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MODELING THE DEVELOPMENT OF SUBSTANCE USE AND DELINQUENCY SIMULTANEOUSLY: AN ASSOCIATIVE LATENT TRANSITION ANALYSIS EXAMPLE

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Abstract

Understanding the simultaneous relation between the development of adolescent substance use and delinquency is important for informing researchers about how changes in substance use are related to changes in delinquency, and how preventive intervention programs designed to influence substance use or delinquent behavior may or may not predict change in the other behavior. Research has shown that substance use and delinquent behavior can simultaneously wax and wane during adolescence. What has been difficult to determine, however, is whether the two processes are independent functions simply occurring during the same age range, or if one process predicts the other. Although traditional methods like correlation, transition matrices, regression, and ANOVA have been used to examine substance use and delinquency, these methods cannot examine the simultaneous development of these two processes over time. Associative latent transition analysis (ALTA; Flaherty et al., 2003) is a new approach that models two longitudinal stage sequential processes simultaneously. Using the ALTA methodology, a series of models is fit to a sample of male participants aged 12 to 16 from the National Longitudinal Survey of Youth 1997. Four models relating substance use and delinquency cross-sectionally and longitudinally in a variety of ways are compared in order to determine the nature of the relation between adolescent substance use and delinquency. The results suggest that these two processes are highly bidirectionally related over time. Implications for preventive interventions are discussed.

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"*A man must learn to understand the motives of human beings, their illusions, and their sufferings.*"
Albert Einstein

Chapter 1

Introduction

Adolescents today are at risk for both substance use and delinquency[1] for a variety of reasons. As it becomes increasingly clear that processes such as substance use and delinquency may be related to each other during development, methodologies that address more than one developmental process simultaneously are required. This study has two main purposes. The first is to explore the extent to which adolescent substance use and delinquency are related. The second is to further explore the possible applications of associative latent transition analysis (ALTA), a new approach to modeling two longitudinal stage-sequential processes simultaneously (Flaherty et al., 2003; Tang, 2001; Flaherty & Collins, 1999).

1.1 Substance Use and Delinquency

Understanding the processes of substance use and delinquency onset during adolescence, individually and simultaneously, is an important objective for a variety of reasons. First, research has shown that the initiation of a variety of both substances and delinquent behavior is related to a host of future problems. For example, adolescent substance use has been shown to be related to declining academic achievement and escalating emotional distress (Crosnoe et al., 2004), future

[1]The use of the term "delinquency" refers to any problem behavior, including ones that are bothersome to adult caregivers, inflict harm or property loss on others, sets of multiple behaviors that can be combined in a clinical classification of conduct disorder, or the category of disruptive behaviors that can lead to referral to a juvenile court. It does not, however, include the use of any substances.

alcohol dependence, smoking, marijuana use, minor delinquency, and criminal activity involvement (Ellickson et al., 2003; Kandel et al., 1992), and psychiatric problems such as anxiety, mood, and disruptive behavior disorders (Kandel et al., 1997). Further, adolescent delinquency has been shown to be related to future substance dependence, unsafe sex, dangerous driving habits, and unemployment (Moffitt et al., 1996), and elevated levels of impulsive personality traits, mental-health problems, financial problems, and later property offenses (Moffitt et al., 2002).

Second, research has shown that substance use and delinquency occur at the same time during adolescence and may be associated. For example, research has shown that problem behaviors (e.g., cigarette, alcohol, and marijuana use; delinquency; sexual intercourse) are positively correlated with each other (Jessor & Jessor, 1977) and negatively correlated with conventional behavior (Vulcano et al., 1990; Farrell et al., 1992). Further, Taylor et al. (2002) noted that males who started delinquent acts earlier were at greater risk for developing substance dependence problems and White et al. (1999) have shown a strong association between substance use and violent delinquency.

Third, if substance use and delinquency are associated, the nature of that association is unclear. For example, research has shown an association between delinquency and substance use where the onset of delinquency coincided with or preceded the onset of substance use disorders, but there are several other studies showing that early onset of substance use predicted later delinquency (for a review of the literature see Keenan et al., 1999). Additionally, using a latent variable and structural equations modeling approach, Mason and Windle (2002) showed that a model of bidirectional effects between substance use and delinquency was plausible for males but not for females. They also noted that the effect of delinquency on substance use was small but consistent over time, whereas the effect of substance use on delinquency was larger but found only at earlier measurement occasions.

1.2 Methodologies

Clearly, substance use and delinquency are occurring at the same time during adolescence. This naturally leads to the question “Are substance use and delinquency

related and if so, what is the nature of their relation?" This question, however, is a difficult one to answer. There are several possible explanations for why substance use and delinquency might be observed together. For instance, substance use and delinquency may both be independent functions of maturation, so that the two behaviors are not related and are simply tracking together. Another possibility is that one process predicts the other. For example, participation in delinquent behaviors may predict future substance use, but using substances may not predict future delinquency. Finally, the two processes may be bidirectionally related to each other. That is, the substance use and delinquency processes may be so intertwined in development that participating in either substance use or delinquent behaviors predicts participation in the other.

The limited, and contradicting, information that researchers have about the relation between substance use and delinquency has been garnered in a variety of ways. Mason and Windle (2002) outlined four main ways causal connections between substance use and delinquency have been examined. These included assessing similarities and differences in correlates and predictors of substance use and delinquency, using risk factors from a variety of domains to try to account for the relation between substance use and delinquency, explaining the covariation among a host of problem behaviors using confirmatory factor analysis and structural equations modeling, and analyzing prospective longitudinal data to examine stability and change in substance use and delinquency over time. More specifically, these main ways included general description from percentages, correlations, transition matrices, modeling approaches such as regression and ANOVA (e.g., Taylor et al., 2002), and latent variable approaches such as group-based latent trajectory analysis and structural equations modeling (e.g., Mason & Windle, 2002).

In addition, another latent variable approach, latent transition analysis (LTA), has also been used to examine substance use and delinquency (Hill et al., 2004). LTA is a measurement model that uses multiple manifest indicators to estimate parameters that measure how strong the measurements are, how participants are distributed among latent stages in the sequence, and how stable stage membership is over time. Using a stage-sequential conceptualization, LTA has been used to test models of stage-sequential change in a single latent variable in a variety of settings, including substance use and delinquency (Collins et al., 2000; Hyatt &

Collins, 2000; Hill et al., 2004). For example, Hill et al. (2004) combined substance use and delinquency together to model a mixed pathway with escalation in both substance use and delinquency, including such stages as "delinquency, alcohol, and marijuana use" and "delinquency, alcohol, index offending, and hard drug use." Their results supported a model of the joint development of substance use and delinquency.

Methods like percentages, correlations, transition matrices, regression, and ANOVA do not provide a clear picture of how the rate of change in substance use relates to the rate of change in delinquency. With the exception of transition matrices, these methods often examine only one time period and do not include longitudinal measures that would provide valuable information about which process predicts change in the other. Mason and Windle (2002) and Hill et al. (2004) provided some evidence about the longitudinal relation between substance use and delinquency, but Mason and Windle's findings need replication and Hill et al.'s findings do not address the prediction of one process by the other. Based on these findings, it appears that researchers to date do not yet have a clear idea about which of these two processes predicts change in the other or if both processes predict change in the other. Hence, further research is needed to investigate the direction and nature of the relation between substance use and delinquency.

The purpose of this study is to show how ALTA can be used to investigate whether substance use and delinquency are related and if so, the nature of their relation. ALTA is a new approach to addressing the question of which process, substance use or delinquency, predicts the other. ALTA is an extension of LTA that analyzes two stage-sequential processes simultaneously to determine to what degree the two processes are linked. That is, ALTA allows researchers to test models about the relation between two stage-sequential processes over time, treating the two sequences as changing categorical variables. Thus, using a stage sequential conceptualization of substance use and delinquency, this study uses ALTA to determine the degree to which these two processes are linked. The ALTA approach is discussed in detail later; for now, it should be noted that the ALTA approach is different from other models that have been used to examine the relation between substance use and delinquency. For example, with ALTA, both sequences are treated as categorical latent variables, categorical variables are used as indica-

tors, the latent categorical variables change over time, and the changing relation between the two categorical variables can be modeled asymmetrically (Tang, 2001; Flaherty et al., 2003).

The ALTA approach can be used to determine the extent to which substance use and delinquency are related but to do this, a stage-sequential conceptualization of both substance use and delinquency is required. Prior research, however, has shown that this is a profitable conceptualization of both substance use and delinquency. For example, researchers such as Kandel et al. (1992) and Collins and colleagues (e.g., Collins et al., 1997; Hyatt & Collins, 2000; Lanza & Collins, 2002; Flaherty & Collins, 1999; Hill et al., 2004) have argued that stage-sequential models are a very useful way of depicting substance use onset and advancement. Using a variety of samples (e.g., AAPT, Graham et al., 1989; Add Health, Udry, 2003), this research has found that a general pattern of substance use onset includes the following stages: no use of any substances, alcohol and/or cigarette use, and then use of marijuana and/or other illegal substances.

Further, Loeber and colleagues (Loeber et al., 1993, 1998; Loeber & Farrington, 2000) have developed a very useful stage-sequential model of developmental pathways to serious disruptive behavior in boys. In this model there are three developmental pathways, including authority conflict, covert, and overt pathways. Within each of these pathways less serious forms of delinquent behavior precede more serious forms. While boys can participate in more than one pathway simultaneously, boys at a particular stage in a pathway may be qualitatively different from boys at another stage in the same pathway or another pathway. For instance, an adolescent who has engaged in only stage 1 authority conflict behaviors may be qualitatively different from one who has engaged in only stage 3 overt behaviors.

1.3 The Current Project: Two Related Studies

As discussed above, it is clear to researchers that substance use and delinquency are occurring at the same time during adolescence. This leads naturally to the question "Are substance use and delinquency related and if so, what is the nature of their relation?" The current study directly examines the relation between substance use and delinquency by ultimately fitting a series of ALTA models to a large sample

of nationally representative, longitudinal data, the National Longitudinal Survey of Youth, 1997 (NLSY97; Ohio State University, 2003).

