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Latent factor structure of a behavioral economic cigarette demand curve in adolescent smokers

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Abstract

Behavioral economic demand curves, or quantitative representations of drug consumption across a range of prices, have been used to assess motivation for a variety of drugs. Such curves generate multiple measures of drug demand that are associated with cigarette consumption and nicotine dependence. However, little is known about the relationships among these facets of demand. The aim of the study was to quantify these relationships in adolescent smokers by using exploratory factor analysis to examine the underlying structure of the facets of nicotine incentive value generated from a demand curve measure. Participants were 138 adolescent smokers who completed a hypothetical cigarette purchase task, which assessed estimated cigarette consumption at escalating levels of price/cigarette. Demand curves and five facets of demand were generated from the measure: Elasticity (i.e., $1/\alpha$ or proportionate price sensitivity); Intensity (i.e., consumption at zero price); $O_{\max}$ (i.e., maximum financial expenditure on cigarettes); $P_{\max}$ (i.e., price at which expenditure is maximized); and Breakpoint (i.e., the price that suppresses consumption to zero). Principal components analysis was used to examine the latent structure among the variables. The results revealed a two-factor solution, which were interpreted as “Persistence,” reflecting insensitivity to escalating price, and “Amplitude,” reflecting the absolute levels of consumption and price. These findings suggest a two factor structure of nicotine incentive value as measured via a demand curve. If supported, these findings have implications for understanding the relationships among individual demand indices in future behavioral economic studies and may further contribute to understanding of the nature of cigarette reinforcement.

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Contributors

Drs. Bidwell, Colby, Murphy, and Tidey contributed to the design and selection of measures for this study. Drs. Bidwell, MacKillop, Murphy, and Colby contributed to statistical analyses. All authors contributed to the final write up of this study.

Conflict of Interest

No conflict declared.

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Keywords

tobacco; smoking; adolescents; behavioral economics; reinforcement; demand curve; nicotine dependence; motivation

1. Introduction

The field of behavioral economics attempts to apply the micro-economic theories of consumer demand and labor supply to understanding how behavior is maintained by various commodities or reinforcers in the environment (Bickel, DeGrandpre, & Higgins, 1993; Hursh, 1980; Murphy, MacKillop, Vuchinich, & Tucker, 2012). Concepts of behavioral economics have been applied to the study of environmental control over behavior for a variety of commodities and have been particularly useful in analyzing the self-administration of drugs in both animals and humans (see Hursh, Galuska, Winger, & Woods, 2005 for a review). Behavioral economic demand curves plot consumption of a drug across a range of response costs or “prices” and are quantitative representations of how drug consumption is affected by changes in drug cost (Bickel & Madden, 1999). Demand curves typically depict an inverse relationship between consumption of any commodity and its price. Drug demand is also reflected in a corresponding curve that plots expenditures as a function of price and typically exhibits an inverted U-shaped curve. Five different facets of demand can be quantified using the demand and expenditure curves: Elasticity of demand (i.e., slope of the demand curve), Intensity of demand (i.e., consumption at lowest cost), $O_{\max}$ (i.e., maximum output, or expenditure), $P_{\max}$ (i.e., price at which expenditures are maximized), and Breakpoint (i.e., price at which consumption is reduced to zero). These facets are depicted in Fig. 1 in prototypical demand and expenditure curves.

Hypothetical purchase tasks have been used to examine demand for cigarettes in a variety of populations, including an initial study of cigarettes and heroin in opiate-dependent adult smokers (Jacobs & Bickel, 1999a) and later studies of cigarette demand in adult smokers (MacKillop et al., 2008), adolescent smokers (Murphy, MacKillop, Tidey, Brazil, & Colby, 2011) and smokers with schizophrenia (MacKillop & Tidey, 2011). Studies have demonstrated that individual facets of nicotine and other drug demand generated from behavioral economic demand curves (i.e. $P_{\max}$, $O_{\max}$, Elasticity) are highly correlated with laboratory measures of actual reinforcer consumption (i.e., peak response rate and breakpoint generated from more traditional progressive ratio tasks) (Bickel & Madden, 1999; Johnson & Bickel, 2006). Data also suggest that most demand curve indices show an association with smoking variables outside the laboratory such as daily smoking rate, nicotine dependence severity, and motivation to quit smoking (MacKillop et al., 2008; Murphy et al., 2011). For example, $O_{\max}$ and Intensity were correlated moderately to highly with the average number of daily cigarettes and nicotine dependence severity, and Intensity was significantly negatively correlated with an individual’s level of motivation to quit smoking (Murphy et al., 2011), which is consistent with studies showing that cigarette consumption is one of the most important predictors of smoking cessation (e.g. Borland, Yong, O’Connor, Hyland, & Thompson, 2010).

