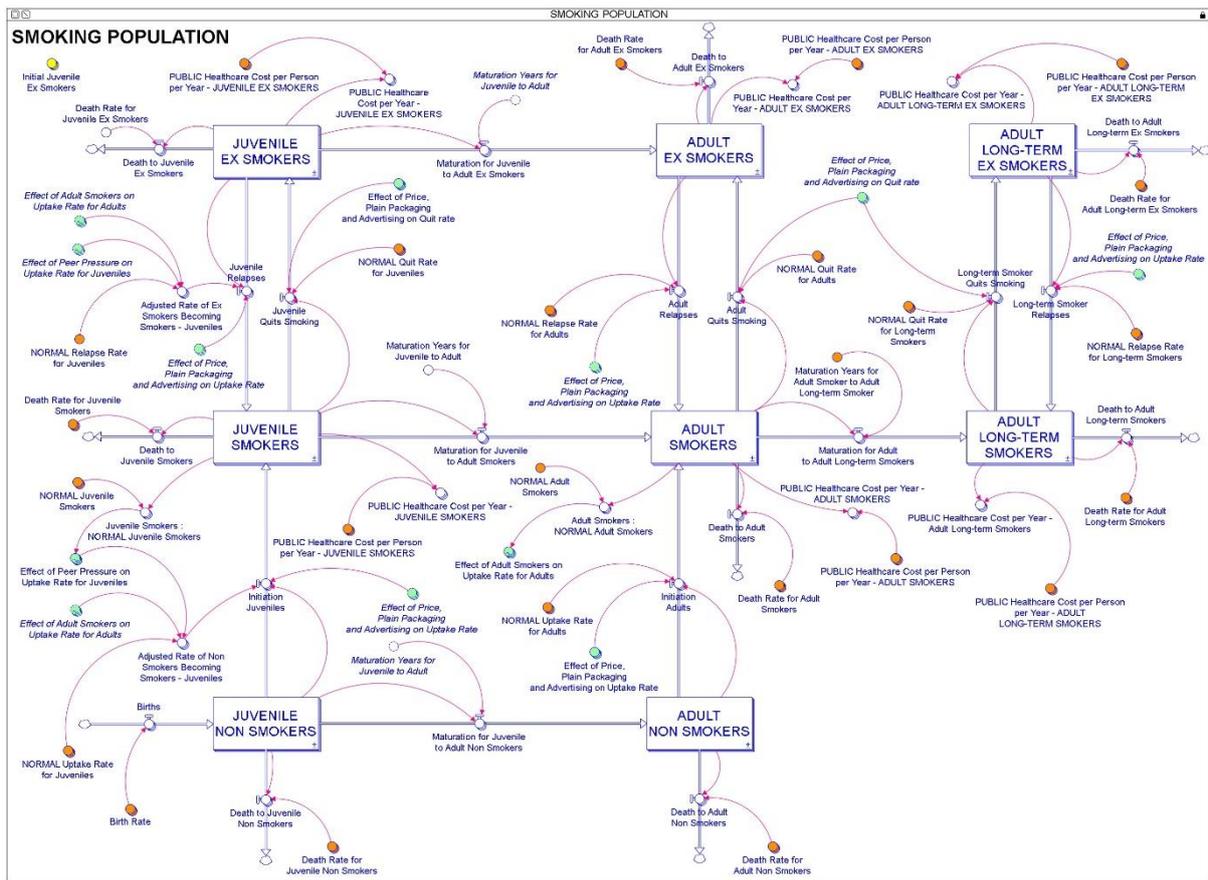


Figure 5 – Stock and Flow Model for the Population Module

Population Module (Figure 5) – this is an age-structured (juveniles, adults) model that separates people into categories of non-smokers (never smoked), smokers and ex smokers. The population module is arrayed for poverty status (poor, non-poor) based on evidence that the smoking rates (Purcell, 2015) and dependence on the public healthcare system (Australian Institute of Health and Welfare, 2016) are different for these two cohorts. That is, it is assumed in the model that the non-poor population has a higher rate of private healthcare cover than the poor population, entailing that they are less reliant on the public healthcare system (and therefore means less cost burden to the Government). The ‘adult ex smokers’ and ‘adult long-term ex smokers’ are separated to allow distinction between the health effects of short-term versus long-term smokers (Institute of Medicine, 2015).