1.3.1 Purpose

The current project strives to answer two main research questions. The first is "Are substance use and delinquency related?" The second is "If they are related, what is the nature of their relation?" To answer these questions, two related studies were conducted. The purpose of Study I was to fit individual stage-sequential models of substance use and delinquency to the NLSY97 data. The purpose of Study II was to combine these two individual sequence models using the ALTA approach. Study II fit a series of ALTA models to determine the degree to which substance use and delinquency are related both cross-sectionally and longitudinally. For example, it may have been the case that past delinquency was related to subsequent substance use, but not vice versa, as previous research weakly suggests (Mason & Windle, 2002).

Details of Study I and Study II are discussed more fully in the following chapters. The new ALTA approach is discussed in detail in Study II, including the mathematical model, parameters, and model definition. Study II specifically addresses the ALTA models and model comparisons of interest for the research questions.

Chapter 2

Methods

2.1 Participants

The Bureau of Labor Statistics sponsors a set of surveys called the National Longitudinal Surveys (NLS) that are designed to gather information from representative groups of men and women (U.S. Department of Labor, nd). The analyses conducted in this study used data from the NLSY97. The NLSY97 was designed to be representative of U.S. residents in 1997 that were born between 1980 and 1984. This is an ongoing survey and data are collected on participants once a year. Currently, there have been 6 waves of surveys and data from all 6 waves are publicly available. Data collection periods correspond roughly to school year, thus, the 6 waves are essentially from the 1997-98 to the 2002-03 school years. The original sample was 8,984 youths aged 12 to 16 as of December 21, 1996 (Ohio State University, 2002). The total sample includes both a representative sample of the U.S. population born between 1980 and 1984 and a supplemental sample of black and Hispanic youths in that age range. Because ethnic differences are not a focus of the current study, the supplemental sample was not included.

The sample for the current study includes only male participants. Historically, delinquency research has often been conducted on males only, for a variety of reasons. One of the most important reasons has been the assumption that girls did not have problems with delinquency or clinical conduct disorder. For example, the stage-sequential delinquency model developed by Loeber and colleagues and used here has most often been used with males. Recent research has shown, however,

that although both genders seem to begin exhibiting first symptoms of delinquency around the same time, gender differences exist in the risk of developing delinquency, the risk of comorbid disorders, and delinquent behavior type (e.g., boys exhibit physical aggression more often; Keenan et al., 1999; Moffitt & Caspi, 2001; Tiet et al., 2001; Broidy et al., 2003). Further, it appears that although girls in general have fewer problems with delinquency, a small subset of girls tend to have more types of problems than boys (Tiet et al., 2001). Analyzing gender differences in the current study, however, is not as simple as it at first seems. Simply adding gender as a latent class in the LTA and ALTA models, to explore differences between males and females, is not sufficient. An analysis of measurement invariance between males and females must be undertaken for both the substance use and delinquency sequences, before adding gender as a latent class. Such an analysis is beyond the scope of the current project. Gender differences, however, must still be addressed in some way. Hence, following the convention of earlier research, the current study uses only male participants of the NLSY97. In future work, we plan to examine the measurement invariance issue and address gender differences in the relation between substance use and delinquency more adequately.

The sample for the current study is restricted to male participants aged 12 to 16 at the time of the first interview. Many researchers feel that it is important to make a distinction between early- (also called child-onset or childhood-onset) and late-onset (also called adolescent-onset) delinquency (Patterson & Yoerger, 2002; Silverthorn et al., 2001; Patterson & Yoerger, 1997; Patterson, 1996; Moffitt & Caspi, 2001; Moffitt et al., 2002, 1996). It is thought that the early-onset delinquency trajectory begins in preschool or early childhood and often produces children who are socially incompetent and at risk for arrest and adult crime, while the late-onset trajectory includes boys who posses marginal levels of social competency, marginal levels of deviancy, fewer arrests, and who are more likely to desist from adult crime (Patterson & Yoerger, 2002; Moffitt et al., 2002). Research suggests that the cutoff for early- versus late-onset delinquency is around age 12 to 14 (Loeber et al., 1998; Patterson & Yoerger, 2002; Moffitt et al., 1996). Further, Moffitt and colleagues (Moffitt et al., 1996, 2002; Moffitt & Caspi, 2001) suggest that a substantial subset of adolescents initiate delinquent behaviors during adolescence. The current study is concerned primarily with delinquency occurring

during adolescence because it is more common. Further, the sample is restricted to participants aged 12 to 16 in an attempt to avoid possible age differences in delinquent behavior processes between those in early adolescence (e.g., age 12) and late adolescence (e.g., age 18).

Due to differences in wording at the time of the first interview for questions regarding substance use and delinquency within the last year, the middle four waves of available data of the cross-sectionally representative NLSY97 data were used (i.e., waves 2, 3, 4, and 5). Participants who were missing responses for every measure of interest were deleted from the sample (individuals providing partial data were retained). This yields an effective sample size of $N = 3,225$.

2.2 Measures

The following measures were used as indicators of recent substance use and delinquent behavior.

2.2.1 Substance Use

At each of the four occasions of measurement, participants were asked four questions about their use of cigarettes, alcohol, marijuana, and harder drugs (e.g., cocaine) since the date of the last interview (i.e., in the last year). Each of the questions was used as an indicator of recent substance use at all four times, yielding 16 total indicators of substance use. The exact question wording and coding is seen in Table 2.1.

2.2.2 Delinquency

At each of the four occasions of measurement, participants were also asked a variety of questions about their participation in delinquent activities since the date of the last interview (i.e., in the last year). Measures of delinquent behavior were chosen based on the underlying developmental model used to inform our delinquency LTA model.

The underlying developmental model is a model of developmental pathways to serious disruptive behavior in boys, developed by Loeber and colleagues (Loeber

Table 2.1. Substance Use Measures

	Question Wording	Answer Given	Recoded Value
Cigarettes	Have you smoked a cigarette since the last interview on [date of last interview]?		
Alcohol	Have you had a drink of an alcoholic beverage since the last interview on [date of last interview]? (By a drink we mean a can or bottle of beer, a glass of wine, a mixed drink, or a shot of liquor.)	YES	2
		NO	1
Marijuana	Since the date of last interview, have you used marijuana, even if only once, for example: grass or pot?		
Hard Drugs	Excluding marijuana and alcohol, since the date of last interview, have you used any drugs like cocaine or crack or heroin, or any other substance not prescribed by a doctor, in order to get high or to achieve an altered state?	MISSING	0

et al., 1998, 1993; Loeber, 1996; Loeber et al., 1997). As discussed briefly in the introduction, a key feature of this model is that it consists of three specific developmental pathways to serious delinquent behavior. Two of these pathways are of interest here, the covert and overt pathways.[1] The covert pathway includes delinquent behavior that is not openly practiced or has a secretive nature, such as stealing, damaging property, and selling drugs. The overt pathway includes delinquent behavior that is open and observable, and/or directly involving other people, such as aggression and violence.

[1]The third pathway, the authority conflict pathway, is not examined here because it best fits boys engaging in delinquent behaviors before age 12.

The delinquency measures used to create indicators of delinquent behavior reflect the idea that delinquent behaviors can be separated into two main domains, covert and overt behavior, and that it is possible for an individual to participate in both domains simultaneously (Loeber et al., 1998; Loeber & Farrington, 2000). Questions regarding participation in a delinquent activity that could be classified under one of the two main domains were used to create two indicators of delinquent behavior—one indicator for covert behavior and one indicator for overt behavior. Table 2.2 lists the activities whose questions fall into each of the domains of interest. Two examples of the wording used for all of these items is also seen in Table 2.2 (wording for each item is similar, but with the appropriate activity inserted). If the participant answered "yes" to any of the items in the box, the indicator for that domain was coded as a "yes." If the participant was "missing" on all of the items in the box, the indicator for that domain was coded as a "missing". There is one indicator for each domain at all four times, yielding 8 total indicators of delinquency. A similar creation of indicators was used by Collins and Wugalter (1992).

2.3 Study I

The purpose of Study I is to use LTA to determine single-sequence models of development for substance use and delinquency that will later be combined using the ALTA methodology. First, the hypothesized substance use and delinquency models are presented. Second, the LTA methodology is briefly discussed. Finally, the final substance use and delinquency models and results are presented.

2.3.1 Models

2.3.1.1 Substance Use

Based on the above indicators of substance use, a simple hypothesized recent substance use model is shown in Figure 2.1. This model is a modified version of the stage-sequential model of substance use onset that Hyatt and Collins (2000) fit in the Adolescent Alcohol Prevention Trial data (Graham et al., 1989) to explore the relation between perceived parental permissiveness and the onset of substance

Table 2.2. Delinquency Measures

Domain	Behavior	Answer Given	Recoded Value
Covert	Destroy property Other property crimes Steal anything < $50 Steal anything > $50 Sell illegal drugs	YES NO	2 1
Overt	Belonged to a gang Attacked anyone Used weapon to steal Carried handgun	MISSING	0

Example wording: Since the last interview on [date of last interview], have you purposely damaged or destroyed property that did not belong to you?

Example wording: Have you carried a handgun since the last interview on [date of last interview]? When we say handgun, we mean any firearm other than a rifle or shotgun.

use. One important difference is that here we are interested in transitions between recent use stages (i.e., substance use in the past year), whereas Hyatt and Collins were interested in transitions between lifetime use stages. Thus, because this is a recent use model, participants can freely transition back and forth between the latent statuses over time.

This model represents a starting point. Using the G^2 fit statistic and examining estimates of measurement error for the indicators, a model that fits the data well, which may include additional latent statuses such as "cigarettes and marijuana" and "alcohol and marijuana" will be determined using LTA. The final model will be as parsimonious as possible.