Although the relationships of specific facets of demand have been associated with both laboratory and real-world measures of the reinforcing efficacy of cigarettes (e.g. Bickel & Madden, 1999), the relationships among the hypothetical cigarette demand curve facets have not been directly examined. Theoretically, the five metrics of demand are thought to reflect related, but nonetheless independent aspects of a commodity’s relative value (Bickel, Marsch, & Carroll, 2000). Some of the indices such as Breakpoint and Intensity are clearly conceptually distinct. However, others are conceptually similar and intuitively closely

related. For example, $P_{\max}$ represents the point on the demand curve at which consumption moves from being inelastic to elastic and thus is mathematically related to Elasticity. In addition, $O_{\max}$ and $P_{\max}$ both correspond to the point on the demand curve where demand becomes elastic, but are not empirically redundant or dependent on one another. Importantly, $O_{\max}$ is in units of expenditure, whereas $P_{\max}$ is in units of price, and individuals can have identical values on one variable but not the other variable.

However, the correlations among some of the demand metrics (Jacobs & Bickel, 1999b; MacKillop et al., 2008; Murphy & MacKillop, 2006; Murphy et al., 2011) do suggest the possibility that the five facets of a demand curve could be more parsimoniously represented by a smaller number of latent factors. Identifying latent factors that underlie the demand curve metrics may provide insight into the nature of reinforcement efficacy and motivation assessed via demand curve by further characterizing both the shared and unique aspects of these different facets. Such latent factors have the potential to serve as novel-dependent variables and reduce the probability of redundancy among the different demand curve metrics in experimental research. In a recent factor analysis of the five demand measures generated from an alcohol purchase task completed by young adult drinkers, the results suggested a two factor solution, with one factor primarily consisting of Elasticity, $P_{\max}$, and Breakpoint and the other factor primarily consisting of Intensity, with $O_{\max}$ loading on both factors (MacKillop et al., 2009). These factors were interpreted as Persistence and Amplitude, and generally reflected the individual's willingness to consume as price increased and a person's level of consumption and expenditure in volume, respectively. These results suggested a two-factor structure to alcohol demand, but it is not clear whether this structure would be present across different types of drug reinforcers or populations. Moreover, the previous study did not address whether individual indices of demand or latent aggregations of indices were more meaningfully related to substance consumption and problems. It is important to test whether latent factor aggregations are incrementally more useful than the individual indices in predicting drug-related behavior. This is an important theoretical question that could refine behavioral economic models of demand and drug reinforcement (Bickel et al., 2000; Hursh and Silberberg, 2008), and one that also has practical implications in terms of predicting aspects of adolescent smoking and nicotine dependence.

1.1 Current study

Thus, the aim of the current study was to characterize the relationships among the various cigarette demand indices in adolescent smokers. Demand data were collected from a relatively large sample of adolescent smokers who completed a cigarette purchase task (CPT) and a number of smoking measures in an initial validation study of a CPT in adolescents (Murphy et al., 2011). In that study, the CPT task was found to generate orderly demand curves and the resulting demand indices were significantly associated with smoking, nicotine dependence, and motivation to change smoking, supporting its validity in adolescent smokers. In the current study, we aimed to use exploratory factor analysis to examine the latent interrelationships among the different facets of nicotine incentive value generated from the CPT measure. In the absence of previous analyses of the interrelationships of cigarette demand metrics, we predicted a multidimensional structure of demand but did not predict a specific number of factors. Second, we aimed to examine the relationships among the factors identified and measures of smoking behavior outside of the laboratory to determine if the factor-based indices were more informative than individual indices. Specifically, we examined factor-based and individual demand indices in relation to measures of smoking behavior, including cigarettes per day, nicotine dependence, longest period of smoking abstinence, and cigarette biomarkers (breath carbon monoxide (CO) and salivary cotinine). As this was an exploratory aim, no specific hypotheses were made.

