MONASH University
Business and Economics

A NEW THEORETICAL FRAMEWORK FOR MODELLING AND ANALYSING COMPLEX TOBACCO CONTROL SYSTEMS

Jian Ying Zhang, David Young, Ken Coghill, Sonja Petrovic-Lazarevic, Ron Borland, Chung-Hsing Yeh & Susan Bedingfield

Working Paper 15/07
May 2007

DEPARTMENT OF MANAGEMENT
WORKING PAPER SERIES
I S S N 1 3 2 7 – 5 2 1 6

Abstract

This paper presents a new theoretical framework for modelling and analysing complex tobacco control systems. First, we propose an interaction model that identifies the key components of a tobacco control system, and how these components interact with each other to affect the outcomes of tobacco control policy planning and development. Second, we provide a conceptual model that articulates a cycle of tobacco control policy planning/making, enactment, monitoring and refinement. Finally, we outline the major challenges of applying this approach to real life. This framework provides a useful way of studying the relationship between science, policy and the outcomes of policy for tobacco control. It has potential to become a good framework for other complex social issues, such as nutrition and its links to various issues including cancer, cardio-vascular disease and ageing.

A NEW THEORETICAL FRAMEWORK FOR MODELLING AND ANALYSING COMPLEX TOBACCO CONTROL SYSTEMS

INTRODUCTION

Pioneering studies conducted by Richard Doll, Alton Ochsner, Ernst Wynder and others in the 1950s (Wynder, 1997), extended by comprehensive investigation from quite different domains about tobacco use and its effects on human health over the next fifty years (Boyle et al., 2004), has led to widespread acceptance that tobacco use is a major cause of premature death around the world. If we also consider the indirect losses caused by tobacco use, such as the amount of sickness and suffering caused by smoking, costs of medical treatment for related illness, absenteeism from work, and costs of fires caused by smoking, we can conclude that human health damage caused by tobacco use is very great indeed. In response, significant progress in tobacco control policy planning and development has been reported (Boyle et al., 2004). One major step is the establishment of the first international public health treaty, the “Framework Convention on Tobacco Control (FCTC)” by the World Health Organization in 2003. Up to now 142 parties, which represent 95% of the world’s population, have ratified the FCTC. Subsequently, developing the most suitable techniques, methodologies and models to monitor the performance and evaluate the effectiveness of relevant tobacco control policies have become important research issues, since an efficient and effective monitoring and evaluating system can provide accurate and timely information on the performance of policies, programs and projects. This information can provide invaluable support for decision-making, decision-refinement and ongoing management of government activities, and can underpin accountability relationships.

Many useful research outcomes have been reported. For example, Sneden et al. (2006) have developed a feedback model for applied research on tobacco control. Fong et al. (2006) have developed a conceptual framework for the International Tobacco Control Policy Evaluation Survey (ITCPES) project. Borland et al. (Borland et al., 2006; Young et al., 2004; Hammond, et al., 2006) report on the effectiveness of tobacco control polices across four countries that are included in the ITCPES study: Australia, UK, USA and Canada. If we take a closer look at these research results, we find that these approaches have some limitations, since majority of them are based on linear regression analysis, and in some cases the assumption of linearity may be problematic. In addition, these available techniques did not address the causal interrelatedness of smokers, non-smokers, researchers, doctors, advocates, tobacco industries, policy makers etc in co-producing the targets of tobacco control policies. As a result, significant gaps in tobacco control policy planning and development remain.

In this paper, we propose a new theoretical framework and associated quantitative analytical techniques for modelling and analysing complex tobacco control systems. With this new approach, we aim to capture the essential features of the complex tobacco production, manufacturing, distribution and consumption system as a discrete dynamic network. All factors in this dynamic network interact each other and affect the outcomes of tobacco control policy as a whole. At the same time, the status of a factor will vary over time because each of them depends heavily on inputs from other factors, and the power of one factor to influence another one can vary considerably. Also, we introduce the concept of feedback (directed cycle). Successfully handling feedback will be one of the most important contributions of this system, since feedback enables the system to adjust (adapt) itself in response to the changing environment, and information about the differences between desirable goals and actual outcomes. This new approach should provide extremely useful ways of evaluating and refining the outcomes of tobacco control policy planning and development in an environment of uncertainty and incomplete information.

