Addiction

RESEARCH REPORT

doi:10.1111/j.1360-0443.2012.03991.x

High-resolution behavioral economic analysis of cigarette demand to inform tax policy

James MacKillop[1,2], Lauren R. Few[1], James G. Murphy[2,3], Lauren M. Wier[4], John Acker[1], Cara Murphy[1], Monika Stojek[1], Maureen Carrigan[5] & Frank Chaloupka[6]

Department of Psychology, University of Georgia, Athens, GA, USA,[1] Department of Behavioral and Social Sciences, Brown University, Providence, RI, USA,[2] Department of Psychology, University of Memphis, Memphis, TN, USA,[3] Program in Public Health, Brown University, Providence, RI, USA,[4] Department of Psychology, University of South Carolina Aiken, Aiken, SC, USA[5] and Department of Economics, University of Illinois-Chicago, Chicago, IL, USA[6]

ABSTRACT

Aims Novel methods in behavioral economics permit the systematic assessment of the relationship between cigarette consumption and price. Towards informing tax policy, the goals of this study were to conduct a high-resolution analysis of cigarette demand in a large sample of adult smokers and to use the data to estimate the effects of tax increases in 10 US States. **Design** In-person descriptive survey assessment. **Setting** Academic departments at three universities. **Participants** Adult daily smokers (i.e. more than five cigarettes/day; 18+ years old; ≥8th grade education); $n = 1056$. **Measurements** Estimated cigarette demand, demographics, expired carbon monoxide. **Findings** The cigarette demand curve exhibited highly variable levels of price sensitivity, especially in the form of 'left-digit effects' (i.e. very high price sensitivity as pack prices transitioned from one whole number to the next; e.g. $5.80–6/pack). A $1 tax increase in the 10 states was projected to reduce the economic burden of smoking by an average of $530.6 million (range: $93.6–976.5 million) and increase gross tax revenue by an average of 162% (range: 114–247%). **Conclusions** Tobacco price sensitivity is non-linear across the demand curve and in particular for pack-level left-digit price transitions. Tax increases in US states with similar price and tax rates to the sample are projected to result in substantial decreases in smoking-related costs and substantial increases in tax revenues.

Keywords Behavioral economics, cigarette demand, nicotine dependence, tax policy.

Correspondence to: James MacKillop, Department of Psychology, University of Georgia, 100 Hooper St., Athens, GA 30602, USA.
E-mail: jmackill@uga.edu

Submitted 22 December 2011; initial review completed 5 March 2012; final version accepted 14 June 2012

INTRODUCTION

Cigarette smoking remains the single largest preventable cause of morbidity and mortality in the United States and the developed world [1–3], imposing a massive public health burden [1,4,5]. One of the major factors in cigarette consumption is its price. Macroeconomic studies using population-level price and consumption data have found consistently that tobacco consumption is related significantly to price, with increases in cost decreasing overall consumption and increasing the number of individuals who quit smoking [6,7]. In absolute terms, however, tobacco demand (i.e. the ratio of proportionate decreases in consumption relative to proportionate increases in price) has been estimated to be inelastic [6,7], meaning that consumption decreases at a lower rate relative to increases in price. For example, price elasticity in the United States is estimated to be 0.25–0.50 (i.e. a 10% price increase in price results in a 2.5–5% decrease in smoking) [7].

The field of behavioral economics integrates principles and methods from psychology and economics to study individual-level preferences and consumption. With regard to the relationship between cigarette consumption and price, behavioral economics has also made significant contributions. Human laboratory studies have examined *in-vivo* cigarette consumption under conditions of escalating cost, permitting comprehensive examination of the demand curve under controlled conditions [8–10]. A prototypic bitonic behavioral economic demand curve is presented in Fig. 1, with an initial phase of relatively low price sensitivity and a subsequent phase of relatively high price sensitivity. Like population-level studies, these studies indicate that consumption is

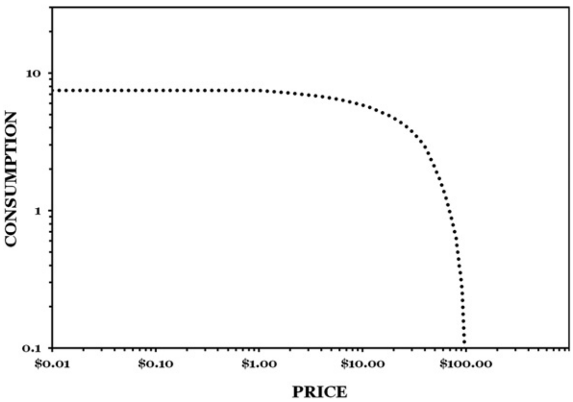

Figure 1 A prototypic behavioral economic demand curve. Note the characteristic bitonic curvilinear form, with an initial period of price insensitivity and a subsequent period of substantially greater price sensitivity. Also note that behavioral economic demand curves differ from traditional economic demand curves by presenting price on the *x*-axis and consumption on the *y*-axis

price-sensitive, and behavioral economic studies also permit fractionating the demand curve into multiple indices of the incentive value of cigarettes [11–13].