2. Method

2.1 Participants

The current analyses used data that were taken from a larger study that compared adolescent smokers to a matched sample of nonsmokers on various measures. Detailed recruitment and sample information can be found in the initial validation of a CPT in this sample (Murphy et al., 2011) that consisted of 138 adolescent smokers. Eligibility criteria included: 1) being a current smoker; 2) smoking at least once in the prior two weeks; 3) being enrolled in high school (grades 9–12); and 4) being able to read and understand English. Adolescents were excluded if they reported using non-cigarette tobacco on more than 4 days in the prior month. The sample was 49% female, 84.1% White, and 9.4% reported Hispanic/Latino ethnicity. On average, the participants were 16.5 years (Standard deviation [SD] = 1.2) and reported smoking 5.97 cigarettes per day (SD = 5.99, Range = 0–38.07).

2.2 Measures

2.2.1. Demographics—Participants completed a brief demographics questionnaire which queried gender, date of birth, grade, and race/ethnicity. In addition, students were asked whether they qualified for free or reduced-price school lunch as a proxy measure of socioeconomic status (SES) (Scarinci, Robinson, Alfano, Zbikowski, & Klesges, 2002). We created a 3 level income variable: highest income (private school students and students who attended public school with full pay lunch), middle income (students who attended public school and qualified for a reduced-price school lunch), and lowest income (students who attended public school and qualified for a free school lunch).

2.2.2. Smoking History and Patterns Questionnaire (Colby et al., 2005)—

Participants completed a questionnaire that asked about their history and patterns of smoking behavior, including the age at which they smoked their first whole cigarette, the age at which they began smoking daily, the number of prior quit attempts they have made, and the longest period of time they had been able to refrain from smoking during a quit attempt.

2.2.3. Timeline Follow back (TLFB)—The TLFB is a calendar-assisted retrospective recall of the number of cigarettes smoked each day; it has been validated for use with adolescents and its summary variables have been shown to have high stability over time (Lewis-Esquerre et al., 2005). Daily smoking over the prior two-week period was assessed.

2.2.4. Contemplation Ladder—The 10-point Contemplation Ladder provided a quasi-continuous index of motivation (readiness) to quit smoking. The assessment depicts a ladder with each rung associated with increasing levels of readiness to change, from 1 (“I enjoy smoking and have decided not to quit smoking for my lifetime. I have no interest in quitting.”) to 10 (“I have quit smoking and I will never smoke again.”). The Ladder has been shown to have good reliability and validity (Abrams & Biener, 1992; Biener & Abrams, 1991).

2.2.5. Modified Fagerstrom Tolerance Questionnaire (mFTQ)—The mFTQ is a 7-item measure of nicotine dependence that has been adapted from the original FTQ (Fagerstrom, 1978) for use with adolescent smokers. It has been shown to have good internal consistency, high test–retest reliability and strong concurrent validity (Prokhorov, Pallonen, Fava, Ding, & Niaura, 1996). Possible scores range from 0 to 9; the mean score in this sample was 3.85 (SD=1.88) and fell within the “moderate dependence” range of the mFTQ.

2.2.6. Smoking biomarkers—Expired carbon monoxide (CO) levels in parts per million (ppm) were obtained via a Bedfont Micro Smokerlyzer®. Saliva samples were collected and levels of the principle nicotine metabolite, cotinine, were analyzed using gas chromatography (Salimetrics, State College, PA).

2.2.7. Cigarette purchase task—The CPT is a hypothetical purchase task to measure demand for cigarettes across a range of prices. The CPT was developed by MacKillop et al. (2008) who based their measure on an earlier CPT measure developed by Jacobs and Bickel (1999) and an alcohol purchase task developed by Murphy and MacKillop (2006). Details of the measure are provided in Murphy et al. (2011). The measure used the following 26 prices in ascending order: zero (free), 1¢, 5¢, 13¢, 25¢, 35¢, 50¢, \$1, \$1.50, \$2, \$2.50, \$3, \$4, \$5, \$6, \$7, \$8, \$9, \$11, \$35, \$70, \$140, \$280, \$560, \$1120. These prices were based on the prices used by Jacobs & Bickel (1999), which were modeled on response requirements for a progressive-ratio operant schedule. However, because of extremely large gaps between prices at the six highest levels and highly infrequent responses that were high-leverage statistical outliers (typically reflecting consumption of a single cigarette), participant responses were only examined for the first 19 price points (\$0–\$11/cigarette) (Murphy et al., 2011).

