Title: Modeling alcohol use behavior at population scale based on social role theory: An exploratory agent-based model

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Modeling alcohol use behavior at population scale based on social role theory: An exploratory agent-based model

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Abstract

**Purpose:** The relationships between social roles and patterns of alcohol use have been explored empirically within the alcohol research community; however, the mechanisms by which social roles impact on alcohol consumption, and vice versa, remain poorly theorized. We present a set of mechanisms based on social role theory to describe how social roles interact with alcohol use behaviors at population-level.

**Methods:** An agent based model was implemented in RepastHPC to simulate dynamic social role change underlining drinking behaviors over time. The model was used to explore population-level alcohol use in San Diego County.

**Data:** The agent-based model was parameterized using the 1980 US Census, the 1980 National Survey on Drug Use and Health (NSDUH), and longitudinal data from the Panel Study of Income Dynamics. Model outputs were compared to repeated cross-sectional data from NSDUH, 1980-2000.

**Results:** The model produced time trends for the average number of social roles in SDC over time, with drinkers consistently having a lower number of roles, on average, compared to the total population. Dynamics in the number of social roles were associated with smaller-scale trends in drinking prevalence and average weekly quantity. Model fit was reasonable compared to NSDUH observations on drinking prevalence, but less satisfactory for drinking quantity.

**Conclusion:** A baseline model has been produced that can examine quantitative, mechanism-based explanations for how changes in social roles impact on alcohol use, and vice versa. Further research is needed to calibrate the model to empirical data, and extend the capabilities of the model structures.

**Conflict of interest statement:** The authors declare that no relationship exists that could be viewed as presenting a potential conflict of interest.

**Topic:** Drinking cultures
1. Introduction

1.1 Motivation
The ability to make predictions about time trends in alcohol use and misuse would be useful for estimating likely changes in the burden of alcohol-related harm and for contextualizing the impact of both historical interventions and prospective interventions designed to reduce the levels of harm. However, predicting alcohol use trends – over a defined period within a jurisdiction – has rarely been a focus of the alcohol research community. Conventionally, such predictions fall within the realm of aggregate time series methods; but these methods have been largely hampered by a range of problems, most notably an insufficient number of data points (Rehm & Gmel, 2001). Mechanism-based approaches (Hedström, 2005) offer an alternative set of tools for representing the dynamics of alcohol use systems. In these approaches, theorized causal relations that drive alcohol use in societies can be represented explicitly. Quantified mechanism-based methods – implemented in frameworks such as agent-based modeling – are then amenable to empirical calibration and analysis. Different disciplines offer alternative theoretical perspectives on mechanisms; ideally it would be possible to combine these into a unified systems perspective (e.g. Zucker’s (2006) sketch of a “developmental-biopsychosocial systems formulation”). The contribution of the present paper is more modest and aims to show how one theoretical approach from a single discipline – sociology – can be interpreted and, subsequently, harnessed for prediction in a quantitative, mechanism-based framework. The theory examined in the paper is social role theory.

1.2 Literature review
The relationships between social roles and patterns of alcohol use and misuse have been explored empirically within the alcohol research community; however, the mechanisms by which social roles impact on alcohol consumption, and vice versa, remain poorly theorized and inadequately conceptualized. Role theory itself is a large field that was the subject of much debate by leading US anthropologists and sociologists (such as Ralph Linton and Talcott Parsons) in the 1940s and 1950s; much of the wider contextualization presented in this paper is based on Biddle’s (1979) text – Role Theory: Expectations, Identities, and Behaviors. For the paper, we undertook a review of papers that considered both alcohol use and the theoretical considerations of social role mechanisms simultaneously – we found just three studies of relevance to alcohol – one of which actually considers marijuana rather than alcohol use (Yamaguchi & Kandel, 1985; Knibbe et al., 1987; Wilsnack & Cheloha, 1987). These three studies have been cited widely by empirical researchers working in the alcohol field and (often loosely) form the basis for study design and discussion of findings.

1.2.1 Role selection and role socialization
Yamaguchi & Kandel (1985) focus on the relationship between social roles and marijuana use; but their propositions are more general and could equally be applied to alcohol use. The authors focus on the timing and sequencing of social roles (as an indication of the normative integration into society – or conversely the deviance – of an individual), with specific consideration of three role transitions: marriage, becoming a parent whilst married, and divorce/separation. The concept of role incompatibility is defined as a specific cause of role strain (or stress), being due to individual behaviors that are not compatible with the demands of a social role. Yamaguchi & Kandel make five propositions underpinned by the notion that individuals act to minimize role strain: (1) a behavioral pattern that is incompatible with a particular social role reduces the rate of entry into the role; (2) retention of an incompatible pattern of behavior following entry into the role increases the rate of leaving the role; (3) entry into a social role while retaining an incompatible behavior promotes termination of the behavior; (4) entry into a social role reduces the rate of initiating or resuming a pattern of behavior which is incompatible with the role; (5) exit from a social role reverses the effects of prior role socialization. The first two propositions form a selection mechanism for role theory (whereby uptake of and departure from roles is conditional on ongoing behavioral patterns); the remaining propositions constitute a socialization (or structural influence) mechanism (whereby behavior changes according to the demands of the role). Anticipatory behavior change for entry into a social role is also examined. Yamaguchi & Kandel then investigate the assumption that marijuana use is a behavior incompatible with marriage and parenthood, finding selection and socialization (including anticipatory) effects for marriage and parenthood, but not divorce/separation (N=1,325 panel survey of New York State graduating high school students 1971-72 followed up in 1980-81).