One of the most potent tobacco control strategies is increasing the cost of cigarettes via taxation [7,14], which has historically been informed by macroeconomic data. This is largely because behavioral economic studies have been limited by very high experimental demands (e.g. multiple sessions of long duration per participant) and therefore have relatively low price resolution and very small sample size. However, the recent development of a novel behavioral economic assessment, a Cigarette Purchase Task (CPT), permits relatively efficient data collection that could be applied directly to informing tobacco tax policy. By assessing estimated daily cigarette consumption from very low to very high prices, a CPT permits full examination of an individual's cigarette demand curve. Moreover, a number of studies have supported the validity of the indices of demand from this approach. For example, CPT indices of demand have been significantly positively associated with smoking rate, nicotine dependence and *in-vivo* smoking topography [15–18]. In addition, CPT indices have been found to be stable over time [19].

The goal of the current study was to apply the CPT methodology to inform tobacco tax policy. To date, CPT studies have had limitations that prevented direct application of the resulting data to policy questions. These include relatively modest sample sizes, preventing generalizability; and, in terms of the prices, previous studies used only a small number of total prices and had relatively large gaps between prices, creating relatively low-resolution data. In addition, initial versions of the CPT did not include both price per cigarette and the associated pack price, meaning that participants may have been making choices without extrapolating the prices to the common unit of purchase. This study sought to extend the previous literature by directly addressing these issues and, in turn, examining the resulting demand curve data in the context of tobacco tax policy. Specifically, the first goal was to characterize the overall cigarette demand curve and identify highly sensitive and insensitive regions. Based on previous behavioral economic studies, we predicted that overall tobacco demand would exhibit a curvilinear form, including both inelastic and elastic regions, indicating varying levels of price sensitivity depending on the portion of the demand curve. The second goal was to apply the data directly to tax policy by using it as the basis for projecting the effects of increased taxation on the economic burden of smoking and tax revenue in 10 US states.

METHOD

Participants

Participants were recruited via newspaper, internet and flyer advertising. Eligibility criteria were intentionally broad for a maximally representative sample of daily smokers. Inclusion criteria were ≥18 years old, smoking more than five cigarettes/day and ≥8th grade education. A sample of 1124 participants was enrolled in three sites: Providence, RI; Athens, GA; and Aiken, SC. Of these, 13 participants were excluded due to excessive missing data (i.e. >10% CPT items missing) and 55 participants were excluded due to low effort (i.e. more than three positive contradictions, reflecting random responding). The final sample comprised 1056 participants, of whom the large majority were enrolled in Athens, GA ($n = 891$), followed by Providence, RI ($n = 113$) and Aiken, SC ($n = 52$). Smoking prevalence in the three states is estimated to be 19.3% (GA), 21.1% (RI) and 23.3% (SC) [20]; of the three, only RI has comprehensive smoke-free laws [21]. Participant characteristics are provided in Table 1; characteristics by site are provided in supplementary materials (Table S1).

Procedure

Potential participants completed a telephone screen and eligible participants completed an in-person assessment in private. Upon arrival, study procedures were discussed with participants and informed consent was completed. The primary assessment comprised questionnaire packets and collection of expired carbon monoxide (CO; PiCO+ Smokerlyzer, Bedfont™ USA). The protocol lasted 90 minutes; the vast majority of participants received $30 for their time, although a small proportion of student participants received research credit (7.5%).

Table 1 Participant characteristics ($n = 1056$).