The paper is organized as follows. Section 2 provides a brief literature review of the available techniques for dealing with the causal relationships among a set of individual and social concepts. Section 3 proposes the new theoretical framework for modelling and analysing complex tobacco control systems, including an interaction model that identifies the main components involved in a tobacco control system, how these components interact each other, and how they work together to affect the outcomes of tobacco control policy planning and development as a whole. Section 4 provides a conceptual model that articulates a cycle of policy making, enactment, monitoring and refinement in tobacco control systems. Section 5 outlines some challenging problems of applying this new technique to real life circumstances, and draws some conclusions.

RELATED WORKS

There are many techniques available for describing, understanding and evaluating the effects of tobacco control policy across different countries. Linear and logistic regression analyses are very popular responses. The basic characteristic of these approaches is as follows. First, data is collected through telephone or face to face surveys of smokers, non-smokers, tobacco industry behaviour etc. across different jurisdictions. Second, statistical software packages (SPSS, SAS or STATA) are used to carry out statistical analysis of various tobacco control policies across the different jurisdictions. This approach assumes a linear sequence between research evidence outlining the need for action, the optimal forms of action, policy development, and the subsequent effects of policies. Considerable research (e.g. Borland et al., 2006; Hammond et al., 2006) has demonstrated that this approach is useful for evaluating the impact of single policies. However, these analyses have concentrated on single police only, and recent analyses (e.g. Hammond et al., 2006; Young et al., 2007) have demonstrated that when evaluating behaviour changes of smokers in response to policy initiatives, such relations are often non-linear. Significant behaviour changes may be a consequence of what appear to be marginal increments in social/health policy. Also, the success of tobacco control is not the result of single policies, but is the outcome of interactions among various policies in various domains. We can imagine that in the real tobacco market, numerous interrelated factors, including human factors (smokers, non-smokers, researchers, doctors, advocates and tobacco producers and policy-makers), non-human factors (regulations, research data, culture, government systems, advertisements, penalties), interact with each other and work together to co-produce the outcomes of tobacco control. These interrelated variables affect not only the behaviours of smokers and the tobacco industry, but also influence the decision making processes of tobacco control policy planning and development by various decision makers. Therefore, regression-based techniques are clearly inadequate for dealing with interrelationships or causalities among a set of such variables.

Actor-network theory (ANT) is a qualitative technique we can use for describing and understanding the effects of tobacco control policy across different countries (Cropper et al., 1997; Law and Hassard, 1999). It was born out of the social study of science and technology and is evolving rapidly. The key concepts of ANT are as follows. When we plan to do something, many heterogeneous, human and non-human agents will influence the outcome. These agents form an actor-network. ANT has found many applications in different areas (Cropper, 1997; Law and Hassard, 1999). However, ANT does not provide efficient and effective techniques to evaluate the potential effectiveness of alternative tobacco control policies in various jurisdictions. For example, the FCTC has proposed two tobacco control policies: putting graphic photographs on warning labels and restricting sponsorship activities of tobacco companies. We could not use ANT to evaluate the overall impact of the two policies on smokers' behaviours, although it could be used to work out why one policy is more effective.

