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Original Investigation

Behavioral Economic Demand for Alcohol and Cigarettes in Heavy Drinking Smokers: Evidence of Asymmetric Cross-commodity Reinforcing Value

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Abstract

Introduction: Previous studies have highlighted a strong bidirectional relationship between cigarette and alcohol consumption. To advance our understanding of this relationship the present study uses a behavioral economic approach in a community sample (N = 383) of nontreatment seeking heavy drinking smokers.

Aims and Methods: The aims were to examine same-substance and cross-substance relationships between alcohol and cigarette use, and latent factors of demand. A community sample of nontreatment seeking heavy drinking smokers completed an in-person assessment battery including measures of alcohol and tobacco use as well as the Cigarette Purchase Task and the Alcohol Purchase Task. Latent factors of demand were derived from these hypothetical purchase tasks.

Results: Results revealed a positive correlation between paired alcohol and cigarette demand indices (eg, correlation between alcohol intensity and cigarette intensity) (rs = 0.18–0.46, $p \le .003$). Over and above alcohol factors, cigarette use variables (eg, Fagerström Test for Nicotine Dependence and cigarettes per smoking day) significantly predicted an additional 4.5% ($p < .01$) of the variance in Persistence values but not Amplitude values for alcohol. Over and above cigarette factors, alcohol use variables predicted cigarette Persistence values ($\Delta R^2 = .013$, $p = .05$), however, did not predict Amplitude values.

Conclusions: These results advance our understanding of the overlap between cigarette and alcohol by demonstrating that involvement with one substance was associated with demand for the other substance. This asymmetric profile—from smoking to alcohol demand, but not vice versa—suggests that it is not simply tapping into a generally higher reward sensitivity and warrants further investigation.

Implications: To our knowledge, no study to date has examined alcohol and cigarette demand, via hypothetical purchase tasks, in a clinical sample of heavy drinking smokers. This study demonstrates that behavioral economic indices may be sensitive to cross-substance relationships and specifically that such relationships are asymmetrically stronger for smoking variables affecting alcohol demand, not the other way around.

Introduction

Despite declining rates of cigarette use,[1–3] couse between alcohol and cigarettes remains high. Recent estimates from the National Epidemiological Survey on Alcohol and Related Conditions (NESARC-III) revealed the odds of having a past 12-month Diagnostic and Statistical Manual-5 (DSM-5) nicotine use disorder is 3.2 times higher in the presence of an alcohol use disorder (AUD), regardless of AUD severity (Adjusted Odds Ratio = 3.2, 95% confidence interval = 2.93–3.49).[4] Couse between alcohol and cigarettes has been associated with an increased risk of head and neck cancers,[5,6] as well as mood disorders.[7] The negative impact of this couse pattern extends to cessation attempts, such that daily smokers with a current or past AUD are less likely to quit smoking[8] and cigarette smoking has been linked with an increased risk of relapse to AUDs.[9] Multiple underlying mechanisms of action have been proposed to explain this robust bidirectional relationship. Genetic studies have highlighted the role of the human gene cluster CHRNA5/A3/B4 in both alcohol and nicotine use.[10,11] Preclinical and behavioral pharmacology studies have also highlighted varenicline (nAChR partial agonist) reducing alcohol consumption and in improving smoking cessation outcomes.[12,13] Taken together, the epidemiological rates of couse, its impact on treatment outcomes, and mechanisms underlying this couse suggests that heavy drinking smokers constitute a unique subpopulation of substance users.

Toward elucidating mechanisms of couse, heavy drinking smokers can be examined through the application of behavioral economics, which combines principles of economics and psychology to further our understanding choice behavior.[14,15] The contemporary application of behavioral economics to addictive behavior is referred to as the reinforcer pathology approach, which emphasizes persistently high reinforcing value of a drug, disproportionate immediate preference for that reward despite long-term consequences, and a paucity of alternative reinforcers.[14,15] Demand curve analyses can be used to operationalize the relative reinforcing efficacy (ie, behavior-strengthening property of a reinforcer compared with a nonreinforcer) of a substance by examining relationship between consumption of a substance and price.[14,16] Hypothetical purchase tasks, in which individuals report how much of a specific substance they would consume at increasing prices, can be used to generate a demand curve. Various indices from the demand curve reflect relative reinforcing efficacy, which has been proposed to be a heterogeneous phenomenon,[17] can be analyzed including intensity (consumption when free), O_{max} (maximum expenditure), P_{max} (price corresponding to maximum expenditure, ie, maximum inelastic price), breakpoint (first price point at which consumption drops to zero), and elasticity (overall slope of the demand curve, ie, rate at which consumption decreases as price increases).

Various indices of demand assessed via hypothetical purchase task have been associated with real-world alcohol use. In a college sample, all five indices of demand have demonstrated significant correlations with self-report drinks per week and heavy drinking episodes per week.[18] Intensity of demand, as well as craving for alcohol, have been associated with a greater number of AUD symptoms.[19] Indices of demand have also been examined as predictors for treatment outcomes. Following a brief alcohol intervention, greater maximum expenditure for alcohol (O_{max}) and first price suppressing consumption to zero (breakpoint) have been demonstrated to predict greater drinking at 6-month postintervention follow-up.[20] In the realm of tobacco use, a recent meta-analysis found all five behavioral economic indices to be strongly associated with cigarette consumption and tobacco dependence, with intensity, O_{max}, and elasticity displaying the most robust associations highlighting the robust associations between cigarette demand and cigarette use.[21] Even among cannabis use, demand for cannabis has been shown to predict cannabis use frequency and quantity.[22] Collectively, these results demonstrate how behavioral economic indices are implicated in both alcohol and tobacco dependence.