	%/mean (standard deviation; range)
Sex	61% male; 39% female
Race	White: 68%; African American: 23%; Asian: 3%; mixed race: 3%; American Indian/Alaskan Native: 1%; other: 1%; Pacific Islander: 0.1%
Hispanic ethnicity	2.4%
Income	<$15 k: 50%; $15–30 k: 21%; $30–45 k: 8%; $45–60 k: 4%; $60–75 k: 4%; $75–90 k: 3%; $90–105 k: 2%; $105–120 k: 3%; >$120 000: 5%
Education (years)	12.89 (2.09; 8–26)
Age	31.61 (12.70; 18–70)
C/D	16.51 (10.95; 0–120)
FTND	4.17 (2.50; 0–10)
COp.p.m.	16.73 (12.27; 0–82)
Cost/pack	$4.57 ($0.92; $1–$9)

C/D: cigarettes/Day; FTND: Fagerström Test of Nicotine Dependence; COp.p.m.: carbon monoxide parts per million. Cost/pack refers to the participants' self-reported typical cost of a pack of cigarettes.

Participation for research credit was considered non-coercive as it was voluntary and alternative options were provided. Participants reporting that they were full-time students comprised 36% of the overall sample, which was not surprising as the catchment areas are 'college towns'; 21 different educational institutions were represented. All study procedures were approved by the respective Institutional Review Boards.

Assessments

Descriptive variables were assessed initially by questionnaire. Cigarette consumption and nicotine dependence were assessed using the Fagerström Test of Nicotine Dependence (FTND) [22]. Cigarette demand was assessed using a CPT with the previously published instructions [15], asking participants to estimate their cigarette consumption on a typical day at escalating levels of price with only their existing resources, no access to any other tobacco products and no stockpiling. Estimated hypothetical cigarette consumption was assessed at 73 prices, from $0 to $10. The price schedule was 1¢ increments from 0–50¢, 4¢ increments from 50¢ to $1 and $1 increments thereafter; an exception was a 2¢ increase from 98¢ to $1. The study originally included prices $2–10 in $1 units, but only responses up to $1 were ultimately included because of the very large intervals between prices and divergence from market prices. The prices were intended to provide maximum resolution prior to, following, and at market prices. Equivalent prices per pack were provided immediately to the right of price/cigarette.

Data processing and analysis

For participants with single missing data points on the CPT (but fewer than 10% in total), mean imputation was conducted between the individual's adjacent prices (19 instances, 0.03%). Missing values on the FTND were also imputed using mean imputation (six instances, 0.3%). Five participants did not complete the FTND and no values were imputed, and CO was not collected for three participants; these participants were not included in analyses of these variables. Similarly to previous studies, outliers were defined as $Z > 3.29$ and recoded iteratively as the highest non-outlying value (2.75%) [23].

Cigarette demand was analyzed using several approaches. Within-subjects t-tests were used to compare consumption at adjacent time-points. Aggregate price elasticity was assessed using an exponential model [24]: $\log_{10}Q = \log_{10}Q_0 + k(e^{-\alpha Q_0 C} - 1)$, where Q = consumption at a given price; Q_0 = maximum consumption (consumption at zero or minimal price); k = a constant across individuals that denotes the range of consumption values in $\log_{10}$ powers, in this case, a constant of 4; C = the cost of the commodity (price); and α = the derived demand parameter reflecting the rate of decline of consumption in standardized price. A trivial non-zero value (0.1) was used to permit modeling of zero consumption values. Local elasticity (i.e. elasticity between two adjacent prices) was defined as the arithmetic ratio of percentage decrease in consumption to percentage increase in price (i.e. %Δconsumption/%Δprice) and reported in positive units. Elasticity was also generated across the two phases of the bitonic demand curve by identifying the 'tipping point' demarcating the less sensitive first phase and the more sensitive second phase. This was defined at an aggregate level as P_{max} (i.e. the price at which expenditure is maximized) [25]. Specifically, consumption from 1¢ to P_{max} was designated as the first phase and consumption from P_{max} to $1 was designated as the second phase. Finally, for comparison across proportionate changes of the same magnitude, arithmetic elasticity was generated between six price changes, each reflecting approximately a 100% price increase (1–2¢, 2–4¢, 4–8¢, 8–16¢, 16–32¢ and 32–62¢).

To apply the data to tax policy, the projected effects of an increase of $1/pack of cigarettes were calculated for both savings in health-care costs/productivity and changes in revenue in the 10 US states with average pack prices most similar to the prices where the majority of the data were collected (Georgia). Estimates were generated for the cost fully passed through to the consumer (i.e. a 50¢ increase in taxation would result in a 50¢ increase in price for the consumer), with increases of 20, 40, 60 and 80¢ to permit estimated effects of an incomplete pass-through. Estimation of the reduction in health-care costs and lost productivity was calculated by multiplying the projected reduction in packs sold by the estimated economic burden per pack sold [26]. Estimation of the effects on gross tax revenue was generated by calculating the 2010 gross tax revenue based on packs sold and the 2010 tax rate, and then comparing it to the projected revenue based on the projected decrease in packs sold and new revenue rate. As absolute amounts are substantially affected by the state population size, proportionate effects were generated to provide an adjusted estimate.