Five demand indices were generated from CPT data: 1) Elasticity of demand (representing the sensitivity of cigarette consumption to increases in cost and defined by the slope of the demand curve (see equation below)); 2) Intensity of demand (defined by the value of cigarette consumption at lowest price), 3) $O_{\max}$ (i.e., output maximum, defined by the value of the largest total expenditure in dollars across price intervals), 4) $P_{\max}$ (i.e., price maximum, defined by the price at which maximum expenditure took place), and 5) Breakpoint (defined by the value of the first price at which consumption is reduced to zero).

Intensity, $O_{\max}$, $P_{\max}$, and Breakpoint values were generated from the raw demand curve consumption and expenditure values (cf., Murphy & MacKillop, 2006). Although Intensity, $O_{\max}$, and $P_{\max}$ can also be estimated from the fitted demand curve, Murphy et al. (2009) found that the raw parameter values were more reliable than values estimated from the fitted demand curves. To generate an estimate of Elasticity, demand curves were estimated by fitting each participant's reported consumption across the range of prices to Hursh and Silberberg's (2008) exponential demand curve equation: $\log_{10} Q = \log_{10} Q_0 + k(e^{-\alpha P} - 1)$, where Q is the quantity consumed, k specifies the range of the dependent variable (cigarette consumption) in logarithmic units, and α specifies the rate of change in consumption with changes in price (elasticity). The value of k (3.5 in the present study, based on the best fit with the sample mean consumption values) is constant across all curve fits. Individual differences in elasticity are thereby scaled with a single parameter (α) which is standardized and independent of reinforcer magnitude. Values of α reflect price sensitivity (elasticity), with lower values indicating relative inelasticity or reinforcement. Following Banks et al. (2011), to make interpretation of the factor structure more intuitive, we used the inverse ($1/\alpha$) for our analyses so that larger values would reflect greater reinforcement value. Demand curves were fit according to the Hursh and Silberberg (2008) guidelines using the calculator provided on the Institutes for Behavior Resources website (<http://www.ibrinc.org/index.php?id=181>). This nonlinear regression was used to generate an R^2 value, reflecting percentage of variance accounted for by the equation. Consistent with Jacobs and Bickel (1999), when fitting the demand curve data, the first zero consumption value (i.e., breakpoint) was replaced by an arbitrarily low but nonzero value of .001, which is necessary for the logarithmic transformations. We did not include subsequent 0 consumption values in our curve estimates. All other analyses were completed using SPSS statistical software (version 19.0).

2.3 Data Analysis

The data were initially examined for outliers and distribution normality. As described in Tabachnick and Fidell (2001), univariate outliers were examined using standard scores (criterion $Z=3.29$), and multivariate outliers were examined by regressing all items onto a dummy variable and generating the Mahalanobis distance (critical χ^2 ($df > 100$) = 149.45; $p < 0.001$), which reflects each subject's multivariate distance from the data centroid. Three outliers for intensity were retained and recoded as one unit greater than the highest non-outlier value. No multivariate outliers were present. O_{max} was log transformed to correct for significant positive skewness and kurtosis. These transformations resulted in generally normal distributions for all demand metrics.

Exploratory factor analysis was conducted using a principal components analysis (PCA) method of estimation with oblique (oblimin) rotation to permit multifactorial solutions with correlated factors. As some indices typically have negligible associations, principal components analysis was selected to examine the factor structure of the overall correlation matrix, rather than shared variance. A factor loading of .40 on the pattern matrix was used as the criterion for determining if an item significantly loaded on a given factor (Stevens, 2002; Tabachnick & Fidell, 2001). Because the objective of the study was exploration of the latent structure of the variables, not identifying mutually exclusive factors (e.g., scale construction), facets of demand were permitted to load on multiple factors. Factor scores were created by summing the standardized scores for individual items that loaded on each factor.