However, when taking these findings together, few studies to date have examined behavioral economic indices of alcohol in a sample of heavy drinking smokers. One previous study has found that heavy drinking smokers, relative to heavy drinking nonsmokers, report greater alcohol O_{max} and breakpoint.[23] An additional study with college students who reported at least one heavy drinking episode in the past month found that the same pattern of higher alcohol O_{max} and breakpoint with those who also reported smoking at least one cigarette in the past month in comparison to nonsmokers, as well as greater P_{max}.[24] Amlung et al.[23] proposed that it is not entirely clear whether heavy drinking smokers are more sensitive to alcohol reward specifically, or if they demonstrate a generalized hypersensitivity to reward and/or multiple drugs. Thus, further research is needed to elucidate how demand for cigarettes and alcohol may be altered and influence each other in a sample that uses both substances.

Previously, the latent structure of demand curve indices has been found to have two components, Amplitude and Persistence, with O_{max} loading on both, intensity loading on the former and P_{max}, elasticity, and breakpoint loading on the latter.[25–28] Persistence reflects measures of sensitivity to increase price whereas Amplitude reflects the amount consumed and spent. In examining these two factors in relation to self-reported alcohol use and alcohol problems, Persistence has been suggested to reflect a more compulsive dimension of alcohol-seeking thus being more relevant to alcohol-dependent individuals.[28] Amplitude has been suggested to be more salient among heavy drinkers as it is closely related to current alcohol use measures. These two factors extend the initial five facets of demand to represent the underlying relationship among these demand indices. Using these two factors as opposed to the five demand indices may aid in reducing Type I error inflation.[26]

To our knowledge, no study to date has examined alcohol and cigarette demand, via hypothetical purchase tasks, in a clinical sample of heavy drinking smokers. The aims of the present study are: (1) examine the association between latent factors of demand and demand indices for nicotine and alcohol in a sample of heavy drinking smokers, (2) examine the association between nicotine and alcohol use severity and latent factors of demand and demand indices for nicotine and alcohol, respectively, and (3) test cross-substance associations between alcohol and cigarette use severity/past 30-day use and latent factors of demand and demand indices. Based on the small existing literature, we hypothesize heavy alcohol use will be associated with increased demand for cigarettes and heavier smoking will predict increased demand for alcohol.

Materials and Methods

Participants and Procedures

Participants consisted of a community sample of nontreatment seeking daily smokers who drank heavily recruited from the greater Los Angeles area. Data for this study were collected at the initial eligibility screening visit and prior to medication assignment as part of a larger study medication study examining varenicline and naltrexone.[29] The study was approved by the Institutional Review Board of the University of California Los Angeles.

Interested participants completed a phone interview to determine eligibility. Eligible participants were nontreatment seeking daily smokers (≥10 cigarettes/day) who were also heavy drinkers, consistent with the National Institute on Alcohol Abuse and Alcoholism guidelines of ≥14 drinks/week for men and ≥7 for women at least monthly over the prior year. If eligible following the telephone interview, participants were invited for an in-person screening visit. Participants were required to have a breath alcohol concentration of 0.000 g/dL and were excluded if they tested positive for any drugs, with the exception marijuana.

Measures

The following individual difference measures were collected during the initial screening visit: (1) demographics questionnaire to gather data on age, sex, race/ethnicity, education, marital status, and income; (2) Time-Line Follow-Back[30] to assess for frequency and quantity of alcohol and smoking use over the past 30 days; (3) Fagerström Test for Nicotine Dependence (FTND)[31] to assess for nicotine dependence severity; and (4) Alcohol Dependence Scale (ADS)[32] to assess for alcohol dependence severity.

Behavioral Economic Indices

Behavioral economic indices were assessed with the Alcohol Purchase Task (APT)[33] and Cigarette Purchase Task (CPT).[34,35] For the APT, participants were provided with the following instructions: "Imagine that you are drinking in a typical situation when you drink. The following questions ask how many drinks you would consume if they cost various amounts of money. The available drinks are standard size domestic beer (12 oz.), wine (5 oz.), shots of hard liquor (1.5 oz.), or mixed drinks containing one shot of liquor. Assume that you did not drink alcohol before you are making these decisions and will not have an opportunity to drink elsewhere after making these stockpile drinks for a later date or bring drinks home with you." The 16 specific prices included for alcohol were: $0.00, $0.01, $0.05, $0.13, $0.25, $0.50, $1.00, $3.00, $6.00, $11.00 $35.00, $70.00, $140.00, $280.00, $560.00, and $1120.00. A similar set of instructions were given for the CPT with reference to cigarettes. The 24 specific prices included for cigarettes were: $0.00, $0.05, $0.10, $0.15, $0.20, $0.25, $0.30, $0.35, $0.40, $0.45, $0.50, $0.60, $0.70, $0.80, $0.90, $1.00, $1.20, $1.40, $1.60, $1.80, $2.00, $4.00, $8.00, and $10.00. The outcomes for these purchase tasks were hypothetical, however hypothetical purchase tasks have been shown to be highly correlated with tangible outcomes.[36,37]

Data Analytic Plan

Prior to the primary analyses for the APT and CPT, invariant responding and excessive preference reversals (ie, consuming more at higher prices) across the task were identified and removed from the analysis. Participants with missing data for intensity (consumption when free) were excluded from all analyses. A total of 461 participants completed the initial screening. For the APT, 111 were removed at the initial data processing stage due to missing data (defined as missing all APT values; n = 46), missing data for intensity (n = 60), and an intensity value close to zero (ie, .005) implying lack of understanding of the task (n = 5). At the effort check stage, 28 were removed due to excessive preference reversals (n = 18) and invariant responding (n = 10). For the CPT, 101 were removed at the initial data processing stage due to missing data (defined as missing all CPT values; n = 42) and intensity values equal to zero implying lack of understanding of the task (n = 59). At the effort check stage, 28 were removed due to excessive preference reversals (n = 16) and invariant responding (n = 9). One additional participant was excluded due to having a majority of outlying values.