It is noteworthy that outside the alcohol field, role theorists also identify role strain associated with individual characteristics other than incompatible behavior. Biddle mentions different kinds of malfit that can lead to a lack of self-role congruence (Biddle, p325) – for example, an identity malfit due to non-normative timing and sequencing of roles, such as transitioning into a parent role as an unmarried teenager. Yamaguchi & Kandel
also do not explore the processes that underpin socialization, e.g. normative role expectations becoming internalized as beliefs or preferences (Biddle, p.293).

Biddle discusses other strategies than role exit (which may not be practically possible for some role holders – e.g. a single parent) for handling role stress (Biddle, p.326). The most relevant of these to a historical perspective on alcohol use is role involvement – in which a person modifies his or her personal investment in a role to handle role stress. There is some evidence that investment in the father role has changed over the second half of the 20th century, with a polarization amongst men in levels of investment (Cabrera et al., 2000).

1.2.2 Structure of everyday life

Knibbe et al. (1987) is a seminal paper on the application of role theory to the alcohol field – it is the only paper that offers a formal definition of social roles, and has also formed the basis for a number of subsequent empirical studies (discussed later). The authors define three types of role: (1) situational roles (expectations for behavior in short-term situations, such as going shopping or being a guest at a party); (2) positional roles (longer-term role-relationships based on obligations, such as being a life partner or a parent); and (3) status roles (expectations for behavior that are largely outside the control of the individual, such as sex or ethnicity). Social roles, as the alcohol research community appears to use the term, are positional roles in Knibbe et al.‘s classification. The authors argue that drinking behaviors occur in situational roles rather than positional roles (i.e. alcohol use is not a characteristic behavior (Biddle, p.58-59) of a social role). However the set of positional roles limits the extent and intensity of drinking behavior, by impacting on the role holder’s ability to participate in situational roles that offer immediate satisfaction. Positional roles also provide meaning to people’s lives and alcohol use can act as a substitute for providing meaning or can reduce stress associated with a lack of meaning. Knibbe et al. use the concept of structure of everyday life to capture these combined opportunity and desire factors. Stresses and other risky behaviors associated with reduced structure can also independently exacerbate the risk of harm. As a result, individuals with less structure to their everyday lives will tend to drink more than those with more structure, and individuals with less structure will tend to suffer more alcohol-related harm, even if consumption levels are equal. The authors construct a combined metric for the structure of everyday life: a count of the following positional roles held: living with a partner, being employed, and caring for children in the home. When applied to empirical data (N=4,130, Netherlands, cross-sectional survey of ages 16-70 for 1980-81), both the combined metric and role-specific indicators were associated with reduced alcohol use in men, but no effects were found in women.

Knibbe et al. also introduce the concept of drinking style into role theory, and hypothesize that this is associated with status roles. Different drinking styles (the authors’ dimensions of style are: drinking at the weekend; drinking on weekdays; frequency of drinking; drinking at home or public places) do not necessarily imply different levels of consumption. The mechanisms by which status role characteristics (such as gender, class or ethnicity) lead to the creation and maintenance of differential drinking styles are not theorized. Knibbe et al. further argue that some forms of drinking style can be more readily integrated into everyday life and so increased structure to everyday life from positional roles will not necessarily lead to reduced consumption in cultures dominated by social roles associated with these styles. Empirical results supported this hypothesis on the basis of religious differences between jurisdictions (with religion – Roman Catholic or Protestant – being a dominant feature of social roles in the Netherlands).

1.2.3 Cultural roles

Wilsnack & Cheloha (1987) focus on women’s drinking and aspects of role theory that may pertain more to women than to men. The paper is also notable for highlighting the importance of roles during later stages of the life course, and the effects of role loss or absence. In addition to role incompatibility and role overload (having a role set – i.e. a combination of roles held – that is too complex), the authors also argue for two further concepts: role deprivation and role entrapment. These latter concepts are both related to the notion that a person suffers distress due to a lack of social roles or lack of high status positional roles, where the idea of entrapment suggests a decrease in opportunity for entering desired roles over time. Wilsnack & Cheloha also consider the interaction of ageing with roles, although do not provide a theoretical justification for why this is important (or why a person would suffer distress due to role deprivation/entrapment). It is perhaps implicit that the authors are considering the impact of normative or cultural roles (Cottrell, 1942), in which society expects people of particular ages (and other characteristics, such as sex, ethnicity or class) to participate in particular roles (i.e. social roles are positional roles, as defined by Biddle (p.66)).

1.2.4 Empirical studies
A number of authors have studied the relationship between social roles and alcohol use. Bachman et al.’s (2002) findings on social roles were based on structural equation modeling of the ‘Monitoring the Future’ survey (an annual sample of US high school students, with annual follow ups). Bachman et al. used data from 1976 to 1998 (N=38,000). Bachman et al.’s review of the literature on marriage (p14-15) indicates that most studies find socialization effects for marriage that reduce alcohol use, with weaker socialization effects found for engagement (these have been interpreted as anticipatory effects for holding a marital social role). Socialization effects have not been found for cohabitation – although the number of studies cited here is small, being from the 1980s and citing deviance as the reason for lack of conventional socialization effects. Bachman et al.’s own analysis found that marriage was associated with reductions in both average alcohol use and heavy episodic use, mediated strongly by a reduction in evenings out and weakly by increased disapproval for use. Smaller effect sizes were found for respondents who were engaged. Effects for cohabitation were not considered.