The population module draws upon information from the ‘Effects Panel’ and ‘Social Acceptance’ modules and provides input to the ‘Costs of Smoking’ and ‘Revenue from Smoking’ modules (Figure 4).

This module is the focus of the whole *Smoking model* because changes in the ratio of smokers, non smokers and ex smokers are primarily used to test the effectiveness of decisions on uptake and quit rates, hence the changes in smoking prevalence.

Social Acceptance Module – this is used to simulate the changing knowledge and social acceptance of the smoking society (denormalisation) (Chapman and Freeman, 2008). ‘Knowledge’ in the model refers to what is known about the deleterious health effects of smoking whilst ‘social acceptance’ represents the society’s level of acceptance (or disapproval) about smoking. These two attributes (knowledge and acceptance) are aggregated as a single variable called ‘social opposition’ in the model – this framing is used because opposition and knowledge increase together whereas ‘social acceptance’ decreases as knowledge increases. A Bass-diffusion (Sterman, 2000) system is used to model this dynamic. That is, the model assumes that social acceptance changes from ‘potential’ to ‘actual’ through a diffusive process. It is an important part of the model as the shift in acceptability was evident in the past and together with knowledge about health effects, it played a major role in contributing to the decreasing smoking rates (Chapman and Freeman, 2008).

Key Interventions Module – this module presents the three intervention options: ‘advertising campaigns’, ‘plain packaging’ and ‘government sales tax’. In the *Smoking model*, the advertising campaigns are separated into different decades, where the advertising budget can be modified and its effectiveness can be analysed.

In terms of the plain packaging, this is a ‘once applied’ decision, which when made, holds for the remainder of the simulation. The year that it is implemented can be set at any year for the future projection period of 2020–2060. An additional specification is the fraction of cost associated with plain packaging that is absorbed by the Government (rather than passed onto the consumers through an increase in price). Also dependant on this fraction of cost absorbed by the Government, the plain packaging influences the government sales tax and the price of cigarettes and this can also be set separately.

Effects Module – this module coalesces the main effects of change in the model and then calculates the multiplicative effect of interventions on uptake and quit rates, as well as social acceptance.

Costs of Smoking Module – this module takes into consideration the Government health care costs associated with smoking (assigning different values for each category and also differentiating based on

Model Results and Testing

The model is being validated based on the process described in Maani and Cavana (2007). This includes testing the plausibility of the model behaviour, the maintenance of conservation of flow, unit consistency and extreme condition testing.

Unit consistency has been tested using the built-in function of Stella Architect, and some base cases were reproduced to start the initial validation of the model.

For the first period of the model, prior to the extreme condition being introduced (i.e. 1980–2019), the model behaviour was considered to be plausible. For example, the total population (i.e. the population of Australia – note that this data is not shown) showed growth consistent with the actual growth for this period (Australian Bureau of Statistics, 2012). The number of smokers has dropped in the first 40 years (Figure 6), and this decrease in the number is consistent with the historical data, presented on Figure 2. The slight rise in smokers just before the 40 year mark might be indicative of the general population growth, which can confound the amount of people smoking.

The extreme condition testing consisted of setting the government sales tax on a packet of cigarette to 100% at the 40 year mark (i.e. the year 2020) of the simulation period (i.e. the mid-way point of the simulation period). This resulted in the outcomes shown in Figures 6-8.

poverty status), and the key intervention costs. This refers to the cost of launching an advertising campaign (this can also be adjusted in the advertising budget) and the cost of plain packaging absorbed by government (this value also correlates with the decision made in the plain packaging intervention in the ‘fraction of cost absorbed by Government’). A key dynamic in this module is the separation of poor and non-poor people to account for the different rates of private and public health care cover. As mentioned previously, the Government cost burden is associated with the public system of health care.

Revenue from Smoking Module – this module puts the emphasis on the revenue stream that the Government receives from the sales of cigarettes. This is heavily dependent on the sales tax that the Government puts on cigarette sales. It correlates with the key interventions and for example determines the available budget for anti-smoking initiatives, such as the advertising campaigns and the fraction of cost of plain packaging that is absorbed by the Government.