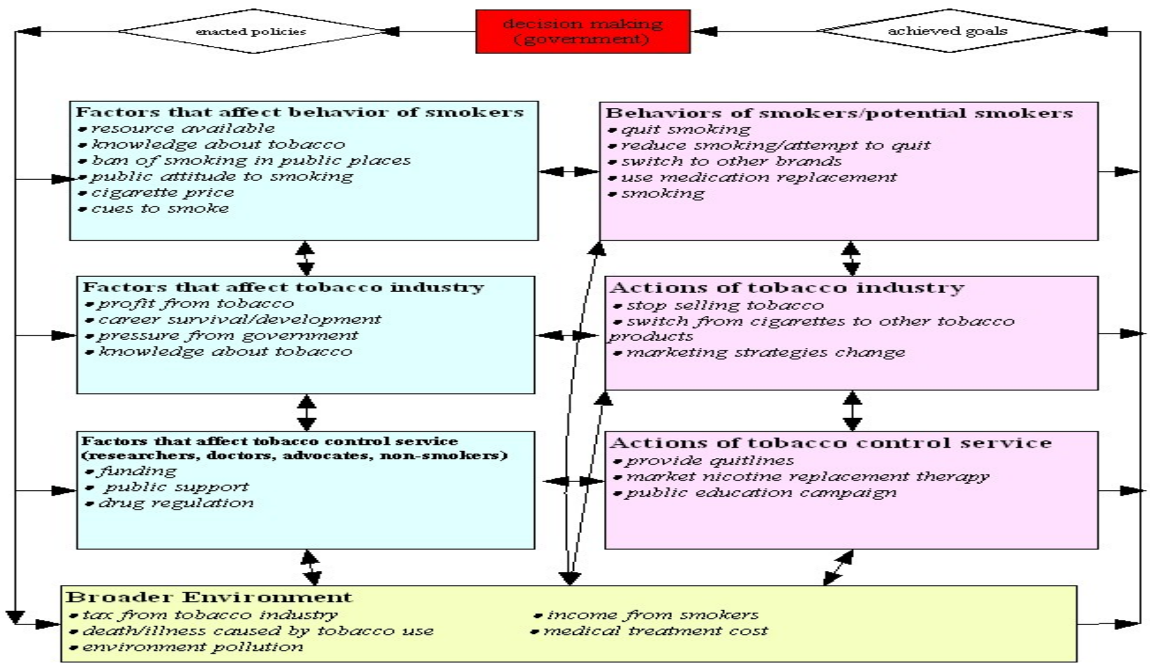
Recently, Petrovic-Lazarevic et al. (2002) proposed a neural-fuzzy model for supporting knowledge management in social regulation Zhang et al. (2006) introduced a fuzzy causal network (FCN) for knowledge discovery and decision support in an environment of uncertainty and incomplete information. All of these are potentially very useful for describing and evaluating the effects of tobacco control policy across different countries. Here we focus on FCN, because its basic concepts are the same as those associated with ANT. In any FCN there are three kinds of elements, namely the agents, the causal relationships between agents and the effects one agent has on another. By convention, we use vertex to represent the agent, directed arc to represent the causal relationship between two agents, and numerical values in [-1, 1] associated with the directed arc to represent the effect of one agent on another. For each vertex, we assign a state value, which is quantified as a real number, to measure the degree of occurrence of a fuzzy event at a discrete time t. At any time, when a vertex receives a series of external stimuli, its state value is updated at the next time according to a state-transition function. This process is iterated until the whole system converges to a stable state or identifies a limit cycle. The limitations of FCNs for modelling and analysing complex tobacco control systems are as follows. The application of FCNs in any real world problem is based on the assumption that once the initial condition is given, it remains unchanged until the influence pattern is obtained through a real data simulation. Also it does not provide an efficient and effective mechanism for time series simulation and prediction. We can imagine that in many real world applications, the relationship between the initial condition and the whole system is mutual. That is, on the one hand, the initial condition will have an impact on the whole system, whilst on the other hand, the whole system will have a feedback impact on the initial condition. All agents (the agents included and excluded in the initial condition) interact each other. As a result, the initial condition will probably be updated before the system converges to a stable state or identifies a limit cycle.

A NEW THEORETICAL FRAMEWORK FOR TOBACCO CONTROL SYSTEMS

In this section, we propose a new theoretical framework and associated quantitative techniques for modelling and analysing complex tobacco control systems. This framework aims to explore whether the use of non-linear techniques could shed new light on the complexity of tobacco control above that provided by traditional linear models using regression or related techniques. Our goal is to develop innovative agent-based techniques and methodologies for evaluating the effectiveness of existing policies, refining relevant policies and proposing new policies. The primary focus will be on formulating an approach that will assist in the efficacious translation of science into policy, and policy into practice, while accommodating national differences. Particular attention will be directed towards examining the factors that influence the effectiveness of tobacco control policies across different countries. One of the authors is a chief investigator of the International Tobacco Control Policy Evaluation Project that has collected policy relevant material from several countries. We have accessed to the database, which we will use to test our techniques, methodologies and models.