Due to purchase task data processing steps the final sample sizes for the Alcohol and CPT indices differ. Specifically, not all participants who had data present for the APT also had data present for the CPT. A total of 383 participants had valid purchase task data, with 322 for the APT and 334 for the CPT. A total of 273 participants had valid data present for both the APT and CPT. Outliers at the price level and at the index level (Z-score cutoff 3.29) were winsorized to the exact next highest nonoutlying value.[36] For the APT, the percentage of outlying responses at the item-level ranged from .6% to 1.9%. The percentage of index-level outliers ranged from .3% to 6.8%. For the CPT, the percentage of outlying responses at the item-level ranged from .6% to 3.0%. The percentage of index-level outliers ranged from .9% to 3.0%.

For alcohol demand, all indices were log transformed for normality. For cigarette demand, O_{max}, breakpoint, and elasticity were log transformed for normality. Four behavioral economic indices from the hypothetical purchase task (intensity, O_{max}, P_{max}, and breakpoint) were generated using an observed values approach.[18] Elasticity was derived using the exponentiated version of Hursh and Silberberg's[38] exponential demand equation for demand curve analysis:

$$Q = Q_0 * 10^{k(e^{-\alpha Q_0 C} - 1)}$$

where Q = consumption at a given price, Q_0 = consumption at zero price, k = constant parameter reflecting the range of consumption values in $\log_{10}$ units and was set at 2 in this sample, α = derived demand parameter reflecting the rate of consumption decline associated with increasing price, and C = the price of the cigarette or alcohol.

Bivariate correlations were used to examine the relationship among behavioral economic indices within each substance (eg, correlation among alcohol intensity and O_{max}) and between pairing indices (eg, correlation between alcohol intensity and cigarette intensity). An exploratory factor analysis was conducted using principal-components analysis (PCA) estimation method with an oblique (oblimin) rotation to allow for a multifactorial solution with correlated factors. The PCA approach is consistent with previous research examining the latent structure of demand,[26–28] with the rationale that characterizing total variance among indices was preferable due to the high levels of variability among associations between demand indices.[34] Factor structure was determined by an eigenvalue greater than 1 and by further examination of the scree plot. When interpreting the rotated factor pattern, factor loading of 0.40 on the pattern matrix was the criteria used to determine if an item significantly loaded onto a given factor.[39,40] The resulting factors were to be used as dependent variables in subsequent analyses.

A series of hierarchical multiple regressions with PROC REG were used to test our second and third aims in relation to same-substance and cross-substance associations between use severity/past 30-day use and latent factors of demand and demand indices. The primary outcomes were the latent factors of demand derived from the PCA. Due to the lack of existing research on the traditional five behavioral economic indices for alcohol and cigarettes in a sample of heavy drinking smokers, we ran parallel models including the five indices of demand as opposed to the latent factors of demand. These results are presented in Supplementary Materials. In the lowest block were demographic characteristics (sex, age, education, employment, race, and income). Due to the possible influence of income on choice behavior, income was included in this block of analyses. The second block included same-substance predictors (ie, ADS and drinks per drinking day for alcohol demand indices), while the third block included cross-substance predictors (ie, FTND and cigarettes per smoking day for alcohol demand indices). The same pattern of analyses was replicated for cigarette smoking indices, such that the second block included same-substance indicators of cigarette smoking and the third block included cross-substance indicators of alcohol use.

To control alpha inflation an omnibus approach was used in the hierarchical regression, such that if the change in R^2 was not significant, the block of coefficients was not considered further. This approach reduces alpha inflation by reducing the total number of tests. No correction for Type I error was implemented based on the rationale that Type I error needs to be considered at the level of families of hypotheses separately and not for the number of variables in the whole set of analyses reported.[41] In the present analyses, the primary outcomes of the two factors of demand represent two families of hypotheses suggesting correction for Type I error may not be necessary. Results from full models including the three aforementioned blocks and reduced models, excluding nonsignificant blocks, are reported. Analyses were conducted in SAS University Edition version 9.4.[42]

Power analyses for the final study sample of n = 322 for the APT and n = 334 for the CPT were conducted in G*Power 3.1.[43] We conducted a sensitivity analysis to determine the minimum effect size that could be reliably detected in the planned hierarchical multiple regressions with three sets of predictors (demographics, same-substance variables, cross-substance variables) in an F test for a fixed multiple regression with an R^2 increase setting the alpha level at p < .05 and power = .80. Across the APT and CPT, the results revealed the sample size afforded an 80% power to detect an effect size of f^2 = .03 which is slightly above the small effect cutoff.[44]

Results

Sample Characteristics

Participants were, on average, 35.78 (SD = 10.61) years old and were 29% female. The racial breakdown was such that 37.5% identified as African American, 30% Caucasian, 3% Asian, 9% Latinx, 2% Native American, and 18% multiracial. Approximately 68% of the sample reported a pretax household income less than $30 000. Participants reported an average of 21.01 (SD = 7.68) drinking days within the last month and an average number of 6.76 (SD = 4.49) drinks per drinking day. For cigarette smoking, participants on average smoked cigarettes 28.91 (SD = 3.55) days in the last month and had a mean of 14.02 (SD = 7.73) cigarettes per smoking day. For alcohol use severity, participants reported an average ADS score of 12.93 (SD = 7.38) indicating low alcohol dependence and endorsed low to moderate nicotine dependence with a mean FTND score of 4.36 (SD = 2.27).