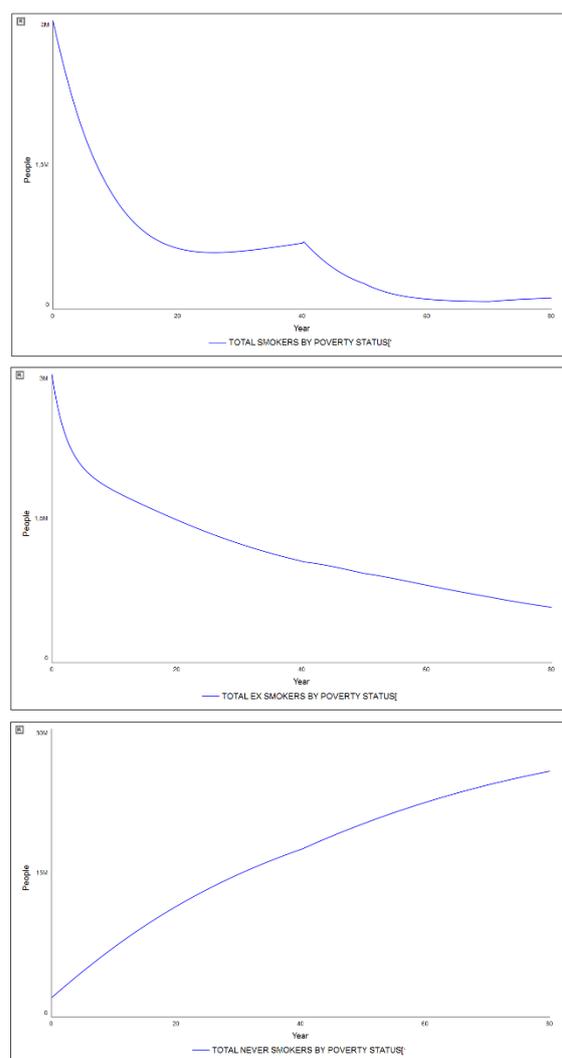


Figure 6 – Total Number of Smokers, Ex Smokers and Non Smokers

The number of smokers (Figure 6) dropped abruptly after the introduction of the increased sales tax, which is consistent with the dynamic hypothesis, meaning that a price increase would encourage people to quit and deter them from uptaking smoking, hence confirming the understanding of the dynamics of this system.

Similarly, as it could have been expected, after the introduction of the 100% government tax, the government revenue increased sharply at the 40 year mark and slowly started to decrease (Figure 7). It is evident that as the number of smokers started to fall, tobacco sales have also decreased, which resulted in the slow decrease in government revenue.

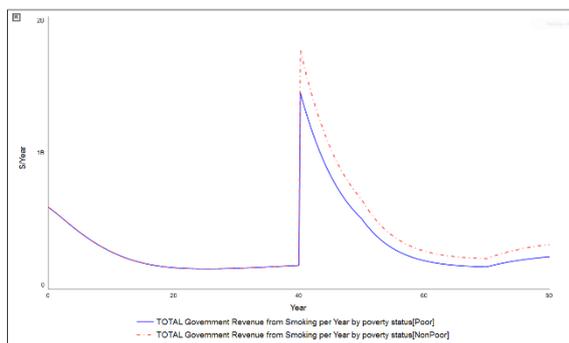


Figure 7 – Total Government Revenue from Smoking per Year

In terms of the healthcare costs (Figure 8), its behaviour follows the one of the smokers in the same pattern – as more people quit, the healthcare costs also decreased. However, it is important to acknowledge the lagged effects in the system, which explains the moderate impact in this aspect.

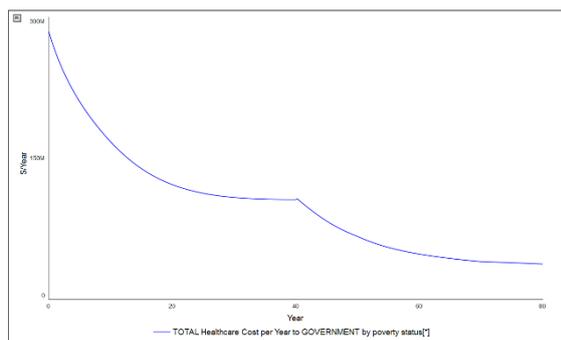


Figure 8 – Total Healthcare Costs per year to the Government

Although the revenue showed a quick reaction after the intervention, it is clear that the costs do not move as quickly and immediately. It is due to the inertia that characterises the system, which is why the healthcare costs would only start to change slowly. As was explained earlier and what the graph output shows is that previous decades of smoking could affect the current healthcare costs.

Overall, this example verifies the plausibility of the model and underlies some key behavioural aspects of the system. Preliminary scenario analysis will be carried out and presented in the final stage of the process (iv), upon the model building and testing and the finalisation of parameterisation of system variables.