2.3.1.2 Delinquency

Based on the above indicators of delinquent behavior, a simple hypothesized recent delinquency model is shown in Figure 2.2. This model also represents a starting point. Note that since there are only two indicators at each time, one each for

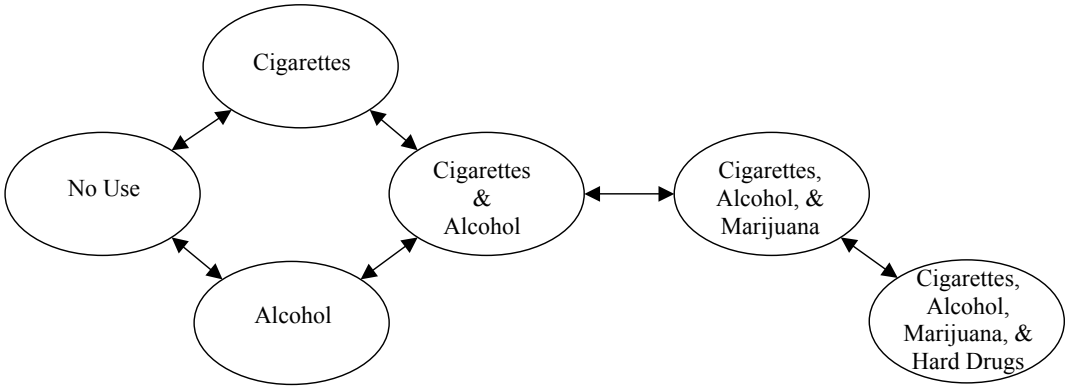

Figure 2.1. Hypothesized Substance Use Model

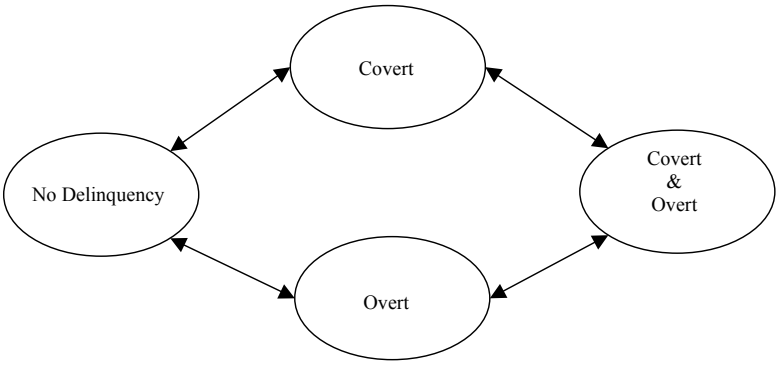

Figure 2.2. Hypothesized Delinquency Model

covert and overt behavior, this is the maximal model that can be fit. Using the G^2 fit statistic and examining estimates of measurement error, a model that fits the data well, which may result in the removal of one of the latent statuses, will be determined using LTA. The final model will be as parsimonious as possible.

2.3.2 LTA Methodology

Latent class analysis (LCA) is a method used to model underlying categorical structures in contingency table data. The general philosophy of measurement employed by LCA is that manifest indicators used to measure a latent variable are fundamentally error-prone. For example, LCA's measurement philosophy recognizes that answers to questions like "Have you taken a drink of alcohol in the past year?" will never be completely error-free indicators for recent substance use.

Thus, LCA models measurement error. Multiple indicators are preferred because they allow the error associated with each indicator to be estimated and removed from parameter estimates.

LTA, a reparameterization of LCA, tests models of longitudinal change in a single, dynamic, categorical latent variable. The latent variable is comprised of different stages called *latent statuses*. LTA estimates transition probabilities to describe how individuals move between latent statuses from time t to $t+1$.

LTA models provide estimates of the probabilities of latent status membership (δ), transitions between latent statuses over time (τ), and measurement error (ρ). First, δ parameters estimate the probabilities of membership in a given latent status; for example $\delta_{alcohol}$ is the probability of membership in the "alcohol" latent status and δ_{covert} is the probability of membership in the "covert" latent status. Second, τ parameters estimate the probabilities of transitioning from one latent status to another, from time t to time $t+1$; for example $\tau_{alcohol|cigarettes}$ is the probability of transitioning into the "alcohol" latent status at time $t+1$ given membership in the "cigarettes" latent status at time t and $\tau_{covert|no\,delinquency}$ is the probability of transitioning into the "covert" latent status at time $t+1$ given membership in the "no delinquency" latent status at time t. Third, the ρ parameters estimate the probability of an indicator response category, conditional on membership in a particular latent status; for example $\rho_{yes,alcohol|alcohol}$ is the probability of answering "yes" to the question about alcohol use in the past year, conditional on membership in the "alcohol" latent status (likely to be close to 1.0) and $\rho_{yes,covert|nodelinquency}$ is the probability of answering "yes" to the indicator of covert delinquent behavior (i.e., answering "yes" to any of the questions about the delinquent behaviors that create the covert indicator) in the past year, conditional on membership in the "no delinquency" latent status (likely to be close to 0).

Details of the LCA and LTA mathematical models are available in several papers, including Collins & Wugalter (1992); Collins et al. (1997); Hyatt & Collins (2000); Lanza & Collins (2002); Lanza et al. (2003); Auerbach (2003).

2.3.2.1 LTA Model Fit

Assessment of LCA and LTA absolute model fit uses the G^2 statistic. This statistic ideally has a χ^2 distribution and the expectation of this distribution is the *number*

of degrees of freedom (*df*) in the model. However, in large, sparse contingency tables the χ^2 distribution may not be an adequate approximation to the distribution of the G^2 statistic. That is, when the sample size is small, relative to the number of cells in the contingency table (possible response patterns), the χ^2 distribution is no longer a good reference for the G^2 statistic and it is then difficult to use G^2 to assess absolute model fit (Flaherty et al., 2003). For this reason, formal hypothesis testing was not used. Instead, to select the best fitting stage-sequential models of substance use and delinquency, the following model evaluation procedure was used. First, a hypothesized model of substance use (or delinquency), based on theory and previous research, was determined. This hypothesized model was then fit using the LTA methodology. The fit to the empirical data was assessed using two criteria. The first criterion was a rough rule of thumb of accepting models with a G^2 statistic at or below the *df* for the model. The second criterion was the interpretability of the estimated parameter results: measurement parameter estimates that were close to zero and one, signaling non-random responses to indicators, and latent status membership estimates that were not too small, signaling latent statuses that are not empty, were desired. If the hypothesized model did not meet these two criteria, it was judged to fit the data poorly and was revised. A revised model was then constructed by examining participant response patterns, latent status membership estimates from the hypothesized model, and measurement parameter estimates from the hypothesized model. This new model may have additional latent statuses added or latent statuses may be removed to adequately fit the data. This new model was then fit to the data using the LTA methodology and the two criteria were again used to determine if the model fit well. This process was repeated until a model with satisfactory fit was identified.

2.3.2.2 Parameter Restrictions

Parameter fixing and equality constraints are two common types of parameter restrictions in LCA and LTA models. (They are also used in ALTA models.) Using parameter restrictions in LTA, a variety of models of stage-sequential change can be defined in order to examine longitudinal change in the categorical latent variable of interest. Fixed parameters do not change during model estimation. For example, within a lifetime substance use sequence, a backwards transition from

ever having tried alcohol to never having tried alcohol is impossible by definition. Thus, all transition parameters estimating the probabilities of membership in any latent status not including alcohol use at time t, conditional on membership in any latent status including alcohol use at time $t-1$, are fixed to zero. Equality constraints create a set of parameters that are set to be equal during model estimation. In longitudinal models, equality constraints are commonly used to make the measurement parameters equal over time. By equating these parameters, the meaning of the latent statuses is kept uniform over time. A discussion of parameter restrictions and the analytic procedure typically used with the ALTA methodology is found in Study II.

2.3.2.3 Missing Data

Finally, an initial assessment of the NLSY97 dataset indicated that the issue of missing data needed to be addressed during the LTA analyses. The "Latent Transition Analysis for Windows" program (WinLTA; Collins et al., 2002) can be used to fit latent class and one-sequence latent transition models and uses a maximum likelihood approach to avoid eliminating participants due to missing data. It has been shown that WinLTA's estimation procedure is robust when the data are missing completely at random (MCAR) or missing at random (MAR; for a more detailed discussion of MCAR and MAR see Collins et al., 2001; Schafer, 1997; for a more detailed discussion of estimation procedure robustness see Hyatt & Collins, 1998). Controlling for missing data is important because parameter estimates can be biased if casewise deletion is used in a missing at random situation.

2.3.3 Results

First, the above hypothesized model of substance use was fit using the LTA methodology. Note that this model freely estimated all latent status membership probabilities (δ; i.e., no restrictions placed on membership in any of the 6 latent statuses) and transition probabilities (τ; i.e., no restrictions placed on transitions between any two of the 6 latent statuses). Measurement parameters (ρ) were constrained to be equal across time and response category. Using the two model fit criteria above, it was determined that this model fit the data relatively well—the G^2 for

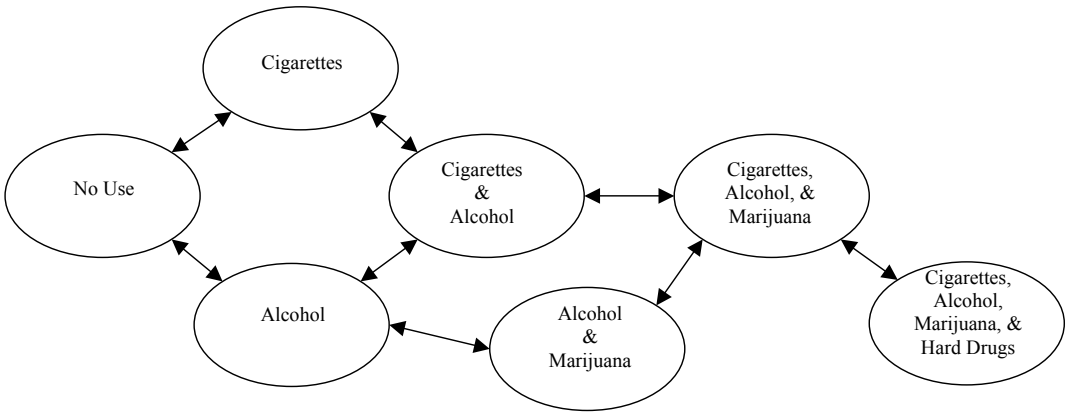

Figure 2.3. Revised Substance Use Model

this model was 4588.022 for 65436 *df*, and the measurement parameters ranged from 0.923 to 0.991 on the high end, and from 0.009 to 0.077 on the low end, for the four indicators. The participant response patterns and residuals of the hypothesized model, however, suggested that a latent status for "alcohol and marijuana" use should be added to the model. This revised model is shown in Figure 2.3.