The reductions in outside-the-home drinking opportunities for marriage observed by Bachman et al. (2002) were also identified for parental roles by Paradis (2011) using GenACIS data for Canada (N=14,067, cross-sectional 18-76 population for 2004). Paradis hypothesized that parents would select drinking situations compatible with “acting out” the parenthood role rather than simply be faced with reduced opportunities through increased structure of everyday life. The analysis supported the hypothesis – identifying increased within-the-home drinking occasions amongst parents (in the cross-sectional sample).

Kuntsche et al. (2009) framed an empirical study into the relationship between social roles and alcohol use using two theoretical perspectives. The first perspective is similar to Yamaguchi & Kendel’s fourth proposition (i.e. a socialization mechanism), suggesting that increased holding of social roles creates a structured environment for the individual (the structure of everyday life) in which some patterns of alcohol use are not compatible with the expectations related to these roles. In Kuntsche et al. (2016), this perspective is referred to as “role accumulation theory”. Note that Kuntsche et al. (2009) mention “drinking situations” but do not explicitly consider affordances as part of this perspective (except as part of the discussion, where increased opportunity to use alcohol as a result of employment is briefly mentioned).

Kuntsche et al.’s second theoretical perspective relates to role overload – that an individual holds a role set that is too complex to cope with and therefore suffers role strain. Rather than assuming any selection mechanisms, the authors consider an alternative way for an individual to act to minimize role strain – by using alcohol as a means of coping with stress. Kuntsche et al. use 10 Western countries from the GenACIS sample (cross-sectional, country-level surveys sampled between 1993 and 2002) to examine the impact of holding a quantity of social roles (defined as partnership – including co-habitation, parenthood, and paid labor). Pooled across all countries, the study found modest support for dominance of the socialization mechanism in both men and women; however this effect was less strongly supported in many of the country-specific analyses (the US study from 1995-96 suggested stronger socialization effects in men).

Crutzen & Knibbe (2012) also investigated the structure of everyday life and role overload processes, with the latter operationalized as “daily hassles” and directly measured by data from the Survey of Recent Life Experiences. Social roles were partnership, parenthood and paid labor. The empirical findings did not support the existence of a relationship between alcohol use and role overload (N=2,440, Netherland, 2010-2011 repeated panel survey). The authors suggest that the use of alcohol to cope with role overload may depend on individual coping skills and motives for drinking (i.e. the negative internal motive associated with drinking to cope).

Lee et al. (2010) investigated Yamaguchi & Kandel’s selection and socialization mechanisms in a longitudinal case-control survey of children-of-alcoholics (N=508, US, mean age of 26 at wave 5). The authors considered one social role – marriage – which was operationalized as never-married versus became-married. The structural equation model used by Lee et al. did not appear to test for selection effects; however socialization effects were found for marriage, with these effects also mediated by reduced involvement in social activities. Lee et al. (2015a) updates the analysis to wave 6 (focusing on particularly heavy drinkers and identifying a socialization effect) and argues for new studies that directly assess the construct of role incompatibility.

Lee et al. (2015b) consider the inter-relationships between personality, social roles and alcohol misuse across young adult life. Social roles were defined in terms of transitions into marriage and parenthood. Using a longitudinal sample of freshmen at a Midwestern US university (N=489, age 21 at wave 4 through to age 34 at wave 7) the authors find that earlier alcohol misuse reduces the likelihood of later role transitions,
whilst earlier role transitions reduce the likelihood of later misuse (i.e. evidence for both selection and socialization mechanisms). Lee et al. (2015b) also include a discussion of individually varying role characteristics, using two examples: role selection of a heavy drinking spouse and experiences of relationship quality (e.g. support). Agent-based modeling offers an opportunity to include such heterogeneity within the model – either as role heterogeneity or via mechanisms from other theories (e.g. social contagion).

Some studies – like Lee et al. (2015b) – have combined analysis of social roles with other developmental processes – particularly personality change. Littlefield et al.’s (2010) earlier analysis of the same data (wave 4 to wave 7) using latent growth models (rather than structural equation modeling) suggested that marriage and parenthood social roles (operationalized as a combined ever-held state rather than a series of transition indicators) had typically similar or smaller effect sizes than changes in personality over the period. However, Lee et al.’s results suggest a fully-mediated pathway between personality traits at age 21, role transitions at age 25, and alcohol misuse at age 29. The direct impact of personality on misuse is only seen between ages 29 and 34. Both sets of findings, however, suggest that heterogeneity between individuals (and within individuals over time) can be important to the timing of role transitions.

Hajema & Knibbe (1998) examine the impact on average consumption and heavy drinking of changes in three social roles (spouse, paid work, parent) using data from the Netherlands (N=1,327 repeated panel of 16-69 year olds at baseline, 1980 and 1989). Transitions both into and out of roles are considered, together with interactions with age of occurrence. There was no empirical support for reductions in the structure of everyday life leading to increased alcohol use (with the exception of heavy drinking in females who had lost the spouse role). The extent to which this rules out Yamaguchi & Kandel’s sixth proposition (on reversal of socialization effects) is unclear since further changes limited to socialized (i.e. already changed) individuals were not analyzed. No impacts of the age of role transition were observed.

1.2.5 Nuanced roles
One of the challenges when using role theory is the lack of convergence in the literature on the abstract definition of a role (Biddle, p55-56) and the lack of attention paid by applied researchers to concrete definitions of the particular roles being studied (e.g. the parent role). In his text, Biddle (1979) reviews a number of historical definitions (e.g. those by Linton and Parsons) and develops his own definition: “those behaviors characteristic of one or more persons in a context” (p58) – essentially this is a clustering of behaviors that are associated with particular types of people in particular environments at particular times. “Positional roles” are then defined (p65) as “behaviors characteristic of those sharing a commonly recognized identity or social position” – i.e. behaviors associated with a labeled group of people. In this sense, an ‘age/sex role’ deliberately excludes age/sex in the definition of the role (since age/sex is not a behavioral characteristic) and merely indicates that the role is associated with a particular age/sex identity. Concrete definitions of roles tend not to be given (as examples) by role theorists.