Relationship Between Demand for Alcohol and Cigarettes APT and CPT

Demand curves representing hypothetical consumption across a range of prices are presented in Figure 1 for alcohol and Figure 2 for cigarettes. Correlations within demand indices of the same-substance and between demand indices of cross-substances (ie, correlation between alcohol intensity and cigarette intensity) are presented in Supplementary Materials. For alcohol, there were significant (ps < .01) positive correlations between intensity and O_{max} (r = 0.15), O_{max} and P_{max} (r = 0.89), O_{max} and breakpoint (r = 0.87), and P_{max} and breakpoint (r = 0.91). Significant negative correlations were observed between O_{max} and elasticity (r = −0.84), P_{max} and elasticity (r = −0.68), and breakpoint and elasticity (r = −0.73). Results revealed three sets of nonsignificant (ps > .31) correlations between intensity and P_{max}, breakpoint, and elasticity. For cigarette demand indices, there were significant positive correlations within all indices with the exception of intensity and P_{max} (r = −.04, p = .44). Correlations between pairing demand indices for alcohol and cigarettes (eg, elasticity for alcohol and elasticity for cigarettes) revealed significant positive correlations among all pairing indices (rs = 0.17–0.45, p < .003).

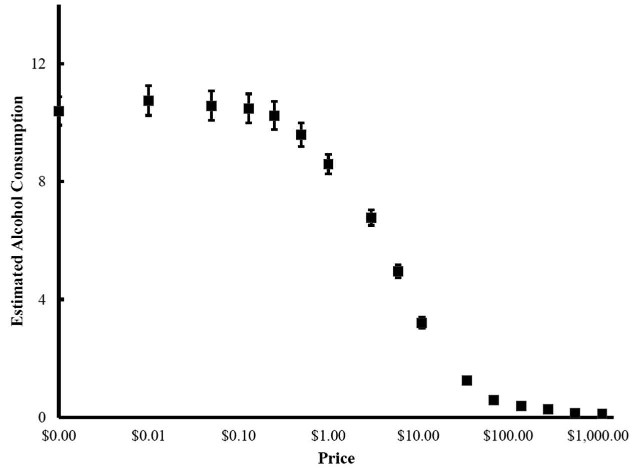

Figure 1. Demand curve for number of drinks purchased on the Alcohol Purchase Task (APT). Log coordinates for price on the horizontal axis are used for proportionality. Intensity is depicted as value of .001 instead of zero due to log axis. Only participants with complete and valid data are included.

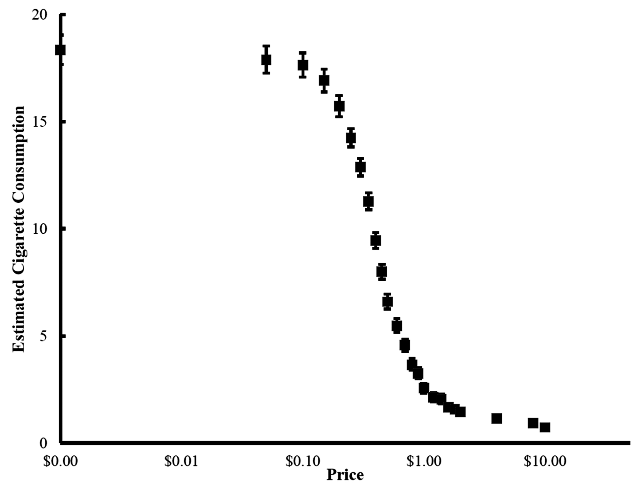

Figure 2. Demand curve for number of cigarettes purchased on the Cigarettes Purchase Task (CPT). Log coordinates for price on the horizontal axis are used for proportionality. Intensity is depicted as value of .001 instead of zero due to log axis. Only participants with complete and valid data are included.

Factor Analysis

Results from the PCA and examination of the scree plot suggested two latent factors. For the APT, the two factors accounted for a total of 89.49% of the variance. The first factor representing Persistence accounted for 69.33% of the variance with an eigenvalue of 3.47. This factor was primarily composed of O_{max}, P_{max}, breakpoint, and elasticity. The second factor representing Amplitude accounted for 20.02% of the variance with an eigenvalue of 1.01. This factor was primarily composed of intensity. The two factors exhibited a small correlation ($r = 0.06$). Remaining factors accounted for a small proportion of the variance with small eigenvalues (all < .36). For the CPT, the two factors accounted for a total of 82.92% of the variance. The first factor representing Persistence accounted for 61.83% of the variance with an eigenvalue of 3.09. This factor was primarily composed of O_{max}, P_{max}, breakpoint, and elasticity. The second factor representing Amplitude accounted for 21.09% of the variance with an eigenvalue of 1.05. This factor was primarily composed of intensity and P_{max}. The two factors exhibited a small correlation ($r = 0.18$). Remaining factors accounted for a small proportion of the variance with small eigenvalues (all ≤.43). Pattern matrix reflecting the partial correlations between each variable and each rotated factor are presented in Supplementary Materials. These resulting factors align with previous research.[26–28]