The revised model freely estimated all latent status membership probabilities (δ) and transition probabilities (τ), and the measurement parameters (ρ) were constrained to be equal across time and response category. Using the two model fit criteria, it was determined that this model fit the data well. The G^2 for this model is 4021.835 for 65399 *df*, and the measurement parameters ranged from 0.917 to 0.987 on the high end, and from 0.013 to 0.083 on the low end, for the four indicators. Although these two models cannot be compared directly via a G^2 difference test to determine if one fit significantly better than the other (because they are not nested), this revised model appears to be an adequate final model because it seems to fit the data well and to fit the response patterns of the participants more adequately than the hypothesized model.

Table 2.3 displays the estimated latent status membership probabilities (δ) at each time for the revised model. The estimated probabilities for the "alcohol and marijuana" latent status are substantial and provide evidence that this latent status is necessary; that is, that the revised model is better suited for this data than the hypothesized model. Note that transition probabilities (τ) were not examined here because they do not provide information about model fit. Given

the model fit criteria, the revised model was chosen as our stage-sequential model of substance use for this data. The individual model of substance use in Figure 2.3 is simultaneously examined with the individual model of delinquency via the ALTA methodology in Study II.

Table 2.3. Substance Use Latent Status Membership Probabilities

	Time 1	Time 2	Time 3	Time 4
No Use	0.459	0.382	0.343	0.282
Cigarettes	0.034	0.051	0.031	0.030
Alcohol	0.148	0.174	0.178	0.215
Cig & Alc	0.138	0.148	0.166	0.187
Alc & Mar	0.026	0.039	0.049	0.038
Cig, Alc, & Mar	0.148	0.150	0.174	0.177
Cig, Alc, Mar, & Hard Drugs	0.047	0.055	0.060	0.070

Second, the above hypothesized model of delinquency was fit using the LTA methodology. This model freely estimated all latent status membership probabilities (δ) and transition probabilities (τ). Measurement parameters (ρ) were constrained to be equal across time and response categories. Using the two model fit criteria, it was determined that this model fit the data relatively well—the G^2 for this model is 405.081 for 214 df, and the measurement parameters are 0.930 and 0.947 on the high end, and 0.053 and 0.070 on the low end, for the two indicators. Examining the participant response patterns and residuals of the hypothesized model, it was determined that it was not appropriate to remove any of the latent statuses.

Table 2.4 displays the estimated latent status membership probabilities for the hypothesized model. The estimated probabilities for all of the latent statuses are substantial and provide further evidence that none of the latent statuses should be removed. Note that the transition probabilities were not examined here because they do not provide information about model fit. Given the model fit criteria, the fact that this is the maximal model with the two indicators, and the fact that the χ^2 distribution is not likely to be a good comparison for the G^2 statistic, this

hypothesized model was chosen as our stage-sequential model of delinquency for this data. The individual model of delinquency in Figure 2.2 is simultaneously examined with the individual model of substance use in Figure 2.3 via the ALTA methodology in Study II.

Table 2.4. Delinquency Latent Status Membership Probabilities

	Time 1	Time 2	Time 3	Time 4
No Delinquency	0.665	0.735	0.753	0.817
Covert	0.148	0.123	0.115	0.075
Overt	0.061	0.061	0.058	0.053
Covert & Overt	0.126	0.082	0.074	0.054

Examining Tables 2.3 and 2.4 together, it appears that substance use is increasing over time, whereas delinquency is decreasing over time. This will be further examined in Study II.

Chapter 3

Study II

Study II uses the ALTA methodology to examine the two research questions of the current project. That is, this new approach provides a way to determine if substance use and delinquency are related and, if they are, to determine the nature of their relation. Study II combines the individual LTA models of substance use and delinquency from Study I to determine the best fitting model of the relation between these two processes.

First, ALTA's mathematical model and notation are introduced. Second, the models used to answer the research questions of interest are discussed. Finally, results from these models and model comparisons are presented.

3.1 ALTA Methodology

As discussed earlier, LCA and LTA models provide a way to examine the process of longitudinal change for a single categorical latent variable. As in this project, however, researchers are often interested in simultaneously analyzing two behaviors that have categorical latent structures. Like LTA, ALTA is a reparameterization of LCA for longitudinal data. ALTA, however, is not limited to a single latent variable sequence. ALTA models longitudinal change in two dynamic, categorical latent variables simultaneously. Parameter restrictions in ALTA can define a variety of models that relate two sequences cross-sectionally and longitudinally to different degrees. By comparing the fit of these models, hypotheses about the manner in which two sequences are related can be tested. Here ALTA's mathematical model

and parameter interpretation, as well as a typical analytic procedure used with the ALTA methodology, is introduced.

3.1.1 ALTA Mathematical Model

In an ALTA model, one sequence is considered to be the exogenous (predictor) sequence and the other is considered to be the endogenous (predicted) sequence. The current study considers substance use to be the exogenous sequence and delinquency to be the endogenous sequence. For clarity, these sequences are used to illustrate ALTA's parameters and mathematical model.

3.1.1.1 Parameters

In the ALTA model, there are five types of parameters. These parameters are: α, β, ϵ, η, and ρ. A brief description of the interpretation of each of the parameters follows.

α_{c_t} The α_{c_t} parameters are the unconditional probability of membership in an exogenous sequence latent status c_t at time t; for example, the unconditional probability of membership in the "alcohol" substance use latent status at time t. The α_{c_t} parameters at any time, after time 1, can be calculated from other parameters. Hence, α_{c_1} is the only α parameter that appears in the mathematical model.

$\beta_{d_t|c_t}$ The $\beta_{d_t|c_t}$ parameters are the probability of membership in an endogenous sequence latent status d_t at time t, conditional on membership in an exogenous latent status c_t at time t; for example, the probability of membership in the "covert" delinquency latent status at time t, conditional on membership in the "alcohol" substance use latent status at time t. The β parameters at any time, after time 1, can be calculated from other parameters. Hence, $\beta_{d_1|c_1}$ is the only β parameter that appears in the mathematical model.

$\epsilon_{c_t|c_{t-1},d_{t-1}}$ The $\epsilon_{c_t|c_{t-1},d_{t-1}}$ parameters are the probability of membership in an exogenous sequence latent status c_t at time t, conditional on membership in an exogenous sequence latent status c_{t-1} and an endogenous sequence latent status d_{t-1} at time $t-1$; for example, the probability of membership in the

"alcohol" substance use latent status at time t, conditional on membership in the "no use" substance use latent status and "covert" delinquency latent status at time $t-1$.

$\eta_{d_t|c_t,c_{t-1},d_{t-1}}$ The $\eta_{d_t|c_t,c_{t-1},d_{t-1}}$ parameters are the probability of membership in an endogenous sequence latent status d_t at time t, conditional on membership in: an exogenous sequence latent status c_t at time t; an exogenous sequence latent status c_{t-1} at time $t-1$; and an endogenous sequence latent status d_{t-1} at time $t-1$. One example is the probability of membership in the "covert" delinquency latent status at time t, conditional on membership in the "alcohol" substance use latent status at time t, and the "no use" substance use latent status and "no delinquency" delinquency latent status at time $t-1$.

$\rho_{t,j,k|c_t,d_t}$ The $\rho_{t,j,k|c_t,d_t}$ parameters are estimates of measurement error. They are the probabilities of answering a particular response category k for a particular item j at time t, conditional on membership in an exogenous sequence latent status c_t and an endogenous sequence latent status d_t at time t. For example, the probability of answering "yes" to the item asking "Have you smoked a cigarette since the date of the last interview?" at time t, conditional on membership in the "alcohol" substance use latent status and the "covert" delinquency latent status at time t.

3.1.1.2 Model

The following notation is used to define the ALTA model. The vector $\mathbf{W}$ is a response vector of length Tq, where T is the number of time points and q is the number of indicators measuring both sequences at a single time point. The vector $\mathbf{r}$ is a vector of length Tq containing the number of response categories of the q indicators at each of the T times. The substance use (exogenous) sequence has C_t latent statuses at time t $(t = 1, ..., T)$ and the delinquency (endogenous) sequence has D_t latent statuses at time t $(t = 1, ..., T)$. Further, c_t represents any substance use latent status at time t and d_t represents any delinquency latent status at time t. The ALTA model is seen in Equation 3.1. This equation models the probability

of observing response pattern $\mathbf{W} = \mathbf{w}$.

$$P(W = w) = \sum_{c_1}^{C_1} \sum_{d_1}^{D_1} \cdots \sum_{c_T}^{C_T} \sum_{d_T}^{D_T} \left[\alpha_{c_1} \beta_{d_1|c_1} \left(\prod_{j=1}^{q} \prod_{k=1}^{r_j} \rho_{1,j,k|c_1,d_1}^{I(w_{1,j}=k)} \right) \times \prod_{t=2}^{T} \left(\varepsilon_{c_t|c_{t-1},d_{t-1}}^{(t)} \eta_{d_t|c_t,c_{t-1},d_{t-1}}^{(t)} \prod_{j=1}^{q} \prod_{k=1}^{r_j} \rho_{t,j,k|c_t,d_t}^{I(w_{t,j}=k)} \right) \right]. \quad (3.1)$$

The first part of this equation, $\alpha_{c_1} \beta_{d_1|c_1} \left(\prod_{j=1}^{q} \prod_{k=1}^{r_j} \rho_{1,j,k|c_1,d_1}^{I(w_{1,j}=k)} \right)$, corresponds to the first measurement occasion and models the probabilities of (a) being in a particular substance use latent status at time 1 and (b) being in a particular delinquency latent status at time 1, given membership in a particular substance use latent status at time 1. The factor in parenthesis is the portion of the measurement model corresponding to time 1.

The second part of this equation, $\prod_{t=2}^{T} \left(\varepsilon_{c_t|c_{t-1},d_{t-1}}^{(t)} \eta_{d_t|c_t,c_{t-1},d_{t-1}}^{(t)} \prod_{j=1}^{q} \prod_{k=1}^{r_j} \rho_{t,j,k|c_t,d_t}^{I(w_{t,j}=k)} \right)$, corresponds to the subsequent measurement occasions and models the probabilities of (a) being in a particular substance use latent status at time t, given membership in a particular substance use latent status at time $t-1$ and a particular delinquency latent status at time $t-1$, and (b) being in a particular delinquency latent status at time t, given membership in particular substance use latent statuses at times $t-1$ and t and a particular delinquency latent status at time $t-1$. The ρ parameters at the end of this part of the equation are the portions of the measurement model for all subsequent measurement occasions.