Alcohol researchers typically do not define the roles they are dealing with, in reference to an abstract template. Since all studies contain an empirical element, the roles are, however, operationalized. Normally these operationalizations are, by necessity, quite crude – e.g. Kuntsche et al. (2009) operationalized parenthood as the existence of children in the household. However a recent study by Staff et al. (2014) did consider more nuanced definitions of social roles. In particular, they categorized the age of the child in a parent role (under 5, 5-16, 17-21) and considered modestly detailed role sets (e.g. simultaneously being parent to a young child, being employed, and being in a co-habiting personal relationship as a divorcee). Staff et al. framed these nuanced roles in terms of theory: the role involvement for marriage was hypothesized as greater than that for co-habitation; similarly, the role involvement for parenting a young child was hypothesized as greater than that for parenting older children. The hypothesis for the impact of levels of role involvement on alcohol use followed an opportunity argument. The authors conducted an empirical study using the National Child Development Study (N=14,589, waves 4-9 of 1958 birth cohort, Britain) and found socialization effects for marriage, which were partially reversed by divorce (lending some support to Yamaguchi & Kandel’s sixth proposition). Effects were also found for parenting of younger children (under 5), with smaller effects found for older children (5-16). Combined marriage and parenting roles tended to have greater effects than either in isolation. Effect sizes tended to be larger for women than for men. The employment role was found to increase consumption in isolation, and tended to reduce socialization effects when appearing as part of a role set.

Staff et al. (2010) also considered more nuanced roles as part of a further study of the Monitoring the Future cohort (based on all sampled 12th graders from 1976 to 1997 who had at least one follow-up study,
Employment roles were categorized into full-time, part-time, professional, non-professional, military and homemaker. Both professional and non-professional employment were associated with increased frequency of drinking, with the greatest effects seen for military personnel. The authors also considered the role of pregnancy, finding a strong negative impact on alcohol use in women (and also reductions in alcohol use for men with a pregnant partner). Perhaps consistent with a dynamic perspective on Yamaguchi & Kandel's third proposition (on socialization), alcohol use reduced further in women holding a resident parenting role.

1.2.6 Social roles beyond parenthood, partnership and paid labor
The trio of parenthood, partnership and paid labor are the social roles most heavily studied in the empirical alcohol literature. Staff et al. (2010) also included student roles in their analysis of the Monitoring the Future cohort. These roles were categorized as part-time or full-time student, with the full-time students also sub-categorized by type of residence (dormitory, fraternity/sorority, or other type of residence). Increases in alcohol use were seen for fraternity/sorority-dwelling students, but not other students (with small protective effects seen in dormitory settings). Staff et al. do not provide theoretical justification for incorporating residence type into the student role – although perhaps fraternity/sorority student could be argued to be one of the few positional roles where alcohol use is a characteristic behavior that forms part of the role definition.

1.3 Overview of the paper
The remainder of the paper is organized as follows. In Section 2, we describe the methods by which role theory has been interpreted in a quantitative, mechanism-based way – including the overarching framework, model design, and implementation. The data used to calibrate and validate the model is also described. In Section 3, we show results of verification testing for the model, in which the impact of the different mechanisms on alcohol use is tested. We also show typical dynamics of alcohol use that can be obtained by a parameterization of the model. Limitations and next steps in this on-going research effort are discussed in Section 4.

2. Methods

2.1 Conceptual framework
We adopt Swedberg & Hedström’s (1996) mechanism-based elaboration of Coleman’s (1986) macro-micro-macro framework. We do not assume that the mechanisms are universal laws; rather we test whether the mechanisms hold over a specific period of time (1980-2018) and in a specific jurisdiction (San Diego County). We have designed an agent-based modeling architecture that realizes the framework and implemented this using the Repast HPC agent-based modeling software library.

The framework consists of individuals who take purposive action within a structural context. It requires three types of mechanism to be defined (the numbering follows Coleman, the naming follows Swedberg & Hedström): (type 1) individual action mechanisms that explain how individuals take action on the basis of their present state (e.g. beliefs, desires and opportunities); (type 2) situational mechanisms that explain how individuals states are shaped by social structures; (type 3) transformational mechanisms that explain how individuals actions act together to shape social structures. The framework is shown in Figure 1.

![Figure 1: Coleman (1986) and Swedberg & Hedström’s (1996) mechanism-based explanations for linking between macro (social structure) and micro (individual persons) levels.](image)

2.2 Entities in the model
2.2.1 Individual agents
The individual-level entities in the model are agents – i.e. people resident in San Diego County. We model residents of SDC from 1980 to the present day. Each agent has the properties shown in Table 1, relating to general socio-demographics, social roles, and alcohol consumption. Where properties appear in subsequent equations, the variable name is given in italics.

In addition to the individual-level entities, we define two structural entities at the macro-level of the model: social role expectancies and social role transition rates. Each entity acts to influence the social roles held by individuals at any point in time.

2.2.2 Social role expectancies
The social role expectancies define injunctive norms (i.e. other people’s expectations) for the timing and sequencing of social roles held by individuals. In the model, expectancies – role_expectancies(sex,age) – are defined separately for each role, i, by sex and age group on a continuous range from 0 (the role is not expected to be held by a person of this age and sex) to 1 (the role is fully expected to be held by a person of this age and sex).