The number of components was determined using parallel analysis (PA; Horn, 1965) and the minimum average partial (MAP) methods (Velicer, 1976). These procedures allow for statistically based decision-making and are recommended as the most accurate methods for determining number of components to retain over the commonly used eigenvalue-greater-than-one or scree test approaches (Zwick & Velicer, 1986). In parallel analysis (Horn, 1965), the focus is on the number of components that account for more variance than the components derived from random data. In Velicer's (1976) MAP test, the focus is on the relative amounts of systematic and unsystematic variance remaining in a correlation matrix after extractions of increasing numbers of components. According to the methods for running these procedures in SPSS outlined in O'Connor (2000), both tests were used prior to the principal components extraction to determine statistically how many components to extract.

Finally, correlation analyses were used to examine the associations among indices of smoking behavior (average daily cigarettes, nicotine dependence, longest period of abstinence from cigarettes, motivation to change smoking) and smoking biomarkers (expired breath CO and cotinine levels) and the five individual demand metrics and resulting factor scores. SES, age, years of daily smoking, race (dichotomously coded White/Non-Hispanic vs. all others), and gender were included as covariates.

3. Results

3.1 Factor Analytic Findings

PA indicated two components should be retained and MAP indicated one component. We subsequently followed the recommendation of O'Connor (2000) on how to proceed when PA and MAP methods do not converge on the number of interpretable components. First, we increased the number of random data sets in the PA. After increasing the number of random data sets from 100 to 500, 1000, and 5000, the PA continued to support the retention of two components. Second, we examined the average squared correlations from the MAP test, revealing that although the one component solution resulted in the lowest average

squared correlation ($R^2 = .14$), the two component solution resulted in the second lowest average squared correlation ($R^2 = .21$). The PCA revealed variance discontinuities that also suggested two latent factors. Thus, taken together, the results were most suggestive of a two component solution. The two factors in total accounted for 75.7% of the variance. The first factor, representing Persistence, accounted for 53.4% of the variance, with an eigenvalue of 2.67, and was primarily composed of three demand indices: Elasticity ($1/\alpha$), $P_{\max}$, and Breakpoint. The pattern matrix, providing the factor loading and reflecting the partial correlations between each variable and each rotated factor, is provided in Table 1. The second factor, representing Amplitude, accounted for 22.3% of the variance, with an Eigenvalue of 1.12, and was primarily composed of Intensity of demand. One metric met the loading criterion for both factors: $O_{\max}$, which exhibited a larger loading on the first factor. The two factors were not significantly correlated, $r = 0.13$, $p > 0.05$.

3.2 Correlational Analyses

The partial correlations among individual and factor demand metrics and behavioral and biomarker smoking measures are presented in Table 2. Both of the factor scores and $O_{\max}$ were significantly associated with greater daily smoking rate, greater nicotine dependence, and both smoking biomarkers (CO and cotinine levels). $P_{\max}$ and Elasticity ($1/\alpha$) were also associated with greater nicotine dependence and, along with Breakpoint, smoking biomarkers (CO and cotinine levels) at varying magnitudes. Finally, both factor scores, Intensity, $O_{\max}$, and Breakpoint were negatively correlated with motivation to quit smoking. Neither of the latent factor scores was correlated with the smoking-related variables at higher levels than their constituent indicators. However, among its constituent items, the Persistence factor was outperformed only by $O_{\max}$ and was more highly correlated with smoking-related variables than Breakpoint, $P_{\max}$, and Elasticity ($1/\alpha$). Further, the Amplitude factor correlated more strongly than did the Persistence factor across the smoking-related variables.

4. Discussion

4.1 Factor Analysis

The aim of the current study was to examine the latent structure among facets of nicotine incentive value from a behavioral economic demand curve. The results of the principal components analysis suggest a robust latent structure for these data that is captured by a two-factor solution accounting for approximately 76% of the total observed variance. The two-factor structure of nicotine incentive value found here is consistent with our previous analysis of the underlying factor structure of alcohol reinforcement using the alcohol purchase task (MacKillop et al., 2009). Consistent with our prior study, the first factor was primarily composed of Elasticity of demand ($1/\alpha$), $P_{\max}$, and Breakpoint and the second factor was primarily composed of Intensity of demand. $O_{\max}$ loaded on both factors and the factors were not significantly correlated.