3.1.2 Model Fit and Analytic Procedure

Assessment of ALTA model fit is identical to the procedures used with LCA and LTA models. That is, ALTA models use Pearson's χ^2 or the G^2 statistic to assess model fit. These statistics ideally have a χ^2 distribution and the expectation of this distribution is the *number of degrees of freedom* in the model.

Testing hypotheses with ALTA, as opposed to the testing of absolute model fit as in Study I, is typically done by comparing the fit of two nested models. Two models are nested when one model is a more complex version of the other, where some parameters constrained in the simpler model are estimated in the

more complex model. It is important to note, however, that models with different numbers of latent statuses are not nested because parameters of the simple model take on boundary values of the parameter space (Lanza et al., 2003). Hence, for the purposes of this project, two models are nested if each single sequence LTA model contains the same latent statuses in each model and the only difference between the two ALTA models are the parameter restrictions used to define each model.

Once two nested models are defined with appropriate parameter restrictions, both models are fit via the ALTA method and the model fit statistic G^2 is estimated and *df* determined for each model. Then, to determine if one model fits significantly worse than the other, the difference in the G^2 statistics is compared with the χ^2 distribution with *df* equal to the difference in the *df* between the two models. For example, if the G^2 of the more complex model is significantly less than that of the simpler model, it is concluded that the simpler model fits the data significantly worse than the more complex model. This analytic procedure is used to select an appropriate model for the relation between substance use and delinquency, so that the research question of interest can be answered.

3.1.3 Missing Data

As discussed earlier, an initial assessment of the NLSY97 dataset indicated that the issue of missing data needed to be addressed during the ALTA analyses. The ALTA FORTRAN program used to run ALTA analyses is similar to WinLTA, but can be used to fit two-sequence models. However, due to computing limitations of the ALTA software, it was necessary to modify the sample for Study II in two ways. First, only the first three waves of data used in Study I were analyzed in Study II. Second, listwise deletion was used to remove any participant with missing data on any indicator at any time. Note that listwise deletion would not have been necessary if there were less missing data, fewer indicators, or fewer waves of data.

3.2 Models

The purpose of Study II is to determine the best fitting stage-sequential model that simultaneously examines substance use and delinquency for the sample participants from the NLSY97. By fitting this model, the questions "Are substance use and delinquency related?" and "If so, what is the nature of that relation?" are addressed. To this end, Study II compares the fit of four different ALTA models to determine the nature of the relation between substance use and delinquency. Each of the four models corresponds to a particular interpretation of whether or not substance use and delinquency are related and the nature of that relation.

Independent Sequences Model The first of the four models is the independent sequences (IS) model. In this model, the exogenous sequence does not predict the endogenous sequence cross-sectionally or longitudinally. That is, in the IS model, substance use and delinquency are independent processes and are not related in any way across time. In other words, delinquency latent status never depends on substance use latent status and substance use latent status never depends on delinquency latent status.

Cross-sectional Relation Model The second model is the cross-sectional relation (CS) model. In this model, the exogenous sequence predicts the endogenous sequence only cross-sectionally. That is, in the CS model, substance use and delinquency are related at time 1, but are not related longitudinally.

Unidirectional Longitudinal Relation Model The third model is the unidirectional longitudinal relation (UDL) model. In this model, the exogenous and endogenous sequences are related cross-sectionally and are related in a specific way across time. Specifically, across time substance use is related to past delinquency, but delinquency is not related to past substance use.

Bidirectional Longitudinal Relation Model The final model is the bidirectional longitudinal relation (BDL) model. In this model, the exogenous and endogenous sequences are fully related cross-sectionally and longitudinally. That is, in the BDL model, substance use predicts delinquency at time 1, substance use is related to past delinquency, and delinquency is related to past substance use.

Parameter restrictions allow the specification of particular ALTA models. A unique set of parameter restrictions specifies each of the four models of interest. The parameter restrictions used to define each of the four models described above are discussed below.

IS Model In the IS model, because substance use and delinquency are not related cross-sectionally or longitudinally, the probability of membership in any delinquency latent status is the same across all substance use latent statuses and the probability of membership in any substance use latent status is the same across all delinquency latent statuses at all times. This requires three types of parameter restrictions:

1. At time 1, the $\beta_{d_1|c_1}$ parameters are constrained to be equal across all substance use latent statuses because the probability of membership in any of the delinquency latent statuses at time 1 does not depend on substance use latent status membership at time 1.
2. At each time, the $\epsilon_{c_t|c_{t-1},d_{t-1}}$ parameters are constrained to be equal across each delinquency latent status d_{t-1} because the probability of membership in any of the substance use latent statuses at time t depends only upon substance use latent status membership at time $t-1$, and not on delinquency latent status membership at time $t-1$.
3. At each time, the $\eta_{d_t|c_t,c_{t-1},d_{t-1}}$ parameters are constrained to be equal across all possible combinations of substance use latent statuses at times t and $t-1$, c_t and c_{t-1} respectively, because the probability of membership in any of the delinquency latent statuses at time t depends only upon delinquency latent status membership at time $t-1$, and not on substance use latent status membership at time t or $t-1$.

A summary of the parameter restrictions placed on the β, ϵ, and η parameters for this model (and the three to follow) is found in Table 3.1.

CS Model In the CS model, because substance use and delinquency are related cross-sectionally but not longitudinally, the probability of membership in any delinquency latent status at time 1 depends on substance use latent status membership at time 1, but at all future times the probability of membership

in any delinquency latent status is the same across all substance use latent statuses and the probability of membership in any substance use latent status is the same across all delinquency latent statuses. This requires two types of parameter restrictions:

1. At each time, the $\epsilon_{c_t|c_{t-1},d_{t-1}}$ parameters are constrained to be equal across each delinquency latent status d_{t-1}.
2. At each time, the $\eta_{d_t|c_t,c_{t-1},d_{t-1}}$ parameters are constrained to be equal across all possible combinations of substance use latent statuses at times t and $t-1$, c_t and c_{t-1} respectively.

In the CS model, the $\beta_{d_1|c_1}$ parameters are unrestricted because the probability of membership in any of the delinquency latent statuses at time 1 may depend on substance use latent status membership at time 1. See Table 3.1 for a summary of these parameter restrictions.

UDL Model In the UDL model, because substance use and delinquency are related cross-sectionally and substance use is related to past delinquency but not vice versa, the probability of membership in any delinquency latent status at time 1 depends on substance use latent status membership at time 1, the probability of membership in any substance use latent status may vary across past delinquency latent statuses, but the probability of membership in any delinquency latent status does not vary across past substance use latent statuses. This requires one type of parameter restriction:

1. At each time, the $\eta_{d_t|c_t,c_{t-1},d_{t-1}}$ parameters are constrained to be equal across all possible combinations of substance use latent statuses at times t and $t-1$, c_t and c_{t-1} respectively.

In the UDL model, the $\beta_{d_1|c_1}$ and $\epsilon_{c_t|c_{t-1},d_{t-1}}$ parameters are unrestricted. See Table 3.1 for a summary.

BDL Model In the BDL model, because substance use and delinquency are fully related cross-sectionally and longitudinally, the probability of membership in any substance use latent status may vary across past delinquency latent statuses and the probability of membership in any delinquency latent status

may vary across past substance use latent statuses. This requires that the estimation of the β, ϵ, and η parameters be unrestricted. See Table 3.1 for a summary.

From the above definition of nested models, we see that the IS, CS, and UDL models are each nested within the BDL model because the parameters constrained in the IS, CS, and UDL models (the simpler models) are estimated in the BDL model (the more complex model), and none of the parameter estimates in the three simpler models take on boundary values of the parameter space.

Table 3.1. ALTA Model Parameter Restrictions

Parameter	IS	CS	UDL	BDL
$\beta_{d_t\|c_t}$	Equal	Unrestricted	Unrestricted	Unrestricted
$\epsilon_{c_t\|c_{t-1},d_{t-1}}$	Equal	Equal	Unrestricted	Unrestricted
$\eta_{d_t\|c_t,c_{t-1},d_{t-1}}$	Equal	Equal	Equal	Unrestricted

Finally, note that in ALTA models, equality constraints are commonly used to make the measurement parameters (i.e., the $\rho_{t,j,k|c_t,d_t}$ parameters) equal over time in order to keep the meaning of the latent statuses uniform over time. In all of the models examined in Study II, the ρ parameters are constrained to be equal across all times.

3.3 Model Comparisons

The first goal of Study II is to answer the question "Are substance use and delinquency related?" The question of whether or not substance use and delinquency are related can be addressed by comparing the fit of the IS model with that of the BDL model. If the IS model does not fit significantly worse, it is concluded that the β, ϵ, and η parameters do not need to be freely estimated for a well-fitting model. That is, a model defined by parameter restrictions that force substance use and delinquency to be independent fits the data well. In this case, it is concluded that substance use and delinquency are not related, in which case the model comparisons are ended. If the BDL model fits significantly better, it is concluded that

substance use and delinquency are related in some way (e.g., either cross-sectionally or longitudinally) and further model comparisons are warranted.

If, after addressing the first question, it is concluded that substance use and delinquency are related, the second goal of Study II is to determine the nature of that relation. The question about the nature of the relation then becomes "Are substance use and delinquency related cross-sectionally or longitudinally?" To address this question, the fit of the BDL model is compared with that of the CS model. If the CS model does not fit significantly worse than the BDL model, it is concluded that the ϵ and η parameters do not need to be freely estimated for a well-fitting model. That is, substance use and delinquency are related only cross-sectionally, in which case the model comparisons are ended. If the BDL model fits significantly better, it is concluded that substance use and delinquency are related longitudinally and further model comparisons to determine the nature of the longitudinal relation are warranted.