<table>
<thead>
<tr>
<th>Property</th>
<th>Variable name</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
<td>sex</td>
<td>Male (0) or female (1)</td>
</tr>
<tr>
<td>Age and age group</td>
<td>age_group</td>
<td>The age of the agent in years, and associated age group (0 = 12-17, 1 = 18-24, 2 = 25-34, 3 = 35-44, 4 = 45-54, 5 = 55-64, 6 = 65+)</td>
</tr>
<tr>
<td>Marital status</td>
<td>social_roles_held</td>
<td>Binary indicator for whether the agent is married (1) or unmarried (0)</td>
</tr>
<tr>
<td>Parental status</td>
<td>social_roles_held</td>
<td>Binary indicator for whether the agent is resident with a dependent child (1) or not (0)</td>
</tr>
<tr>
<td>Employment status</td>
<td>social_roles_held</td>
<td>Binary indicator for whether the agent is employed (1) or unemployed (0).</td>
</tr>
<tr>
<td>Role involvement</td>
<td>role_involvement</td>
<td>A measure of the individual's involvement in the social roles they held, defined over a continuous range from 0 (no involvement) to 1 (full involvement). Involvements are defined separately for each social role, i.</td>
</tr>
<tr>
<td>Role skill</td>
<td>role_skill</td>
<td>A measure of the individual's ability to perform their roles and hence avoid role stress, defined over a continuous range from 0 (no skill) to 1 (mastery of their roles). In the current version of the model, role skill is not considered to vary with between roles or over time, but this is a potential extension.</td>
</tr>
<tr>
<td>Drinking disposition</td>
<td>dispositionj</td>
<td>A measure of the individual's long-run desire to drink alcohol, defined as a sequence of dispositions to consume the next drink, j, in a drinking occasions, with each disposition having a continuous range from 0 (no desire) to 1 (full desire). Disposition is interpreted as the probability of consuming the next drink, conditional on having consumed the previous drink in a drinking occasion.</td>
</tr>
<tr>
<td>Drinking status</td>
<td>drinking_status</td>
<td>Binary indicator for whether the individual has consumed (1) or not consumed (0) alcohol in the previous 12 months.</td>
</tr>
<tr>
<td>Drinking level</td>
<td></td>
<td>Average weekly consumption of the individual (in US standard drinks).</td>
</tr>
</tbody>
</table>

Table 1: Individual agent properties defined in the model

2.2.3 Social role transition rates
The social role transition rates define the typical frequencies with which individuals change their social roles. The rates are defined as annual transition probabilities and, like the social role expectancies, are defined separately for each role by sex and age group. In the present version of the model, transition probabilities are defined as incoming or outgoing: social_role_transition_in(sex,age) and social_role_transition_out(sex,age).

2.2.4 Drinking opportunities
Drinking opportunities (drinking_opportunities) is a structural entity that captures the general opportunities open to agents to participate in drinking occasions, defined over a continuous range from 0 (no opportunities) to 1 (full opportunities). Opportunity can be interpreted as the availability of alcohol in society.

2.3 Mechanisms
Here we describe the details of how elements of role theory from the literature review have been interpreted as situational, action, and transformational mechanisms. The set of mechanisms included should be
considered as a minimum set— it is not intended, at this stage, to represent the full richness of representation that role theory could offer.

2.3.1 Situational mechanisms
The situational mechanisms realize the process by which macro structures influence individuals. We define six key parameters (shown in Table 2) relating to situational mechanisms and subsequent equations that enable these to be calculated from individual and structural properties.

**Role overload**
The role overload is the strain caused by a complex set of roles, which is calculated as:

\[
role_{\text{overload}} = (\sum_{i=1}^{3} role_{\text{involvement}}_i \times \text{social}_{\text{roles}}_{\text{held}}_i)^p
\]

(1)

where \(role_{\text{involvement}}\) and \(\text{social}_{\text{roles}}_{\text{held}}\) are individual-level properties defined in Table 1. Here, greater numbers of roles held, together with high levels of involvement in roles, will lead to overload. The exponent, \(p\), in the equation enables the holding of multiple roles to induce higher levels of stress than that resulting from the sum of individual roles. \(p=2\) in the baseline model.

**Role incongruence**
The role incongruence measures how suitable the agent's current roles are according to societal expectations, calculated as:

\[
role_{\text{incongruence}} = \sum_{i=1}^{3} \left| \text{social}_{\text{roles}}_{\text{held}}_i - \text{role}_{\text{expectancies}}_i(\text{sex, age}_\text{group}) \right|
\]

(2)

where \(\text{social}_{\text{roles}}_{\text{held}}\) is the vector of roles held by the individual (see Table 1) and \(\text{role}_{\text{expectancies}}\) are the injunctive norms relating to a person of the individual's age group and sex (see Section 2.2.3).