The basic ideas of this new approach are as follows. First, we assume that at the national/local government level within any country, all factors involved in tobacco control form a discrete dynamic system with feedback. The topological structure of this system is a directed graph $\Omega = (V, A)$, where V is the set of vertices and A the set of directed edges of Ω. Each vertex $v_i \in V$ represents a fuzzy event, like smokers' behaviour, tobacco industry's response to tobacco control policies, and impact of tobacco control policies on national/local economies. Associated with each v_i is a vertex state value x_i (t) $\in [0; 1]$, which specifies the degree that the fuzzy event occurs at a discrete time t. Each directed edge $(v_i, v_j) \in A$ represents a causal relationship from v_i to v_j. Associated with each (v_i, v_j) is a numerical value $w_{ij} \in [-1, 1]$, which measures the strength that v_i influences v_j. A state transition function f_i at each v_i then transfers the total inputs received by v_i at time t to the next state x_{i+1}(t) $\in [0; 1]$ of v_i at time t + 1. According to scientific evidence, expert opinion and the nature of the tobacco market, we identify and choose some suitable vertex state values x_i (t) $\in [0; 1]$ at time t as an initial condition. Also we assign a state transition function f_i for each vertex v_i. After constructing a discrete dynamic system for the purpose of tobacco use control, we can perform a quantitative simulation for this system. As a result, we can provide qualitative as well as quantitative data analysis. Subsequently, we can provide concrete evidence to decision makers for tobacco control policy planning and development. Secondly, based on the assumptions above, we provide an interaction model for tobacco control system, which is shown in Figure 1.

Figure 1. An interaction model for tobacco control systems

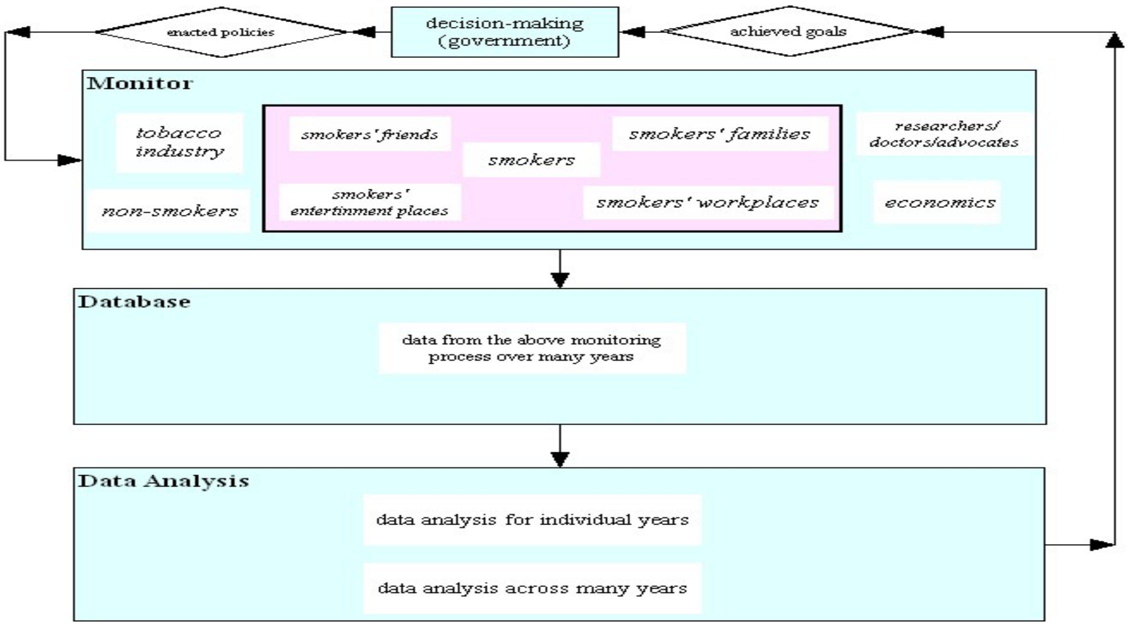


From Figure 1, we can see that at the national/local government levels, all proposed tobacco control policies will impact on various agents, including smokers, non-smokers, researchers, doctors, advocates, tobacco industries and national/local economies. Also, these tobacco control policies and various agents interact with each other and influence the relative effectiveness of specific tobacco control policies. Developing the most suitable techniques and methodologies to evaluate such impacts and interactions would be the fundamental research activities. In doing so, we consider various real life scenarios through the set of different initial conditions. Then we should propose techniques to estimate the impact of an initial condition on the whole system by calculating its causal inference pattern. We expect that with available techniques and methodologies, we can confirm that when some vertices receive a series of external input sequences, their next states will be updated by a predefined formula. We take individual years as the time series for real life data simulation. After each year, the appropriate state value at any vertex v_i will be updated. This process is repeated until the state values at all vertices settle to a stationary stage that does not undergo any further change. This provides us a limit cycle, which represents the final inference pattern for this system given the updated initial conditions. This set of vertices forms a resonant state of ``hidden pattern" that corresponds to the expert's response to "what-if" questions about the system's behaviour. Different scenarios can be examined by varying the initial conditions.