The first factor was interpreted as Persistence in light of the three dimensions of the demand curve over the course of escalating price, with Elasticity ($1/\alpha$) being the overall slope of the demand curve, $P_{\max}$ being the point of transition from inelastic to elastic demand, and Breakpoint being the terminus of demand, where consumption is suppressed to zero. Taken together, these dimensions can be thought of as measures of sensitivity to escalating price on the X-axis and thus this factor reflected how far the individual would go for cigarettes in terms of cost. The second factor, interpreted as “Amplitude,” primarily included intensity of demand, or cigarette consumption under conditions of minimal cost, and reflected how many cigarettes the individual would consume or spend. Although most variables clearly loaded on one of the two factors, $O_{\max}$ significantly loaded on both factors. $O_{\max}$ is an index

of the maximum amount an individual will expend for a drug and incorporates both a volumetric dimension (via number of cigarettes) and a price-sensitivity dimension (via price) and supports the idea that $O_{\max}$ uniquely represents both dimensions.

It should be noted, however, that the MAP test was suggestive of a single factor solution for these data. Thus, an alternative solution is a single “Persistence” factor made up of four of the five demand indices, with a single metric, Intensity, not loading on the resulting factor. While this is a possibility, we note that when PA and MAP methods do not agree, the MAP test tends to result in a recommendation of underextraction (O’Connor, 2000) and the examination of scree plot discontinuities also suggested a two factor solution. Taken together, the majority of the indicators examined supported a two factor solution for these data.

4.2. Correlational Analyses

The two factors were significantly associated with greater daily smoking, greater nicotine dependence, less motivation to quit, and higher levels of smoking biomarkers (CO and cotinine levels). The Amplitude factor performed better than its primary constituent item, Intensity. However, $O_{\max}$, which also loaded on the Amplitude factor, generally displayed similar magnitude (.21 – .41) correlations with smoking variables. Similarly, the Persistence factor outperformed some metrics of price sensitivity (i.e. Elasticity, $P_{\max}$, and Breakpoint), but not others (i.e. $O_{\max}$). Although future research should examine the prospective predictive utility of the individual demand indices as well as the latent factors, the present results provide mixed support for combining the variables into their latent factors. The strength of the individual indices is that they offer greater specificity and precision. However, given their considerable overlap, using five separate measures also has the potential to inflate Type 1 error. Factor analyses such as this one permit examination of the latent relationships and incorporate overlap. Our findings of a two-factor structure suggest that two informative summary scores are a viable alternative in studies where inflated α error is a significant concern.

The correlations reported here are consistent with prior research showing that the demand metrics are reflected in naturalistic smoking measures, including nicotine dependence and daily smoking (MacKillop, et al 2008). However, significant correlations with smoking measures in our study accounted for a relatively low proportion of the variance in demand (ranging from 3–17%), potentially reflecting that factors beyond smoking behavior and dependence contribute to adolescent smoking (e.g. peer influences). The current study also provides new evidence that demand indices are associated with smoking biomarkers (CO and cotinine levels). These findings converge with recent findings (Mackillop & Tidey, 2011) showing that demand indices generated from a hypothetical cigarette purchase task were associated with number of cigarettes consumed and number of puffs per cigarette and together provide further support for the validity of demand curve measures of cigarette incentive value.

4.3 Limitations

These findings should be interpreted in the context of the study’s limitations. First, although the sample size is large for studies of drug demand, it may be considered only of moderate size for the application of factor analytic approaches. Second, although the results are suggestive of the underlying structure of cigarette demand in adolescents, the influence of price interval on purchase task responding is an important consideration. Third, the generalizability of the findings to other populations or drugs is not currently known. For example, while we do not have complete information about how often participants in the current study purchase their own cigarettes, we do know that a large majority of our sample

regularly purchased cigarettes (27 of the 27 participants (100%) asked endorsed having spent money on cigarettes and 37 of the 42 participants (88%) asked responded as spending money on cigarettes during an “average week” [Mean = \$17.22, S.D. = 12.0]). Thus, these results from our sample of regular smokers may not be generalizable to lighter adolescent smokers who potentially acquire cigarettes from other sources. Finally, future studies attempting to replicate findings using confirmatory factor analysis will be necessary. Despite these limitations, the results generated complementary findings to our prior analysis of the factor structure of the alcohol purchase task and suggest consistency in the underlying structure of drug incentive value. Given that this is the only the second study to examine the underlying structure of these facets of demand, the consistency in structure between alcohol and cigarette demand represents an important contribution to our understanding of the underlying structure of drug incentive value and reinforcement (Bickel et al., 2000; Hursh & Silberberg, 2008).