<table>
<thead>
<tr>
<th>Role theory parameter</th>
<th>Variable name</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Role overload</td>
<td>role_{\text{overload}}</td>
<td>The stress experienced by an individual as a result of needing to perform social roles, defined on a continuous range from 0 (no overload) to a positive integer (maximum overload, given by MAXIMUM_{\text{OVERLOAD}} – in the baseline model this value is 9).</td>
</tr>
<tr>
<td>Role incongruence</td>
<td>role_{\text{incongruence}}</td>
<td>The stress associated by an individual as a result of a mistiming of roles with respect to normative expectations, defined on a continuous range from 0 (no overload) to a positive integer (maximum incongruence, given by MAXIMUM_{\text{INCONGRUENCE}} – in the baseline model this value is 3.</td>
</tr>
<tr>
<td>Role strain</td>
<td>role_{\text{strain}}</td>
<td>The total stress experienced by the individual as a result of social roles, defined on a continuous range from 0 (no stress) to 1 (maximum stress).</td>
</tr>
<tr>
<td>Agent transitions</td>
<td>agent_{\text{transitions}}<em>{\text{in}}, agent</em>{\text{transitions}}_{\text{out}}</td>
<td>The individual probabilities that an agent will transition in or out of role (i) in the current year.</td>
</tr>
<tr>
<td>Drinking opportunity</td>
<td>opportunity</td>
<td>The current opportunity open to the agent to participate in drinking occasions, defined over a continuous range from 0 (no opportunity) to 1 (full opportunity). Opportunity at the individual-level is interpreted as the daily probability of engaging in a drinking occasion.</td>
</tr>
<tr>
<td>Daily disposition</td>
<td>daily_{\text{disposition}}_j</td>
<td>The short-run desire held by an agent for consuming the next drink, (j). This is based on the long-run disposition defined in Table 1, but applies to the current drinking occasion only, rather than being a more inherent state of desire to drink.</td>
</tr>
</tbody>
</table>

Table 2: Social role theory parameters defined in the model

**Role strain**
In the model, role strain is caused by the average stresses of role overload and incongruence, and is eased by role skill:
\[
role_{\text{strain}} = (1 - role_{\text{skill}}) \times \left( \frac{role_{\text{overload}}}{MAX_{\text{OVERLOAD}}} + \frac{role_{\text{incongruence}}}{MAX_{\text{INCONGRUENCE}}} \right) / 2
\]

where \( MAX_{\text{OVERLOAD}} \) and \( MAX_{\text{INCONGRUENCE}} \) are terms that normalize the levels of role overload and role incongruence to be on the same units.

**Agent transitions**

The role transition equations at agent-level modify the societal transition rates to account for role selection (assuming that alcohol reduces the likelihood that an agent enters or remains within a given role). The mechanism is implemented by the following equations:

\[
\text{agent}_{\text{transitions}}_{\text{in}_i} = \text{social}_{\text{role}}_{\text{transition}}_{\text{in}_i}(\text{sex, age, group}) - \beta_{\text{in}} \times \text{drinking status}
\]

\[
\text{agent}_{\text{transitions}}_{\text{out}_i} = \text{social}_{\text{role}}_{\text{transition}}_{\text{out}_i}(\text{sex, age, group}) + \beta_{\text{out}} \times \text{drinking status}
\]

where \( \beta_{\text{in}} \) and \( \beta_{\text{out}} \) are coefficients for adjusting the transition probabilities as a result of alcohol consumption. Values for these coefficients in the baseline model are given in Table 3.

**Drinking opportunity**

In the model, role overload acts to reduce the drinking opportunities available to individual agents. An adjustor \( \alpha \) is included to represent the social integration of drinking (where \( \alpha = 0 \) would indicate that drinking was fully integrated into aspects of social life relating to marriage, parenting and working). The equation to represent drinking opportunity is:

\[
opportunity = \text{opportunities} \times \left( 1 - \alpha \frac{role_{\text{overload}}}{MAX_{\text{OVERLOAD}}} \right)
\]

**Role socialization**

A role socialization mechanism is also included within the model. This mechanism acts to reduce an agent's long-run desire to drink, the longer they are in possession of social roles. The drinking disposition is also influenced by role socialization, where the effects are from the set of roles the individual holds. In this model, the role set is represented by role overload.

\[
disposition_{j}(t + 1) = disposition_{j}(t) \times (1 + \beta_{\text{socialization}} \times \sum_{i=1}^{3} \text{social roles held}_i)
\]

where \( \beta_{\text{socialization}} \) is a coefficient that describes the progressive impact of holding social roles on desire to drink, and \( t \) is the current day in the model.

**Daily disposition**

The agent's short-run desire to drink is modeled as the long-run desire, mediated by the immediate role strain being experienced by the agent. Each agent is assumed to believe that drinking will help the agent to cope with the role strain being experienced — alternative coping skills and beliefs are not presently represented in the model. The equation to calculate the sequence of next-drink, \( j \), dispositions is given by:

\[
daily_{\text{disposition}}_{j} = daily_{\text{disposition}}_{j} + \beta_{\text{strain}} \times role_{\text{strain}}
\]

where \( \beta_{\text{strain}} \) is a coefficient to adjust the effect of role strain on drinking disposition. Again the baseline setting for the coefficient is shown in Table 3.

**2.3.2 Action mechanisms**

In the model we have implemented a generic action mechanism that generates drinking behaviors based on: (1) opportunity to participate in a drinking occasion; and (2) disposition to drink. The means by which the dispositions arise have been detailed in the previous section. Recall that the disposition is given a series of probabilities of an agent having the next drink within a drinking occasion, conditional on having the previous drink.
Drinking occasion and first drink
In the model, a drinking occasion occurs when the agent has both the opportunity and disposition to drink – these factors are given by the variables opportunity and daily_disposition, in Table 2, where $j=1$ – i.e. the first drink. These variables are interpreted as probabilities and so the drinking occasion is simulated as occurring if two randomly drawn numbers (from a uniform distribution on the range 0 to 1) are greater than opportunity and daily_disposition, respectively.

Next-drink disposition
If a drinking occasion is initiated then the next-drink dispositions of the individual will be considered in a sequence, until such time as the drinking occasion is deemed to have ended. An individual will continue to drink the $j+1$th drink so long as a newly randomly drawn number does not exceed daily_disposition. The ceiling for maximum number of drinks per day is set to 40.