If it is concluded that further investigation of the nature of the longitudinal relation is warranted, the question about the nature of the relation then becomes "Are substance use and delinquency related unidirectionally or bidirectionally over time?" For example, substance use and delinquency would be related unidirectionally over time if starting to participate in overt delinquent behaviors predicts starting the use of marijuana, but starting the use of marijuana does not then predict starting combinations of covert and overt behavior. Additionally, substance use and delinquency would be related bidirectionally over time if starting the use of cigarettes and alcohol predicts starting to participate in overt delinquent behaviors, which in turn predicts starting the use of marijuana. To answer this question, the fit of the BDL model is compared with that of the UDL model. If the UDL model does not fit significantly worse, it is concluded that the η parameters do not need to be freely estimated for a well-fitting model. That is, previous delinquency is related to subsequent substance use but not vice versa. If the BDL model fits significantly better, it is concluded that substance use and delinquency are fully related cross-sectionally and longitudinally.[1]

[1]Note that these same model comparisons can be made with delinquency as the exogenous sequence and substance use as the endogenous sequence. For the same hypothesis tests, however, parameter constraints would have to be placed on the ϵ parameters, instead of the discussed parameter constraints on the η parameters, in the UDL model.

3.4 Results

First, to address the question "Are substance use and delinquency related?" the fit of the BDL model was compared with that of the IS model. Table 3.2 displays the model fit statistics and *df* for each of the four models. All differences are in relation to the BDL model. Examining the differences in the G^2 statistics and the *df* of the BDL and IS models shows that the IS model fit significantly worse than the BDL model ($\Delta G^2 = 2489.86, \Delta df = 720, P(\chi^2 > 2489.86) < 0.001$). Thus, it was concluded that substance use and delinquency are related in some way and further model comparisons are warranted.

Table 3.2. Model Fit Statistics

	G^2	ΔG^2	*df*	Δdf
Bidirectional Longitudinal	6208.30	-	261354	-
Unidirectional Longitudinal	7756.09	1547.79	261930	576
Cross-sectional Relation	8085.50	1877.20	262056	702
Independent Sequences	8698.16	2489.86	262074	720

Now, to answer the question "What is the nature of the relation between substance use and delinquency?" two model comparisons were necessary. First, the fit of the BDL model was compared with that of the CS model. Examining the differences in the G^2 statistics and the *df* of the BDL and CS models shows that the CS model fit significantly worse than the BDL model ($\Delta G^2 = 1877.20, \Delta df = 702, P(\chi^2 > 1877.20) < 0.001$). Thus, it was concluded that substance use and delinquency are related longitudinally and further model comparisons are warranted. Second, the fit of the BDL model was compared with that of the UDL model. Examining differences in the G^2 statistics and the *df* of the BDL and UDL models shows that the UDL model fit significantly worse than the BDL model ($\Delta G^2 = 1547.79, \Delta df = 576, P(\chi^2 > 1547.79) < 0.001$). Thus, it was concluded that substance use and delinquency are fully related both cross-sectionally and longitudinally.

As the best fitting model, the BDL model was further investigated. This model

has good measurement overall. The ρ parameters range from 0.955 to 1.000 on the high end, and from 0.000 to 0.0445 on the low end, for all six indicators of substance use and delinquency.

Recall from Study I that the results of the single sequence models showed that substance use was increasing over time while delinquency was decreasing over time. To explore what is happening with this overall downward trend of delinquency and its relation to the overall increasing trend of substance use, additional results from the BDL model were investigated. To do this, a series of questions was posed.

1. What is the trend in substance use over time? To answer this question, the α_{c_t} parameters were examined. The α_{c_t} parameters for all three times are shown in Table 3.3 and Figure 3.1; the α_{c_t} parameters are the unconditional probabilities of belonging to a particular substance use latent status. The probabilities sum to one within each time. From Table 3.3 and Figure 3.1, the biggest increase in substance use occurred between times 1 and 2, with rates of use staying stable between times 2 and 3. From Figure 3.1, the trend of increasing substance use appears to be mostly driven by large increases in the use of two or more substances from times 1 to 2.

Table 3.3. Bidirectional Longitudinal Relation Model α Parameter Estimates

	Time 1	Time 2	Time 3
No Use	0.4359	0.2150	0.2119
Cigarettes	0.0560	0.0699	0.0721
Alcohol	0.1616	0.1704	0.1504
Cig & Alc	0.1277	0.1469	0.1648
Alc & Mar	0.0359	0.0744	0.0791
Cig, Alc, & Mar	0.1350	0.2205	0.2185
Cig, Alc, Mar, & Hard Drugs	0.0479	0.1029	0.1032

2. What is the trend in delinquency over time? To answer this question, the $\beta_{d_t|c_t}$ parameters were examined. The $\beta_{d_t|c_t}$ parameters for all three times are shown in Table 3.4 and Figure 3.2; the $\beta_{d_t|c_t}$ parameters are the con-

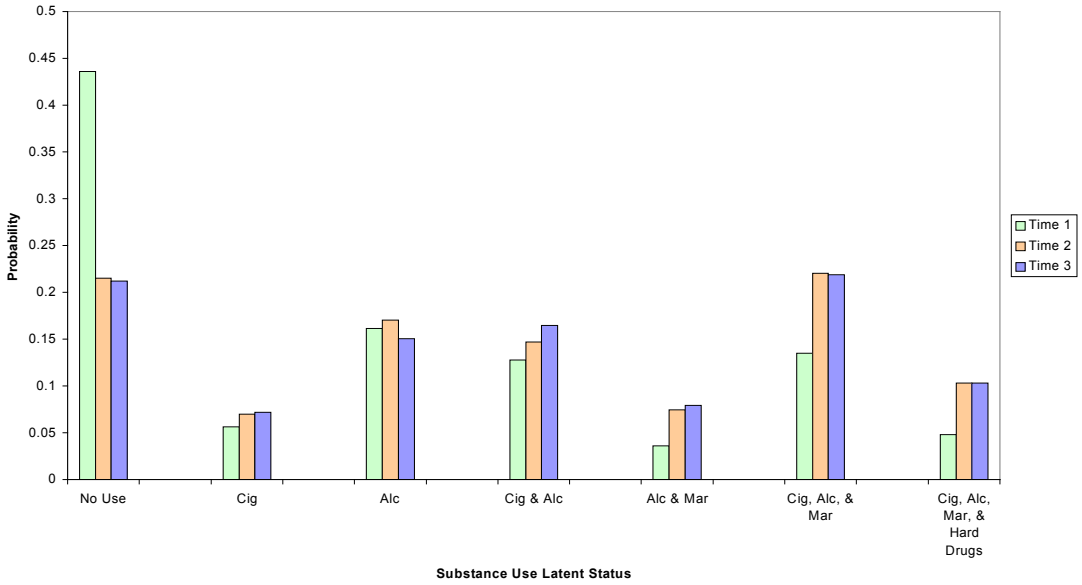

Figure 3.1. Bidirectional Longitudinal Relation Model α Parameter Estimates

ditional probabilities of belonging to a particular delinquency latent status given substance use latent status. The probabilities sum to one within each substance use latent status, within each time. To understand what happened to the overall downward trend in delinquency, we examined Table 3.4 closely. Within Table 3.4 the same cell must be compared over the three times to see the downward delinquency trend. Take, for example the latent status "Cigarettes, Alcohol, Marijuana, and Hard Drugs," whose membership probabilities are highlighted in Table 3.4. Within this latent status, the percentage of individuals not committing any delinquent acts increases greatly over time. This pattern is also clearly seen in latent statuses with participants using two or more types of substances. If the trend in delinquency was not decreasing, these probabilities should stay relatively stable over time, even if more and more participants start using substances over time. From Table 3.4, the trend of decreasing delinquency appears to be mostly driven by large decreases in delinquency among those who have used three or more substances. This pattern can also be seen in Figure 3.2 by comparing the relative heights of the "no delinquency" membership probability bars within each latent status across the three times.