Demand for Alcohol

Results from the hierarchical regression analyses for alcohol demand are presented in Table 1. When examining Persistence, full models revealed the first block of demographics was not significant as it accounted for 4% of the variance ($p = .31$) and thus was not considered further for Persistence models. Alcohol use variables accounted for 4.0% of the variance ($p < .01$) such that greater drinks per drinking day ($p = .01$) predicted greater Persistence values. ADS scores were nonsignificant ($p = .08$). Over and above these alcohol factors, the addition of cigarette use variables significantly predicted an additional 4.5% (R^2 of the block = .09). Specifically, FTND scores predicted significantly greater Persistence values ($p < .01$), however cigarettes per smoking day was not a significant predictor ($p = .73$). When examining Amplitude, the first block of demographics accounted for 15.2% of the variance ($p < .01$). The second block adding alcohol use variables accounted for an additional 18.2% of the variance ($p < .01$) such that greater ADS scores and greater drinks per drinking day predicted greater intensity of demand for alcohol (ps < .01). However, the addition of cigarette use variables in the third block did not significantly predict alcohol intensity over and above alcohol use variables ($\Delta R^2 = .003$, $p = .55$). A summary of the results with the traditional five indices of demand as opposed to the two factors are presented in Supplementary Materials. The results align directly with the results presented above with the 2-factor solution.

Demand for Cigarettes

Results from the hierarchical regression analyses for cigarette demand are presented in Table 2. When examining Persistence, the first block of demographics accounted for 7.3% of the variance ($p = .01$). The second block adding cigarette use variables accounted for an additional 7.0% (R^2 of the block = .14) of the variance ($p < .01$) such that greater FTND scores and greater cigarettes per smoking day predicted greater Persistence values (ps < .02). However, the addition of alcohol use variables in the third block did not significantly predict Persistence values over and above cigarette use variables ($\Delta R^2 = .010$, $p = .16$). When examining Amplitude, full models revealed the first block of demographics was not significant as it accounted for 3.9% of the variance ($p = .31$) and thus was not considered further for Amplitude models. Cigarette use variables accounted for 3.24% of the variance ($p < .01$) such that greater FTND scores and greater cigarettes per smoking day predicted greater

Table 1. Hierarchical Regression Analysis Predicting Latent Factors of Alcohol Demand

	Persistence			Amplitude		
	ΔR^2	b	Std. Err.	ΔR^2	b	Std. Err.
Block 1	---			.152		
Sex		---	---		.325*	.116
Age		---	---		−.032*	.005
Education		---	---		−.023	.016
Employ. = Full-Time		---	---		.140	.155
Employ. = Part-Time		---	---		.027	.152
Race = African Am.		---	---		−.098	.136
Race = Asian		---	---		.151	.368
Race = Latino/a		---	---		.143	.199
Race = Native Am.		---	---		−.195	.486
Race = Multi-Racial		---	---		−.020	.154
Income		---	---		−.020	.033
Block 2	.040			.182		
ADS		.014	.008		.039*	.007
DPDD		.032*	.013		.059*	.011
Block 3	.045			---		
FTND		.099*	.028		---	---
CPSD		−.003	.009		---	---

ADS = Alcohol Dependence Scale; CPSD = Cigarettes per Smoking Day; DPDD = Drinks per Drinking Day; Employ. = Employment; FTND = Fagerström Test for Nicotine Dependence. R^2 change, unstandardized regression coefficients, and standard errors presented for each block. Reference group for employment status is unemployed, and Caucasian for race. Results presented are from reduced models excluding blocks that were not significant ("---" indicates nonsignificant block where block coefficients were not considered further).

*Significance at $p \le .05$.

Table 2. Hierarchical Regression Analysis Predicting Latent Factors of Cigarette Demand

	Persistence			Amplitude		
	ΔR^2	*b*	Std. Err.	ΔR^2	*b*	Std. Err.
Block 1	.073			---		
Sex		.253*	.120		---	---
Age		.005	.006		---	---
Education		−.023	.020		---	---
Employ. = Full-Time		.029	.160		---	---
Employ. = Part-Time		.260	.156		---	---
Race = African Am.		−.344*	.138		---	---
Race = Asian		−.135	.313		---	---
Race = Latino/a		−.440*	.205		---	---
Race = Native Am.		.086	.450		---	---
Race = Multi-Racial		−.095	.160		---	---
Income		.080*	.034		---	---
Block 2	.070			.328		
FTND		.074*	.033		.060*	.024
CPSD		.020*	.008		.065*	.007
Block 3	---	---	---	.013		
ADS		---	---		.010	.006
DPDD		---	---		.017	.011

ADS = Alcohol Dependence Scale; CPSD = Cigarettes per Smoking Day; DPDD = Drinks per Drinking Day; Employ. = Employment; FTND = Fagerström Test for Nicotine Dependence. R^2 change, unstandardized regression coefficients, and standard errors presented for each block. Results presented are from reduced models excluding blocks that were not significant ("---" indicates nonsignificant block where block coefficients were not considered further).
*Significance at $p \leq .05$.

Persistence values (*p*s < .01). The addition of alcohol use variables in the third block significantly predict Amplitude over and above cigarette use variables ($\Delta R^2 = .01$, $p = .05$), however when examining the coefficients neither ADS scores nor drinks per drinking day were significant (*p*s > .13). A summary of the results with the traditional five indices of demand as opposed to the two factors are presented in Supplementary Materials. The results generally align directly with the results presented above with the 2-factor solution.