A CONCEPTUAL MODEL FOR DECISION MAKING ENACTMENT MONITORING AND REFINEMENT IN TOBACCO CONTROL SYSTEMS

The new approach proposed above provides a potentially useful way of monitoring the performance of various tobacco control policies and evaluating the effectiveness of these policies within a jurisdiction in individual years. It can be regarded as the combination of available techniques mentioned in Section 2. However, this is not sufficient for the consideration of longer-term goals. For example, we believe that the development of smoke free environments around the world has been and still is a very challenging task. It could not be achieved solely by the efforts of individual countries within a short period of time. Therefore, we need to provide an efficient and effective system to decision makers for longer term policy making, enactment, monitoring and refinement. The design of such a system should be based on available data from a large variety of domains across different countries. We provide a conceptual model that describes a cycle for policy making, enactments, monitoring and refinement, which is shown in Figure 2.

Figure 2. A cycle for policy making, enactment, monitoring and refinement



From Figure 2, we can see that based on the adoption of FCTC and real world situations, the national/local government within any country is responsible for making some initial decisions for tobacco use control. Once these decisions are made, and goals established, they would impact on various agents, including smokers, non-smokers, researchers, doctors, advocates, tobacco industries, national/local economies and many others. Then, as the system monitors the performance of these policies it collects relevant data from a large variety of agents. During the process of policy monitoring and data collection, all available data will be put on a large database. The database should include all relevant data from various agents across different countries over many years. Then we carry out case-by-case data analysis for different countries in individual years. This kind of data analysis should include the estimation of the single impact of one policy on all agents; as well as the estimation of the impacts of many policies on all agents. We should also address the interactions among various policies and different agents, within the varieties of culture and governmental systems. We should analyse the available data flow across many years, so that we can clarify data, identify data trends, analyse data patterns across these years, and provide accurate evaluation on the effectiveness of tobacco control policies across different countries and over a long time period. Based on this data analysis, we would then make recommendation for existing policy refinement and new policy planning to decision makers. This process will be repeated until the expected goals of having smoke-free environment are achieved.

DISCUSSIONS AND CONCLUSION

The new approach presented in this paper proposes a methodology and techniques for analysing and evaluating the translation of science into policy, policy into practice; practice; and practice back into science in tobacco control systems. This new approach has four key features: First, the dynamics of each agent in a tobacco control system, like smokers' behaviours, tobacco industry's response to tobacco control policies, can be quantified as a fuzzy degree (real value) and updated through real life data simulation. Second, it addresses not only the single impact of one policy on various agents (e.g. smokers), but also the overall impact of many policies on various agents (e.g. smokers, doctors, tobacco manufacturers) or on the whole system. Third, the strength of one policy not only influences various agents, but also the interactions among all possible policies and various agents are addressed. Fourth, it provides a feedback mechanism, which enables the tobacco control system to adjust (adapt) itself in response to the changing environment, and to information about the relationship between expected goals and actual outcomes. However, while applying the new approach to real life circumstance, we have to deal with many challenging problems. First, when we carry out case-by-case data analysis for each country at each year, we should investigate all possible agents that could have causal influence on the effectiveness of tobacco control policies. The diagram shown in Figure 1 describes an imaginary scenario only. In a real world application, the scenario will vary across different countries and over many years. At the moment, The VicHealth Centre for Tobacco Control holds a large volume of data through the ITC survey across several countries. But, with exception of Malaysia, these surveys focus exclusively on smokers' response to tobacco control policies. More reliable data needs to be collected from a large variety of agents. This would be a very time-consuming work, but it is the foundation of accurate data analysis. Regardless, we still can run this new model partially with focus on evaluating overall impact of the existing policies on smokers. Second, the task of identifying the relative importance of each agent within a tobacco control system is another challenging issue. Before applying this approach to case-by-case simulation, we need to apply regression analysis to identify and confirm the importance of each agent among all possible agents within different tobacco control systems. Third, when we assess the impact of an initial condition on various agents or on the whole system, we have to set an initial condition, assign an initial state value for each agent, and choose the most suitable state transition function for each agent. All these would be very challenging problems. Fourth, we need to have a clear idea of the possible benchmarks that can inform the decision-making process, since the benchmarks can provide objective standards by which the utility of tobacco control policy planning and development can be measured and judged.