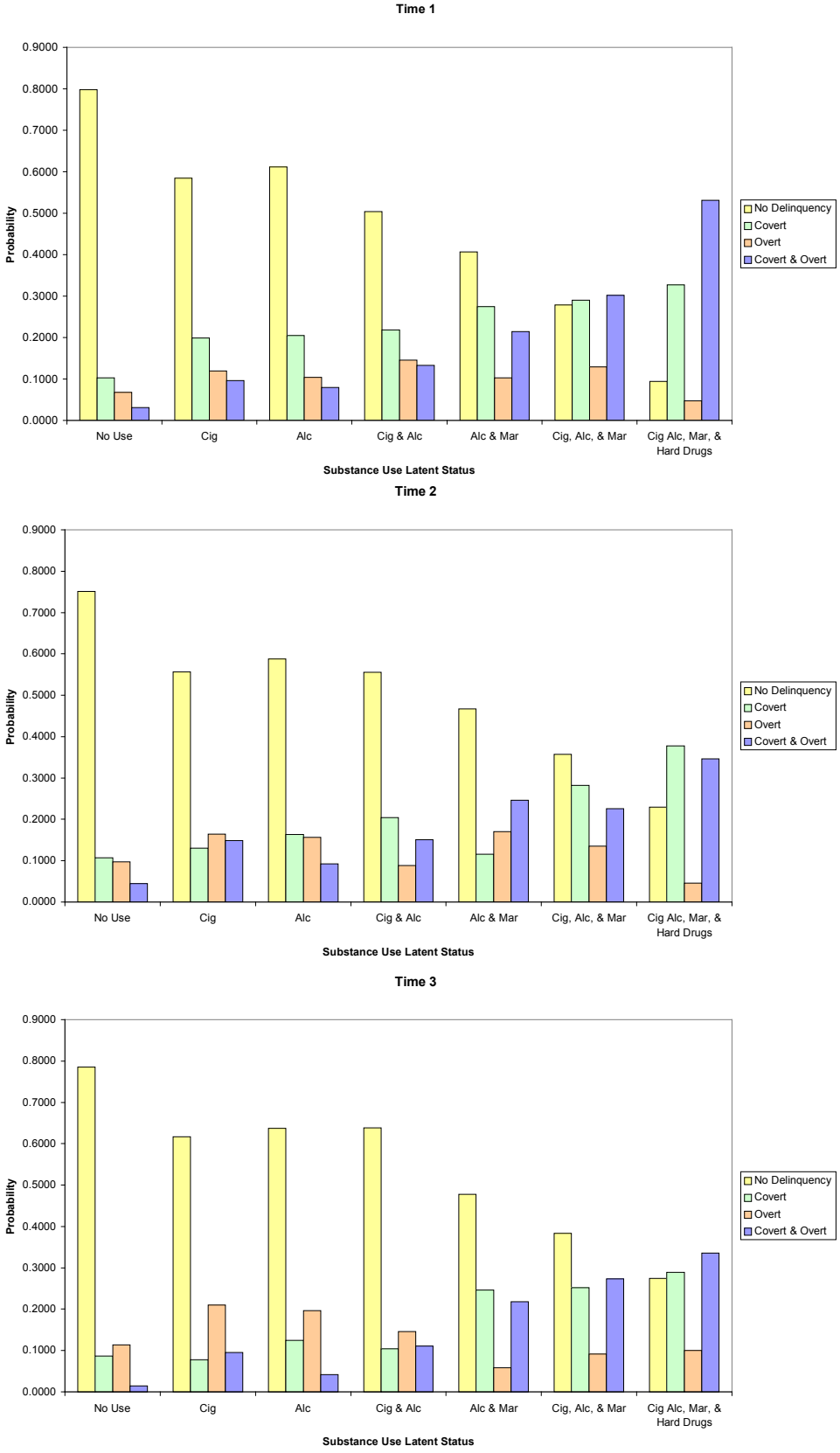

Figure 3.2. Bidirectional Longitudinal Relation Model β Parameter Estimates

Table 3.4. Bidirectional Longitudinal Relation Model β Parameter Estimates

Time 1				
	No Delin.	Covert	Overt	Covert & Overt
No Use	0.7981	0.1033	0.0677	0.0309
Cigarettes	0.5840	0.1995	0.1199	0.0966
Alcohol	0.6115	0.2051	0.1042	0.0792
Cig & Alc	0.5040	0.2180	0.1452	0.1328
Alc & Mar	0.4070	0.2752	0.1028	0.2150
Cig, Alc, & Mar	0.2791	0.2899	0.1287	0.3023
Cig, Alc, Mar, & Hard Drugs	0.0944	0.3276	0.0474	0.5306
Time 2				
	No Delin.	Covert	Overt	Covert & Overt
No Use	0.7508	0.1073	0.0969	0.0450
Cigarettes	0.5565	0.1306	0.1641	0.1488
Alcohol	0.5873	0.1637	0.1567	0.0923
Cig & Alc	0.5560	0.2042	0.0889	0.1509
Alc & Mar	0.4674	0.1162	0.1705	0.2458
Cig, Alc, & Mar	0.3571	0.2823	0.1352	0.2254
Cig, Alc, Mar, & Hard Drugs	0.2296	0.3776	0.0461	0.3466
Time 3				
	No Delin.	Covert	Overt	Covert & Overt
No Use	0.7854	0.0866	0.1134	0.0146
Cigarettes	0.6172	0.0781	0.2097	0.0950
Alcohol	0.6369	0.1246	0.1965	0.0419
Cig & Alc	0.6386	0.1042	0.1461	0.1111
Alc & Mar	0.4778	0.2462	0.0583	0.2178
Cig, Alc, & Mar	0.3832	0.2517	0.0918	0.2733
Cig, Alc, Mar, & Hard Drugs	0.2744	0.2892	0.1003	0.3361

3. When adolescents start using cigarettes, do they also start participating in delinquent behaviors? To address this question, we focused on the delinquent behaviors of those participants who transitioned from the "no use" to "cigarettes" only latent status between times 1 and 2 and times 2 and 3. To do this, the $\eta_{d_2|c_2,c_1,d_1}$ and $\eta_{d_3|c_3,c_2,d_2}$ parameters were examined; the $\eta_{d_t|c_t,c_{t-1},d_{t-1}}$ parameters are the conditional probabilities of belonging to a particular delinquency latent status given substance use latent status at the same time and substance use and delinquency latent statuses at the previous time. An average of 37.29% of participants who started using cigarettes also started participating in some form of delinquent behavior. Of the participants who started participating in some form of delinquent behavior, an average of 13.54% started participating in covert behavior and an average of 15.36% started participating in overt behavior (an average of 8.39% started participating in both types of behaviors). Comparatively, an average of 8.48% of participants who did not start using cigarettes (or any other type of substance) started participating in some form of delinquent behavior.

4. When adolescents start using alcohol, do they also start participating in delinquent behaviors? To address this question, we focused on the delinquent behaviors of those participants who transitioned from the "no use" to "alcohol" only latent status between times 1 and 2 and times 2 and 3. Again, the $\eta_{d_2|c_2,c_1,d_1}$ and $\eta_{d_3|c_3,c_2,d_2}$ parameters are examined. An average of 22.03% of participants who started using alcohol also started participating in some form of delinquent behavior. Of the participants who started participating in some form of delinquent behavior, an average of 10.37% started participating in covert behavior and an average of 8.24% started participating in overt behavior (an average of 3.43% started participating in both types of behaviors). Recall that an average of 8.48% of participants who did not start using alcohol (or any other type of substance) started participating in some form of delinquent behavior.

5. When adolescents start using marijuana, do they also start participating in delinquent behaviors? To address this question, we focused on the delinquent behaviors of those participants who transitioned into the "alcohol and mari-

juana" and "cigarettes, alcohol, and marijuana" latent statuses from the "no use," "cigarettes" only, "alcohol" only, and "cigarettes and alcohol" latent statuses between times 1 and 2 and times 2 and 3. Again, the $\eta_{d_2|c_2,c_1,d_1}$ and $\eta_{d_3|c_3,c_2,d_2}$ parameters were examined. An average of 36.85% of participants who started using marijuana also started participating in some form of delinquent behavior. Of the participants who started participating in some form of delinquent behavior, an average of 17.14% started participating in covert behavior and an average of 14.38% started participating in overt behavior (an average of 5.33% started participating in both types of behavior). For participants who started using marijuana (in addition to cigarettes and/or alcohol) without having used any substances previously (i.e., they transitioned from the "no use" to the "alcohol and marijuana" or "cigarettes, alcohol, and marijuana" latent statuses), the average percentage of participants who also started participating in some form of delinquent behavior increased from 36.85% to 41.81%. Comparatively, an average of 22.09% of participants who did not start using marijuana (but who may be using combinations of cigarettes and alcohol) started participating in some form of delinquent behavior. Recall that an average of 8.48% of participants who did not start using any type of substance started participating in some form of delinquent behavior.

6. When adolescents stop using cigarettes, do they stop participating in delinquent behaviors? To address this question, we focused on the delinquent behaviors of those participants who transitioned from the "cigarettes" only to "no use" latent status between times 1 and 2 and times 2 and 3. Again, the $\eta_{d_2|c_2,c_1,d_1}$ and $\eta_{d_3|c_3,c_2,d_2}$ parameters were examined. An average of 71.92% of participants who stopped using cigarettes also stopped participating in any form of delinquent behavior. Comparatively, an average of 70.95% of participants who continued using cigarettes stopped participating in any form of delinquent behavior. Note that another important and likely way participants stopped using cigarettes was to transition from the "cigarettes and alcohol" to "alcohol" only latent status—on average, 65.79% of these adolescents stopped participating in any form of delinquent behavior. Comparatively, an average of 45.25% of participants who continued using cigarettes and alcohol stopped participating in any form of delinquent behavior.

7. When adolescents stop using alcohol, do they stop participating in delinquent behaviors? To address this question, we focused on the delinquent behaviors of those participants who transitioned from the "alcohol" only to "no use" latent status between times 1 and 2 and times 2 and 3. Again, the $\eta_{d_2|c_2,c_1,d_1}$ and $\eta_{d_3|c_3,c_2,d_2}$ parameters were examined. An average of 78.19% of participants who stopped using alcohol also stopped participating in any form of delinquent behavior. Comparatively, an average of 36.53% of participants who continued using alcohol stopped participating in any form of delinquent behavior. Note that another important and likely way participants stopped using alcohol was to transition from the "cigarettes and alcohol" to "cigarettes" only latent status—on average, 55.44% of these adolescents stopped participating in any form of delinquent behavior. Recall that an average of 45.25% of participants who continued using cigarettes and alcohol stopped participating in any form of delinquent behavior.

8. When adolescents stop using marijuana, do they stop participating in delinquent behaviors? To address this question, we focused on the delinquent behaviors of those participants who transitioned into the "no use," "cigarettes" only, "alcohol" only, and "cigarettes and alcohol" latent statuses from the "alcohol and marijuana" and "cigarettes, alcohol, and marijuana" latent statuses between times 1 and 2 and times 2 and 3. Again, the $\eta_{d_2|c_2,c_1,d_1}$ and $\eta_{d_3|c_3,c_2,d_2}$ parameters were examined. An average of 52.37% of participants who stopped using marijuana also stopped participating in any form of delinquent behavior. For those participants who stopped using any kind of substance after having tried marijuana (i.e., they transitioned into the "no use" latent status from the "alcohol and marijuana" and "cigarettes, alcohol, and marijuana" latent statuses), an average of 77.71% also stopped participating in any form of delinquent behavior. Comparatively, an average of 30.79% of participants who continued using marijuana stopped participating in any form of delinquent behavior.

Chapter 4

Discussion

The purpose of this project was to show how ALTA can be used to investigate questions about the simultaneous relation between developmental processes over time. Specifically, the purpose was to answer the question "Are substance use and delinquency related and, if so, what is the nature of their relation?" by directly examining the relation between substance use and delinquency over time in the NLSY97.

4.1 Summary

To accomplish this goal, Study I first utilized a stage-sequential conceptualization of substance use and delinquency to hypothesize developmental models of these processes. LTA was used to assess the fit of and revise these two models to find well-fitting models of substance use and delinquency in the NLSY97. It was determined that a 7-stage model (Figure 2.3), including latent statuses like "alcohol" only and "alcohol and marijuana," was most appropriate for substance use. It was also determined that a 4-stage model (Figure 2.2), including latent statuses like "covert" and "covert and overt," was most appropriate for delinquency. Examining the latent status membership probabilities (δ parameters) from these two models suggested that substance use was increasing over time, whereas delinquency was decreasing over time.

After determining the two individual stage-sequential models of substance use and delinquency, Study II compared the fit of four ALTA models designed to have

particular interpretations about the nature of the relation between substance use and delinquency over time. These were the IS, CS, UDL, and BDL models. The model comparisons suggested that the BDL model fit significantly better than the other three models. This suggests that the developmental processes underlying substance use and delinquency are highly bidirectionally interrelated over time. That is, adolescent participation or non-participation in substance use predicts participation or non-participation in delinquent behaviors over time, and vice versa.