Discussion

In a large sample of heavy drinking smokers, this study examined the association between latent factors of demand for nicotine and alcohol, in terms of same-substance associations cross-substance associations between use severity/past 30-day use for each substance in relation to demand for the other substance (ie, how alcohol dependence and use predicts demand for cigarettes). In examining same-substance relationships reflected in the second block of the hierarchical regression models for alcohol, a relatively consistent pattern emerged such that greater alcohol use severity, as indexed by ADS and past 30-day use, was associated with greater derived Persistence and Amplitude values. For demand for cigarettes, there was a similar pattern of consistency in cigarette use variables, represented by FTND and past 30-day cigarette use, as these variables were associated with both Persistence and Amplitude.

These findings were consistent with the literature and support the notion that use and dependence of a substance is related to demand for a substance that can be captured through hypothetical purchase tasks.[19,21] Results from our final aim of testing cross-substance associations revealed an interesting pattern whereby cigarette dependence and use predicted Persistence values for alcohol, however not Amplitude values for alcohol. For Persistence, these effects were seen in the expected direction whereby greater FTND predicted greater Persistence values. The same pattern was not seen in predicting cigarette demand such that alcohol dependence and use did not significantly predict Persistence values over and above alcohol use factors. However, alcohol use and dependence significantly predicted Amplitude values. Notably, this alcohol variables in the final block reached statistical significance with change in R^2, but when examining the coefficients of this block, neither drinks per drinking day nor ADS scores were significant. Further, the additional amount of variance this cross-substance use block was able to predict in Amplitude was rather small (1.3%) in comparison to the significant cross-substance use block predicting Persistence values (4.5%).

Results of our PCA aligned with previous literature supporting that Persistence reflects four main dimensions of the demand curve, maximum expenditure (O_{max}), price corresponding to maximum expenditure (P_{max}), first price suppressing consumption to zero (breakpoint), and the overall slope of the demand curve (elasticity). This factor Persistence represents interrelated measures of sensitivity to escalating price that has been hypothesized to reflect how far, in terms of price, an individual is willing to spend on alcohol.[28] The second factor Amplitude consisted of only one demand indices, intensity, thus reflecting how much in consumption an individual is willing to consume.[28] These findings suggest that the Persistence factor is operative in these findings for alcohol, suggesting that greater tobacco involvement is associated with insensitivity to the escalating response cost for alcohol. This pattern did not transition to cigarette outcomes, where results indicate the alcohol involvement is associated with greater overall consumption when free as represented by the Amplitude factor.

These results align in part with previous work examining alcohol demand in a sample of heavy drinking smokers. We found greater nicotine dependence to relatively consistently predict greater willingness to spend on alcohol reflected in the Persistence factor which is consistent with Amlung et al. findings of smokers experiencing greater alcohol O_{max} and breakpoint than nonsmokers.[23] Additionally, our results support Yurasek et al. finding that P_{max} for alcohol was also elevated among smokers. When examining additional comorbidities, a recent study found greater alcohol demand among those who couse alcohol and cannabis.[45] Furthermore, an early study of commodity specificity revealed that tobacco demand is fundamentally independent of food demand suggesting that purchase tasks are not simply capturing a generic reward sensitivity.[46] In line with what has previously been suggested,[23] there is the possibility of a general hypersensitivity to all rewards that individuals who couse both alcohol and cigarettes may experience. If there were a generalized hypersensitivity to reward, we would expect to see a consistent pattern across cigarettes and alcohol such that alcohol use would predict cigarette demand and vice versa. In our sample, we found nicotine dependence and use to be relatively consistent in predicting greater insensitivity to the escalating response cost for alcohol via Persistence factor while alcohol dependence and use only predicted Amplitude reflecting intensity of demand for cigarettes.

These results imply from a behavioral economics framework, there may be a stronger effect of nicotine dependence on demand for alcohol than the other way around (ie, asymmetric cross-commodity reinforcing value). There are various possibilities by which tobacco involvement would predict greater reinforcing value of alcohol. One possibility is a methodological issue such that is plausible that this sample had a more stable smoking pattern (10+ cigarettes/day) with more variability in alcohol use, which in turn may explain these effects. In samples that use cigarettes more sporadically, alcohol may have a stronger effect driving demand for cigarettes. Another possibility is asymmetric pharmacological interactions with alcohol potentiating nicotine's effects but the opposite not being true to the same extent. From a behavioral economics standpoint, this is turn could mean there are asymmetrical behavioral interactions, such that smoking is more of a complement than alcohol with smoking making drinking better to a larger extent than drinking makes smoking better. A final possibility is that smoking involvement is a proxy for other items, such as comorbid psychiatric issues (eg, depression and anxiety) or other risk factors, such as adverse childhood events. From this perspective, alcohol becomes more valuable because smokers tend to be more disadvantaged and otherwise vulnerable.

Results indicated significant correlations within demand indices for cigarettes among all demand indices, with the exception of intensity and P_{max}. When examining demand for alcohol, nearly all demand indices were highly correlated apart from intensity which did not correlate with P_{max}, breakpoint, and elasticity. While each of these demand indices is functionally related all having been derived from the same demand curve, the construct of relative reinforcing efficacy value is proposed to be heterogenous in nature.[17] Thus, the consistent patterns of correlations may serve as a reflection of the demand curve, and deviations in correlations within a substance may reflect a unique aspect of our couse population where by demand indices for one substance, namely cigarettes, are more strongly interrelated than demand indices for alcohol. The higher correlations may also have been a result of the differences in pricing structure.