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REFERENCES

- Australian Bureau of Statistics. (2012). *Australian Bureau of Statistics*. Retrieved from: <https://www.abs.gov.au>
- Australian Institute of Health and Welfare. (2016). *Australia's health 2016*. Canberra: Australian Institute of Health and Welfare.
- Bardsley, P., & Olekalns, N. (1999). Cigarette and tobacco consumption: Have anti-smoking policies made a difference? *Economic Record*, 75(230), 225-240.
- Borland, R., & Balmford, J. (2003). Understanding how mass media campaigns impact on smokers. *BMJ Journals*, 12(2). doi:10.1136/tc.12.suppl_2.ii45
- Chapman, S., & Freeman, B. (2008). Markers of the denormalisation of smoking and the tobacco industry. *BMJ Journal*, 17(1). doi:10.1136/tc.2007.021386
- Collins, D. J., & Lapsley, H. (2011). *The costs of tobacco, alcohol and illicit drug abuse to Australian society in 2004/05*. Canberra: Department of Health and Ageing. doi:10.1037/e674312010-001
- Commonwealth of Australia. (2010). *2010-11 Australian Government Budget - Budget Paper No. 1*. Canberra: CanPrint Communications Pty Ltd.
- Ekpu, V. U., & Brown, A. K. (2015). The Economic Impact of Smoking and of Reducing Smoking Prevalence: Review of Evidence. *Tobacco Use Insights*, 8, 1-35. doi:10.4137/TUI.S15628
- Hefler, M., & Carter, S. M. (2017). Smoking to fit a stigmatised identity? A qualitative study of marginalised young people in Australia. *SAGE journals*, 23(3). doi:10.1177/1363459317745690
- Hill, D., & Carroll, T. (2003). Australia's National Tobacco Campaign. *BMJ Journals*, 12(2). doi:10.1136/tc.12.suppl_2.ii9
- Hirono, K. T., & Smith, K. E. (2018). Australia's \$40 per pack cigarette tax plans: the need to consider equity. *BMJ Journals*, 27(2). doi:10.1136/tobaccocontrol-2016-053608
- Hurley, S. F. (2006). Hospitalisation and costs attributable to tobacco smoking in Australia: 2001–2002. *The Medical Journal of Australia*, 184(1), 45. doi:10.5694/j.1326-5377.2006.tb00102.x
- Institute of Medicine. (2015). *Public Health Implications of Raising the Minimum Age of Legal Access to Tobacco Products*. Washington DC : The National Academies Press.
- Jarman, H. (2013). Attack on Australia: Tobacco industry challenges to plain packaging. *Journal of Public Health Policy*, 34(3), 375-387. doi:10.1057/jphp.2013.18
- Kelly, A. B., O'Flaherty, M. C., Connor, J. P., Homel, R., Toumbourou, J. W., Patton, G. C., & Williams, J. (2010). Multi-level and modifiable factors that underlie community variation in child tobacco use. *27th International Congress of Applied Psychology*. Melbourne: Australian Psychological Society.
- Maani, K. E., & Cavana, R. Y. (2007). *Systems Thinking, System Dynamics: Managing Change and Complexity* (2nd ed.). Auckland: Pearson Education New Zealand.
- Numbeo. (2019). *Cost of Living*. Retrieved from Numbeo: https://www.numbeo.com/cost-of-living/country_price_rankings?itemId=17&displayCurrency=AUD
- O'Bannon, J., & Clark, J. (2019). *Tobacco Excise: Historical Trends and Forecasting Methodology - Treasury Working Paper*. Australia: Australian Government - The Treasury.
- Purcell, K. (2015). *Evidence review: Addressing the social determinants of inequities in tobacco use*. Victoria: Victorian Health Promotion Foundation.

Scollo, M. M., & Winstanley, M. H. (2019). *Tobacco in Australia: Facts and Issues*. Melbourne: Cancer Council Victoria 2019.

Sterman, J. D. (2000). *Business Dynamics: Systems Thinking and Modeling for a Complex World*. Boston: Irwin/McGraw-Hill.

Weiland, T., Jelinek, G. A., Taylor, S. E., & Taylor, D. M. (2016). Tobacco smoking by adult emergency department patients in Australia: a point-prevalence study. *Public Health Research & Practice*, 26(3). doi:10.17061/phrp2631634