Using the BDL model, it was possible to examine more closely how substance use and delinquency are related. Because it was not possible to examine every parameter and its interpretation, a series of specific questions was posed to address potentially interesting relations between the two processes.

First, two questions about the overall trends of substance use and delinquency were addressed to confirm the trends observed in the single-sequence LTA models. From the BDL model, it was apparent that substance use was increasing over time, whereas delinquency was decreasing over time. Further, the BDL model showed that the greatest increase in substance use occurred between times 1 and 2 and may be partially due to large increases in the use of two or more substances. Additionally, the BDL model showed that the decrease in delinquency may be partially due to decreases in delinquent behaviors among adolescents using two or more substances.

Second, six questions about the delinquent behaviors of adolescents who changed their substance use behavior were addressed. In general, these questions were designed to understand how participation in delinquent behavior changes for adolescents when they start or stop their use of cigarettes, alcohol, and marijuana. From the LTA model of substance use (Figure 2.3), adolescents are most likely to begin using substances by using either cigarettes or alcohol. Two of these questions addressed whether an adolescent starting the substance use process also starts to participate in delinquent behavior. The results showed that adolescents who start participating in substance use by using cigarettes or alcohol are at highly increased risk of also starting delinquent behaviors—those who start using cigarettes are almost 4.5 (37.29%) times more likely to start delinquent behaviors and those who start using alcohol are 2.5 (22.03%) times more likely to start delinquent behaviors than those who do not start the use of any substances (8.39%). Thus, the results

also showed that adolescents who started using cigarettes are at an increased risk of also starting delinquent behaviors when compared with those who started using alcohol. An additional question addressed how starting marijuana use is related to starting delinquent behaviors. On average, 36.85% of adolescents who started using marijuana also started participating in delinquent behaviors during the same year. These results suggest that starting alcohol use puts adolescents at lower risk for starting delinquent behaviors than starting cigarette and marijuana use. These results further suggest that starting cigarettes puts adolescents at only a slightly decreased risk of starting delinquent behaviors than if they had started the substance use process with marijuana use (37.29% of cigarettes users versus 41.81% of marijuana users with no previous substance use start participating in delinquent behavior). Clearly, cigarettes play an important role in an adolescent's risk of starting delinquent behavior.

Further, three questions addressed whether an adolescent who stopped the use of cigarettes, alcohol, or marijuana also stopped participating in delinquent behaviors. For those adolescents who used cigarettes only, stopping the use of cigarettes does not appear to have much impact on their delinquent behavior participation—there is approximately the same percentage of participants who stop participating in delinquent behavior whether or not they stop using cigarettes (71.92% of those who stop cigarettes and 70.95% of those who do not stop, stop their delinquent behavior). In comparison, however, for those adolescents who use cigarettes and alcohol, stopping the use of cigarettes does appear to have an impact on their delinquent behavior participation—stopping cigarette use increases the likelihood that they will also stop delinquent behavior (65.79% of those who stop cigarettes and 40.25% of those who continue to use cigarettes and alcohol stop their delinquent behavior).

Now, stopping alcohol use seems to have a more substantial impact on stopping delinquent behavior. For those adolescents who used alcohol only, stopping the use of alcohol greatly increases the likelihood of also stopping delinquent behavior (78.19% of those who stop alcohol use and 36.53% of those who do not stop alcohol use, stop their delinquent behavior). In comparison, however, for those adolescents who use both cigarettes and alcohol, this effect is not as large (55.44% of those who stop alcohol and 40.25% of those who continue to use cigarettes and alcohol

stop their delinquent behavior).

Finally, those adolescents who stop using marijuana have an increased likelihood of stopping delinquent behavior—between a half and three-quarters of adolescents who stop using marijuana or stop using substances altogether stop delinquent behavior, compared to only one-third who stop delinquent behavior while still using marijuana (52.37% and 77.71% of those who stop marijuana or all substances and 30.79% of those who continue to use marijuana stop their delinquent behavior).

Taken together, these results appear to show that the substance use and delinquency processes are highly related. Adolescents who start using substances like cigarettes and marijuana are at an increased risk for starting delinquency, while stopping the use of substances altogether, especially marijuana use, is related to substantially decreased participation in delinquent behavior. That is, it appears that as substance use waxes, so does delinquency and as substance use wanes, so too does delinquency.

4.2 Parameter Restrictions and Interpretation

As discussed above, unique sets of parameter constraints are used to define each of the four models of interest. Recall that the parameter constraints used to define the UDL model place constraints on the η parameters. Because the substance use sequence is identified as the exogenous sequence, and delinquency the endogenous, these parameter constraints give the desired interpretation that previous delinquency predicts subsequent substance use but not vice versa. Had the delinquency sequence instead been identified as the exogenous sequence, and substance use the endogenous, parameter constrains would have been placed on the ϵ parameters to get the desired interpretation. The four models of interest would have been fit and the model comparisons conducted in the same way to determine the most well-fitting model—arriving at the same conclusion in this case.

This becomes a more complicated issue, however, when the UDL model is the most well-fitting model. This is due to the conditional nature of the ϵ and η parameters. When substance use is the exogenous sequence, and the ϵ parameters are freely estimated, the interpretation is one of immediate past delinquency predicting subsequent substance use—the ϵ parameters are conditional on immediate

past substance use and immediate past delinquency (i.e., substance use and delinquency at the previous time). When substance use is the endogenous sequence, and the η parameters are freely estimated, however, the interpretation is slightly different. Now, the interpretation is one of past transitions in delinquency predicting subsequent substance use—the η parameters are conditional on immediate past substance use and the combination of delinquency latent statuses from the immediate past and current time (i.e., a participant's transition in the delinquency sequence from time $t-1$ to t).

While both give the interpretation that past delinquency is related to subsequent substance use, they are slight different. One is actually that immediate past delinquency is related to subsequent substance use and one is that transitions in delinquency are related to subsequent substance use. Thus, researchers should be careful when defining the research questions and the exogenous and endogenous sequences in combination with parameter restrictions when attempting to define models with specific interpretations so that model comparisons provide the correct answers.

4.3 Study Limitations

This project had three main limitations when reaching its conclusions about the specific nature of the relation between substance use and delinquency. First, due to possible issues of measurement invariance between males and females, which were beyond the scope of this project, gender differences in substance use and delinquency and in the relation between the two processes were addressed by only focusing on males in the analyses. Second, only male participants aged 12 to 16 were included in the analyses. This did not allow for the comparison of possible differences in the relation between substance use and delinquency for males who had childhood-onset versus adolescent-onset or adolescent-limited delinquency. Nor did this allow for possible differences in the relation between substance use and delinquency for males in early versus middle or late adolescence. Finally, in the ALTA models, due to computing limitations, listwise deletion was used to eliminate any participant with partial missing data. The extent to which the relation between substance use and delinquency differs for participants with missing data from those

with complete cases cannot be addressed. Overall, these limitations restrict the generalizability of the substantive results.

This project, however, is a first attempt to explore the simultaneous developmental relation between substance use and delinquency. While the sample and missing data limits the interpretability of results, this project does provide the opportunity to begin to understand the importance of one process' influence on the development of another. Further, future studies should use the ALTA methodology to further explore the nature of the relation between substance use and delinquency for females and other age groups.

4.4 Strengths and Limitations of ALTA

Finally, there are both strengths and limitations of using the ALTA approach to examine the nature of the relation between substance use and delinquency. One strength of the ALTA model is its ability to make sense of very large contingency tables. Using other methods it may be difficult to see patterns of transitions in contingency tables with thousands of cells. Second, the ALTA model allows the conceptualization of substance use and delinquency as dynamic latent variables (Flaherty et al., 2003); as a measurement model, ALTA provides a way to examine transitions and the relation between substance use and delinquency that is less contaminated by error. That is, if statuses were constructed with manifest data, instead of using the model described here, it would be difficult to deal with the response patterns that do not map directly onto one of these statuses. Finally, ALTA allows the testing of models of both related and unrelated processes. That is, ALTA provides a way of addressing questions about linked developmental change.

Similar to LTA models, one limitation of the ALTA model is assessing absolute model fit. Because ALTA models are often quite large, analyses are often based on very large contingency tables and the issue of the χ^2 distribution no longer being a good reference for the G^2 statistic is a frequent concern. When this situation arises, model fit must be assessed in other ways. One important consideration, as with LTA models, is the interpretability of the estimated parameter results. As with LTA models, a rough rule of thumb is to accept models with G^2 statistics at or below the *number of degrees of freedom* in the model (Flaherty et al., 2003).

Another potential limitation of the ALTA model is that it can break down under conditions of poor measurement. Poor measurement occurs when responses to indicators are not clearly linked to latent status membership. That is, when participants randomly choose their answers to an indicator, that indicator is not able to provide information as to the latent status to which participants likely belong—it is said, then, that this indicator has poor measurement. For example, poor measurement on the indicator for having smoked in the past year occurs when the probability of answering "no" to the smoking question is similar to the probability of answering "yes" to the same question within a latent status; that is, when the probabilities of responses to the smoking question are close to random conditional on latent status membership. These probabilities are estimated by the ρ parameters in LCA, LTA, and ALTA models. The ρ estimates link the indicator responses (e.g., "no" or "yes") to latent status membership (e.g., "cigarettes"). Estimates that are close to random for the ρ's (e.g., 0.5) do not clearly link indicators with latent status membership, where ρ estimates close to 0 and 1 (e.g., 0.1 and 0.9) show good measurement and clearly link indicator responses to latent status membership. Simulation work with LTA and ALTA has shown that good measurement is needed for good parameter estimation (Collins et al., 1996; Tang & Collins, 2004). Thus, proceeding with an ALTA model when ρ estimates are close to random may result in poor parameter estimation. As noted above, the measurement parameters for the BDL model are close to 0 and 1. Hence, poor measurement does not seem to be a concern for our parameter estimation.

4.5 Conclusion

In conclusion, substance use and delinquency are highly bidirectionally interrelated during adolescence. Decreasing adolescent use of cigarettes, alcohol, and marijuana predicts decreases in adolescent participation in delinquent behaviors of both a covert and overt nature. The implication of these findings for preventive interventions and prevention researchers is that programs designed to target only substance use or delinquency may influence adolescent involvement in the other. It is also likely that designing programs to target both processes simultaneously may be more effective at reducing involvement in substance use and delinquent

behaviors among adolescents.

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