2.3.3 Transformational mechanisms
In the conceptual framework, transformational mechanisms represent the process of changing the structural entities represented in the model – here, this means changes to social role expectations, social role transition rates and opportunities to drink. In the present model, the agent behaviors are not used to make endogenous changes to social entities. Instead, the change is driven by exogenous time series inputs gathered externally to the model. At present, time series data has been collected for social role transition rates. Both social role expectations and opportunities to drink are considered to be static over the 20 years of the model.

2.5 Software design and implementation
The software design for the conceptual framework in Section 2.1 has been designed according to object-oriented principles and makes use of a ‘mediator’ design pattern that enables different, diverse mechanisms to be integrated within a single model. The social roles model extends the abstract core architecture of this design (using the inheritance paradigm from object-oriented design) to represent the specific entities and mechanisms needed for the model. The software design has been implemented on the Repast HPC platform, which is an agent-based modeling system for large-scale distributed computing platforms (Collier & North 2012). Repast HPC is written in C++ and able to run on multiple platforms with different operating systems, such as workstations, clusters and supercomputers running MacOS, Linux or UNIX. The social role model was implemented in Repast HPC v2.2.0 running on Ubuntu 16.04.4.

2.6 Data and assumptions
Data in the modeling is used in two forms: (1) to estimate inputs and parameters for the model; (2) to represent the target outputs that the model is aiming to produce.

2.6.1 Model inputs and parameters
The population for the model is initialized for San Diego County in 1980 (for individuals aged 12 and over) using US Census data at census tract level. Sex, age group, marital status, employment status and presence of children in the household are available. Within each age group, specific ages are allocated to individuals at random; parenting status is set to positive if the census respondent is the head of household or the partner of the head. Alcohol use at baseline (drinking prevalence, quantity and frequency) is imputed via iterative proportional fitting (IPF) using the National Survey on Drug Use and Health (NSDUH) for 1980.

Estimates for the annual transition probabilities for marriage, parenting and employment are derived from the Panel Study of Income Dynamics (PSID) using data from 1980 to 2000. The cross-year individual file for 2015 was used (N=77,273). Transitions into first and latest marriages are captured in the data, together with presence of dependent children in the household (used to assign parenting status to heads of household and their partners) and employment status (the latter is available from 1983 onward).

Other parameters in the model have not been derived from data and have been selected to generate plausible model outputs. Uncertainty in these parameters is not presently captured; future versions of the model will have parameters that have been derived from a Bayesian model calibration procedure that aims to appropriately represent the uncertainty. The baseline parameterization of the model is given in Table 3. Note that some of the ‘beta’ parameters appear small in comparison to those in more conventional statistical models because the simulation betas are applied on a repeated, daily basis and, thus, have a larger-than-apparent cumulative effect.
Model input or parameter | Baseline assumption | Source |
---|---|---|
*role_expectancies* | Typical expectancies profile: Marriage: 12-17 = 0; 18-24 = 0, 25+ = 1 | None used |
*social_role_transition_in* | Typical annual transition probabilities (1980 and 2000): Marriage in = 0.010 and 0.008 Marriage out = 0.005 and 0.004 Parenting in = 0.042 and 0.047 Parenting out = 0.029 and 0.064 Employment in = 0.060 and 0.094 Employment out = 0.080 and 0.085 | PSID, 1980-2000 |
*β*_in | 0.0001 | None used |
*β*_out | 0.0001 | None used |
*β*_socialization | -0.00001 | None used |
*β*_strain | 10 | None used |
*α* | 0.01 | None used |
*opportunities* | 0.08 | None used |
*disposition* | Population heterogeneity hyperparameters: beta(1,3) | None used |

Table 3: Baseline assumptions in the social roles model

2.6.2
Population-level model outputs from the model are compared annually against observations of alcohol use extracted from NSDUH – both for prevalence of drinking in the previous 12 months and average weekly quantity consumed by drinkers (measured in standard drinks).

3. Results

3.1 Dynamics of baseline model
We initialize the baseline model in 1980 and simulate drinking occasions for all agents in San Diego County for every day over the subsequent 20 years. The outputs from the model are population summary statistics collected on the final day of each calendar year:

- Population average for the number of social roles held
- Population prevalence of drinking over the last 12 months
- Population average for the average weekly quantity consumed amongst drinkers (in US standard drinks).

We compare the latter two outputs against independent observations from repeated cross-sections of the NSDUH dataset. Note that observations are not available for all years of NSDUH data and that smoothing has been applied.

The time series for the average number of roles held is shown in Figure 2 – results are shown for both the overall population and the drinking population. In the model, the average number of roles held by drinkers is consistently below that of the overall population, although the gap between the two measures fluctuates slightly. Independent observations are needed to verify this finding for SDC. In both populations, the average number of roles is seen to increase during the 1980s before falling back over the course of the 1990s.
Results for the prevalence of drinking are shown in Figure 3. During the 1980s, only sporadic observations are available from NSDUH (for 1982, 1985 and 1988) and the model outputs lie close to these. During the 1990s the model outputs depart from the observations (although fit in 1991 and 1994 is quite close) and consistently over-estimate drinking prevalence by up to 6 percentage points. Qualitatively, the NSDUH data suggests that drinking prevalence has been in shallow decline over the 20 year observation window; this is also the trend suggested by the model, although the shallowness of the decline is almost imperceptible.

The time series for average weekly drinking amongst drinkers is shown in Figure 4. Again, NSDUH observations are sporadic over the 1980s but consistently available from 1990. Whilst the model does show some variation over time, the independent observations show much more variability. The model also consistently underestimates average weekly consumption.
3.2 Calibrated model outputs

The baseline model will be replaced by a revised model that has been fully calibrated to the population of SDC for the period 1980-2000, but results were not available in time for the initial deadline for this paper. In addition to calibration, the model will also be validated to show how it performs against data for the period 2001-present.