The present study should be interpreted in light of its strengths including a large sample size and use of all five behavioral economic indices to examine the effects alcohol could have on all aspects of the demand curve for cigarettes and vice versa. Limitations include the use of ADS and FTND as self-report measures of use severity, as opposed to a formal AUD or Tobacco Use Disorder diagnoses. In addition, the APT used an early price structure that was modeled on a progressive-ratio operant schedule, with a doubling of response requirements that leads to the inclusion of nonmarket prices. This approach includes large intervals between prices that can inflate variance and may be responsible, for example, in the within-task differences in correlations for the APT and CPT, which used a narrower range of market-compatible prices.

In summary, our results show that latent factors of demand derived from behavioral economic indices may be sensitive to cross-substance relationships and specifically that such relationships are asymmetrically stronger for smoking variables affecting alcohol demand, not the other way around. Whether this is a function of differential pharmacological interactions between alcohol and nicotine or whether it is because smoking severity is a proxy for other factors that lead to higher alcohol reinforcing value cannot be inferred in the current study, but warrants subsequent examination. More broadly, understanding cross-commodity demand relationships has the potential to illuminate both overlapping and nonoverlapping aspects of substance misuse.

Supplementary Material

A Contributorship Form detailing each author's specific involvement with this content, as well as any supplementary data, are available online at https://academic.oup.com/ntr.

Supplementary data are available at *Nicotine & Tobacco Research* online.

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Declaration of Interests

LAR has received study medication from Pfizer and Medicinova and consulted for GSK. None of the authors have other conflicts of interest to disclose.

References

1. Dwyer-Lindgren L, Mokdad AH, Srebotnjak T, Flaxman AD, Hansen GM, Murray CJ. Cigarette smoking prevalence in US counties: 1996–2012. *Popul Health Metr.* 2014;12(1):5.
2. Jamal A, King BA, Neff LJ, Whitmill J, Babb SD, Graffunder CM. Current cigarette smoking among adults—United States, 2005–2015. *MMWR Morb Mortal Wkly Rep.* 2016;65(44):1205–1211.
3. Ng M, Freeman MK, Fleming TD, et al. Smoking prevalence and cigarette consumption in 187 countries, 1980–2012. *JAMA.* 2014;311(2):183–192.
4. Chou SP, Goldstein RB, Smith SM, et al. The epidemiology of DSM-5 nicotine use disorder: results from the national epidemiologic survey on alcohol and related conditions-III. *J Clin Psychiatry.* 2016;77(10):1404–1412.
5. Blot WJ, McLaughlin JK, Winn DM, et al. Smoking and drinking in relation to oral and pharyngeal cancer. *Cancer Res.* 1988;48(11):3282–3287.
6. Dal Maso L, Torelli N, Biancotto E, et al. Combined effect of tobacco smoking and alcohol drinking in the risk of head and neck cancers: a re-analysis of case-control studies using bi-dimensional spline models. *Eur J Epidemiol.* 2016;31(4):385–393.
7. Le Strat Y, Ramoz N, Gorwood P. In alcohol-dependent drinkers, what does the presence of nicotine dependence tell us about psychiatric and addictive disorders comorbidity? *Alcohol Alcohol.* 2010;45(2):167–172.