4.5 Future directions

The general thrust of behavioral economic demand curve research is to improve the ability to measure motivation for and incentive value of drugs and to apply such approaches to improving basic and clinical research. Research that examines the utility of these measures in prevention and clinical settings is essential, including studies that examine differential relationships between demand indices, nicotine dependence, and smoking cessation. An important direction for future research will be to examine if individual differences in cigarette demand predict response to nicotine treatment as alcohol demand indices have been shown to do for alcohol treatment, over and above drinking levels (MacKillop & Murphy, 2007). For example, given that the Amplitude factor was more related to motivation to quit smoking than was the Persistence factor, future studies could examine whether these factors differentially predict smoking cessation outcomes. In addition, studies should seek to clarify the state vs. trait nature of demand. For example, recent animal work from Christensen et al. (2008) provides evidence in rat models that the strength of cocaine demand increases with increased experience, suggesting a recursive escalation of drug incentive value over time. In addition, our recent study (MacKillop et al., 2010) indicates that demand intensifies after craving induction for alcohol in human heavy drinkers. However, it is unclear whether this also applies to cigarette craving and further if effective treatment ameliorates high demand states. Behavioral economic approaches may also improve the understanding of underlying motivations for smoking in comorbid populations with high rates of smoking (i.e. smokers with attention-deficit hyperactivity disorder (ADHD) or schizophrenia) (Mackillop & Tidey, 2011), who are likely to differ on baseline demand characteristics as well as the relative environmental influences on demand.

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Highlights

Behavior economic demand curves generate multiple metrics of drug demand.

We used a cigarette purchase task to generate 5 demand metrics in adolescent smokers.

We examined the latent structure of the metrics using exploratory factor analysis.

Results suggested a 2-factor structure of the demand curve metrics.

Latent factors were associated with naturalistic measures of adolescent smoking.

Figure 1.

Prototypic cigarette demand and expenditure curves. Data are provided in conventional log–log units for proportionality. Zero prices are not presented to permit logarithmic units. In Panel A, Intensity reflects consumption at zero or minimum price; $P_{\max}$ reflects the price at which demand becomes elastic (i.e., disproportionately decreasing relative to increases in price); and Breakpoint reflects the price at which consumption is completely suppressed; Elasticity is a property of the aggregate curve and is thus not depicted. In Panel B, $O_{\max}$ refers to maximum expenditure on cigarettes across prices and corresponds with the $P_{\max}$ price.

Table 1

Pattern matrix for the principal components analysis of the indices of nicotine incentive value.

	Principal Components	
	Persistence Factor	Amplitude Factor
Variance Explained	53.4%	22.3%
Eigenvalue	2.67	1.12
Index	Persistence Factor	Amplitude Factor
Elasticity ($1/\alpha$)	0.62	-0.05
Breakpoint	0.90	0.02
$P_{\max}$	0.92	0.20
$O_{\max}$	0.73	0.43
Intensity	-0.05	0.97

Note: A criterion of 0.40 was used to determine whether an index significantly loaded on a factor.

Table 2

Partial correlations between individual demand metrics and factor index scores and smoking variables.

Demand Metric	Mean Daily Cigarettes	Nicotine Dependence	Longest Abstinence from Smoking	Motivation to quit	CO level	Cotinine	Mean r^2 (Absolute Value)
Intensity ²	.09	.12	-.16	-.32**	.04	.07	0.13
P _{max} ¹	.12	.19	.09	-.15	.22*	.17	0.17
O _{max} ^{1,2}	.32**	.21*	-.02	-.25**	.41***	.28**	0.25
Breakpoint ¹	.05	.12	.14	-.22*	.17*	.13	0.14
Elasticity (1/ α) ¹	.08	.18	-.05	-.08	.24*	.06	0.12
Persistence Factor ¹	.17*	.22*	.05	-.21*	.31**	.20*	0.20
Amplitude Factor ²	.24**	.21*	-.12	-.35***	.34**	.21*	0.25
Mean r^2 (Absolute Value)	0.15	0.18	0.09	0.23	0.23	0.16	--

Note:

* p-value < 0.05;

** p-value < 0.01;

*** p-value < 0.001.

Subscripts indicate which individual demand metrics loaded on which factor:

¹ Persistence,

² Amplitude.

Covariates included SES, age, years of daily smoking, race, and gender.