4. Conclusion

4.1 Key findings

The most conclusive finding from the model is the indication that drinkers, on average, hold a smaller number of social roles than non-drinkers. More work is needed to understand if this association is strongly influenced by the initialization of agents into the model, or whether it emerges from the interplay between the mechanisms in the model.

The dynamics in the average number of roles shown in Figure 1 is driven by three mechanisms in the model: the exogenously-specified transition probabilities, the endogenous process of role selection, and the ageing population in the model (new 12 year olds are not presently added to the model over time). Of key interest is how much of the model dynamics are driven by the exogenous inputs in contrast to the endogenous mechanisms. Further analysis is needed to uncover the relative contributions of these mechanisms, but formal verification testing (where components of the model are systematically switched on and off) should help to uncover the relative magnitude of these factors.

From Figure 3 and Figure 4 it is apparent that there is not much variation in the model outputs over time. Whilst this is reasonably representative of the empirical data for drinking prevalence, it is not very representative of changes in average weekly consumption over the period. Notably, the variation in outputs is small in comparison to the 15% change in average roles held by drinkers, suggesting a degree of balancing between mechanisms that promote drinking with increased roles (e.g. role strain) and those that attenuate drinking (e.g. role socialization). Further work is needed to understand the gearing of dynamic effects in the model.

At present it is difficult to tease out the relative impacts of the various mechanisms at work in the model. The forthcoming model calibration exercise will help to identify how sensitive the model outputs are to choices for model parameters and, hence, which mechanisms (and combinations of mechanisms) are most closely implicated in variability in model outputs.

4.2 Limitations and future work
4.3.1 Limitations
A key limitation of the model is that the structural abstractions of role theory (i.e., the role expectancies and rates of role transition) are represented as fully exogenous inputs to the model. As a result, the model is reliant on external estimates and predictions for these inputs, and no feedback processes are represented that explain how alcohol use shapes the structure of roles in society. Feedback is, however, captured at the individual-level, where – through role selection – an individual’s future role choices are affected by their current alcohol use. There is thus a degree of macro-micro inconsistency in the modeling. Whilst recognizing that trends in social roles are driven by mechanisms much wider than substance use, a deeper consideration of transformational mechanisms in the model would be beneficial. Societal integration of drinking is one possible area of focus, where increased prevalence of drinking in social roles could lead to improved affordances, or more receptive norms, for drinking whilst holding or performing certain roles.

The operationalization of roles within the model remains quite crude (i.e. presently married or not; presently responsible for dependent children or not; presently in employment or not). Agent-based models offer a convenient means of expanding the definitions of roles, and the model is presently limited in its lack of consideration for the more nuanced roles presently being explored in the alcohol research community. Level of role involvement – which is captured by the model but not explored in the present simulations – offers one means of handling more nuanced roles without the need to restructure the categories of roles themselves. In terms of the transition rates implemented in the model, these do not presently account for correlations in the sequencing (i.e. that the probability of becoming a parent is not independent of marital status or employment status).

The model includes a representation of a population in a jurisdiction, but the spatial and temporal demographic dynamics of that population are assumed to be stationary: beyond inclusion of the ageing of individuals, the processes of births, deaths and migration are all absent. For a model aimed at reproducing empirical reality over medium-term timescales (i.e. decades), this is clearly an area of concern. The field of spatial demographic microsimulation continues to grapple with these issues, with migration remaining a problematic area due to a lack of data at any spatial scale (Ballas et al., 2005). In addition to improving the population representation, consideration of socio-demographic contexts would also enable the societal integration of drinking to be varied across those contexts. In terms of socio-demographics, the model includes both age and sex, but is missing other factors that are sometimes considered to be important structural considerations for role theory – for example ethnicity and socio-economic status. If population changes in alcohol use are driven by structural role entities that are differentiated by ethnicity, under conditions of differential ethnic dynamics (e.g. Hispanic migration into SDC), then the existing model is likely to struggle to explain or represent the subsequent population dynamics of alcohol use in a way that is satisfactory from either a theoretical or empirical perspective.

4.3.2 Future work
This paper has presented preliminary findings from a longer-term modeling study that incorporates the co-dynamics of alcohol use and social roles. The immediate next steps are to calibrate the model to a specific real-world context (San Diego County from 1980 to the present) – such a calibration goes beyond qualitative comparisons against the time series data, with the aim of reproducing as faithfully as possible the time trends in alcohol use that are observed in SDC. The calibration will also incorporate the uncertainty in estimates from the model, using a Bayesian model calibration framework (Andrianakis et al., 2015).

Subsequently, the calibration will be extended to state-level (specifically, California, New York, and Texas) and country-level (the US as a whole, and England, UK).

The social roles model is one of four models that are being built according to a common architecture that permits different mechanisms from different models to be blended together. Future research will seek to incorporate the social role mechanisms into a wider, systems-based model that may have improved ability to capture the dynamics of alcohol use in populations over time.

The modeling of alcohol use will also be used to feed epidemiological models for alcohol poisoning and liver cirrhosis, and further developed into policy models that aim to explore the effects of taxation and minimum legal drinking age policies on the dynamics of both alcohol use and harm. Whilst the current model lacks representation of the detail of drinking situations (beyond indicating that a drinking occasion has occurred on a given day), situational contexts for alcohol use (Greenfield & Room, 1997) would be useful for integration into the model, due to their implications for alcohol-related harm.
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