Our next step is to apply this new theoretical framework and associated quantitative techniques to real data implementation and testing, where the data is provided by the VicHealth Centre for Tobacco Control. Our work will focus firstly on evaluating overall impact of many enacted policies on smokers for four countries (Australia, UK, USA and Canada) within five years (2002-2006). We will make a comprehensive comparison between our new research results and the research outcomes provided by our team members from VicHealth Centre for Tobacco Control, where almost all of their works are based on the techniques of linear regression analysis. We believe that this proposed theory has potential to become a framework for other complex social issues, such as nutrition and its links to various issues including cancer, cardio-vascular disease and ageing.

ACKNOWLEDGEMENTS

The research outcomes represented in this paper are based on our team work for the project **Maximizing the Effectiveness of Public Health Policies: The Case of Smoke-Free Policies**, which is supported by an Australian Research Council Linkage Project grant, Monash University and The Cancer Council Victoria (Australia).

REFERENCES

Borland, R., Yong, H. H., Cummings, K. M., Hyland, A., Anderson, S., Fong, G. F., "Determinants and Consequences of Smoke-free Homes: Findings from the International Tobacco Control Four Country Survey", *Tobacco Control*, Vol. 15, (2006): iii42-iii50.

Boyle, P., Gray, N., Henningfield, J., Seffrin, J., Zatonski, W., *Tobacco and Public Health: Science and Policy*. Oxford University Press, 2004.

Cropper, S., *Designing and Delivering Processes for Collaboration: An Actor Network Perspective New Perspectives in Collaboration Integrating International Experience*. Boston: USA, Academy of Management Summer Meetings, 1997.

Fong, G. T., Cummings, K .M., Borland, R., Hastings, G., Hyland, A., Giovino, G.A., Hammond, D. and Thompson, M. E., **"**The Conceptual Framework of the International Tobacco Control (ITC) Policy Evaluation Project," *Tobacco Control*, Vol. 15, (2006): iii3-iii11.

Hammond, D., Fong, G. T., Borland, R., Cummings, K. M., McNeill, A., Driezen, P., "Communicating Risk to Smokers: The Impact of Health Warnings on Cigarette Packages," *American Journal of Preventive Medicine*, Vol. 32, (2006): 210-217.

Law, J. and Hassard, J., *Actor Network Theory and After*. Sociological Review Monographs, Blackwell, Oxford, 1999.

Petrovic-Lazarevic, S., Abraham, A., Coghill, K., "Neuro-Fuzzy Support of Knowledge Management in Social Regulation," in Dubois, D. (ed) *Computing Anticipatory Systems: CSYS 2001-Fifth International Conference*, Liege, Belgium, American Institute of Physics, New York, 2002: 387-400.

Sneden, G.G., Gottlieb-Nudd A., Gottlieb N.H., and Huang, P.P., "A Feedback Model for Applied Research on Tobacco Control," *Preventing Chronic Disease*, 2006.

Wynder, E. L. "Tobacco As A Cause of Cancer: Some Reflections," *American Journal of Epidemiology*, Vol. 146 (1997): 689-694.

Young, D., Borland, R., Hastings, G., Fong, G., Cummings, K. M., Hammond, D. and Stahpush, M., "Smokers Support Stronger Regulatory Controls on Tobacco: Findings From ITC 4-Countries Survey," *Australian and New Zealand Journal of Public Health* (in press).

Zhang, J. Y., Liu, Z. Q. and Zhou, S., "Dynamic Domination in Fuzzy Causal Networks," *IEEE Transactions on Fuzzy Systems*, Vol. 14, No. 1 (2006): 42-57.