8. Weinberger AH, Pilver CE, Hoff RA, Mazure CM, McKee SA. Changes in smoking for adults with and without alcohol and drug use disorders: longitudinal evaluation in the US population. *Am J Drug Alcohol Abuse.* 2013;39(3):186–193.
9. Weinberger AH, Platt J, Jiang B, Goodwin RD. Cigarette smoking and risk of alcohol use relapse among adults in recovery from alcohol use disorders. *Alcohol Clin Exp Res.* 2015;39(10):1989–1996.
10. Li MD, Xu Q, Lou XY, Payne TJ, Niu T, Ma JZ. Association and interaction analysis of variants in CHRNA5/CHRNA3/CHRNB4 gene cluster with nicotine dependence in African and European Americans. *Am J Med Genet B Neuropsychiatr Genet.* 2010;153B(3):745–756.
11. Wang JC, Grucza R, Cruchaga C, et al. Genetic variation in the CHRNA5 gene affects mRNA levels and is associated with risk for alcohol dependence. *Mol Psychiatry.* 2009;14(5):501–510.
12. Hendrickson LM, Zhao-Shea R, Pang X, Gardner PD, Tapper AR. Activation of α4* nAChRs is necessary and sufficient for varenicline-induced reduction of alcohol consumption. *J Neurosci.* 2010;30(30):10169–10176.
13. Rollema H, Hurst RS. The contribution of agonist and antagonist activities of α4β2* nAChR ligands to smoking cessation efficacy: a quantitative analysis of literature data. *Psychopharmacology (Berl).* 2018;235(9):2479–2505.
14. Bickel WK, Johnson MW, Koffarnus MN, MacKillop J, Murphy JG. The behavioral economics of substance use disorders: reinforcement pathologies and their repair. *Annu Rev Clin Psychol.* 2014;10:641–677.
15. MacKillop J. The behavioral economics and neuroeconomics of alcohol use disorders. *Alcohol Clin Exp Res.* 2016;40(4):672–685.
16. Johnson MW, Bickel WK. Replacing relative reinforcing efficacy with behavioral economic demand curves. *J Exp Anal Behav.* 2006;85(1):73–93.
17. Bickel WK, Marsch LA, Carroll ME. Deconstructing relative reinforcing efficacy and situating the measures of pharmacological reinforcement with behavioral economics: a theoretical proposal. *Psychopharmacology (Berl).* 2000;153(1):44–56.
18. Murphy JG, MacKillop J. Relative reinforcing efficacy of alcohol among college student drinkers. *Exp Clin Psychopharmacol.* 2006;14(2):219–227.
19. MacKillop J, Miranda R Jr, Monti PM, et al. Alcohol demand, delayed reward discounting, and craving in relation to drinking and alcohol use disorders. *J Abnorm Psychol.* 2010;119(1):106–114.
20. MacKillop J, Murphy JG. A behavioral economic measure of demand for alcohol predicts brief intervention outcomes. *Drug Alcohol Depend.* 2007;89(2–3):227–233.
21. González-Roz A, Jackson J, Murphy C, Rohsenow DJ, MacKillop J. Behavioral economic tobacco demand in relation to cigarette consumption and nicotine dependence: a meta-analysis of cross-sectional relationships. *Addiction.* 2019;114(11):1926–1940.
22. Strickland JC, Lile JA, Stoops WW. Unique prediction of cannabis use severity and behaviors by delay discounting and behavioral economic demand. *Behav Process.* 2017;140:33–40.
23. Amlung M, MacKillop J, Monti PM, Miranda R Jr. Elevated behavioral economic demand for alcohol in a community sample of heavy drinking smokers. *J Stud Alcohol Drugs.* 2017;78(4):623–628.
24. Yurasek AM, Murphy JG, Clawson AH, Dennhardt AA, MacKillop J. Smokers report greater demand for alcohol on a behavioral economic purchase task. *J Stud Alcohol Drugs.* 2013;74(4):626–634.
25. Epstein LH, Stein JS, Paluch RA, MacKillop J, Bickel WK. Binary components of food reinforcement: amplitude and persistence. *Appetite.* 2018;120:67–74.
26. Aston ER, Farris SG, MacKillop J, Metrik J. Latent factor structure of a behavioral economic marijuana demand curve. *Psychopharmacology (Berl).* 2017;234(16):2421–2429.
27. Bidwell LC, MacKillop J, Murphy JG, Tidey JW, Colby SM. Latent factor structure of a behavioral economic cigarette demand curve in adolescent smokers. *Addict Behav.* 2012;37(11):1257–1263.
28. Mackillop J, Murphy JG, Tidey JW, Kahler CW, Ray LA, Bickel WK. Latent structure of facets of alcohol reinforcement from a behavioral economic demand curve. *Psychopharmacology (Berl).* 2009;203(1):33–40.
29. Ray LA, Courtney KE, Ghahremani DG, Miotto K, Brody A, London ED. Varenicline, low dose naltrexone, and their combination for heavy-drinking smokers: human laboratory findings. *Psychopharmacology (Berl).* 2014;231(19):3843–3853.
30. Sobell MB, Sobell LC, Klajner F, Pavan D, Basian E. The reliability of a timeline method for assessing normal drinker college students' recent drinking history: utility for alcohol research. *Addict Behav.* 1986;11(2):149–161.
31. Heatherton TF, Kozlowski LT, Frecker RC, Fagerström KO. The Fagerström test for nicotine dependence: a revision of the Fagerström tolerance questionnaire. *Br J Addict.* 1991;86(9):1119–1127.
32. Horn J, Skinner H, Wanberg K, Foster F. *Alcohol Use Questionnaire (ADS).* Toronto: Addiction Research Foundation; 1984.
33. Kiselica AM, Webber TA, Bornovalova MA. Validity of the alcohol purchase task: a meta-analysis. *Addiction.* 2016;111(5):806–816.
34. MacKillop J, Murphy JG, Ray LA, et al. Further validation of a cigarette purchase task for assessing the relative reinforcing efficacy of nicotine in college smokers. *Exp Clin Psychopharmacol.* 2008;16(1):57–65.
35. MacKillop J, Brown CL, Stojek MK, Murphy CM, Sweet L, Niaura RS. Behavioral economic analysis of withdrawal- and cue-elicited craving for tobacco: an initial investigation. *Nicotine Tob Res.* 2012;14(12):1426–1434.
36. Amlung MT, Acker J, Stojek MK, Murphy JG, MacKillop J. Is talk "cheap"? An initial investigation of the equivalence of alcohol purchase task performance for hypothetical and actual rewards. *Alcohol Clin Exp Res.* 2012;36(4):716–724.
37. Amlung M, MacKillop J. Further evidence of close correspondence for alcohol demand decision making for hypothetical and incentivized rewards. *Behav Process.* 2015;113:187–191.
38. Hursh SR, Silberberg A. Economic demand and essential value. *Psychol Rev.* 2008;115(1):186–198.
39. Stevens JP. *Applied Multivariate Statistics for the Social Sciences.* Routledge; 2012.
40. Tabachnic B, Fidell LS. *Using Multivariate Statistics.* Boston, MA: Allyn and Bacon; 2000.
41. Dar R, Serlin RC, Omer H. Misuse of statistical test in three decades of psychotherapy research. *J Consult Clin Psychol.* 1994;62(1):75–82.
42. *SAS V, Version S. 9.4 [Computer Program].* Cary: SAS Institute; 2003.
43. Faul F, Erdfelder E, Buchner A, Lang AG. Statistical power analyses using G*Power 3.1: tests for correlation and regression analyses. *Behav Res Methods.* 2009;41(4):1149–1160.
44. Cohen J. *Statistical Power Analysis for the Behavioral Sciences.* Hillsdale, NJ: Lawrence Erlbaum Associates Inc; 1988:403.
45. Morris V, Patel H, Vedelago L, et al. Elevated behavioral economic demand for alcohol in co-users of alcohol and cannabis. *J Stud Alcohol Drugs.* 2018;79(6):929–934.
46. Chase HW, Mackillop J, Hogarth L. Isolating behavioural economic indices of demand in relation to nicotine dependence. *Psychopharmacology (Berl).* 2013;226(2):371–380.