RESULTS

High-resolution characterization of cigarette demand

Overall demand for cigarettes across prices is presented in Fig. 2. Consistent with previous behavioral economic studies, cigarette demand exhibited a prototypic bitonic curvilinear form, with one phase reflecting low initial sensitivity followed by a second phase reflecting substantially higher elasticity. For overall demand, the model provided an excellent fit ($R^2 = 0.98$, $\alpha = 0.02$) and, for individuals, the model provided a very good fit [median $R^2 = 0.75$, interquartile range (IQR) = 0.71–0.82, mean $\alpha = 0.03$, standard error of the mean (SEM) = 0.002]. Aggregate elasticity suggested relatively low overall price sensitivity, but the local elasticity values were highly variable across prices, ranging from very low to very high levels. Reflecting this, statistically significant decreases were present between each successive price interval (Ps < 0.05–0.00001), but magnitudes of reduction ranged dramatically. The largest decreases took place as pack prices transitioned from one whole-number dollar amount to the next whole-number dollar amount (e.g. $5.80–6/pack), revealing clear 'left-digit' effects for pack price. Illustrative left-digit transitions are provided in Table 2 and Fig. 2.

For elasticity estimates across the two phases of the curve, P_{max} was determined to be 24¢/cigarette. The two elasticity estimates suggested highly inelastic demand during the first phase and substantially greater price sensitivity during the second phase (Table 2), with an absolute magnitude that was relatively close to previous macroeconomic estimates. Similar findings were present when examining consistent doubling of price (Table 2), which illustrated progressively greater price sensitivity across the demand curve. The complete list of prices, consumption, changes and price elasticity are presented in supplementary materials (Table S2).

Application to tobacco tax policy: projections of a $1 tax increase in 10 US states

Projected effects are presented in Table 3. With regard to economic burden, the projections suggested that a $1 increase would result in substantial savings in terms of health-care costs and lost productivity, with an average of $530.6 million. For tax revenue, the projections suggested uniform increases that were substantial in magnitude, with an average of $250.8 million. This was equally evident in proportionate effects, with an average of 162%.

DISCUSSION

The goal of this study was to use behavioral economics to inform tobacco tax policy by addressing previous methodological challenges and directly applying the findings to projected effects of various price increases. Consistent with laboratory-based behavioral economic studies, we found evidence that the cigarette demand curve was curvilinear in form, with periods of inelastic and elastic demand, and highly variable local price elasticities. Here, perhaps the most important finding was that a major influence on price effects came in the form of pack-level 'left-digit effects', or large magnitude influences on consumption based on the pack price transition from one whole-dollar amount to the next. For example, the change in pack price from $6.60 to $6.80 was associated with a 2.41% decrease in consumption (local elasticity = 0.80), but the change from $6.80 to $7 was associated with a 13.98% consumption decrease (local elasticity = 4.57). Although the adjacent prices both involved a 3% increase in price, the left-digit transition was associated with a fivefold greater level of elasticity. Indeed, as illustrated in Table 2, the price changes prior to a left-digit transition were consistently associated with inelastic demand, whereas the left-digit price transitions were consistently associated with elastic demand. Importantly, the prices were assessed sequentially and both the individual price and pack price were available, meaning that participants did not have incomplete information and were aware of the similarly sized intervals of price increases.

The disproportionate influence of left-digit effects has been established in relatively small experimental consumer research studies [27,28] and the strategy is ubiquitous in the market at large. However, no previous studies (to our knowledge) have detected left-digit effects in a sample of this size and in relation to tobacco demand. These findings suggest that policy makers and public health researchers should be aware of these price changes of disproportionate influence. Towards the goal of maximally reducing tobacco consumption, these data suggest that enacting tax changes to traverse whole-dollar pack prices will augment the success of tax increases alone. In other words, in the same way that tobacco companies and retailers may seek to make cigarettes more appealing with prices below left-digit transitions (e.g. $4.99/pack, $5.99/pack), these data suggest that tobacco control policies may similarly use an 'anti-marketing'

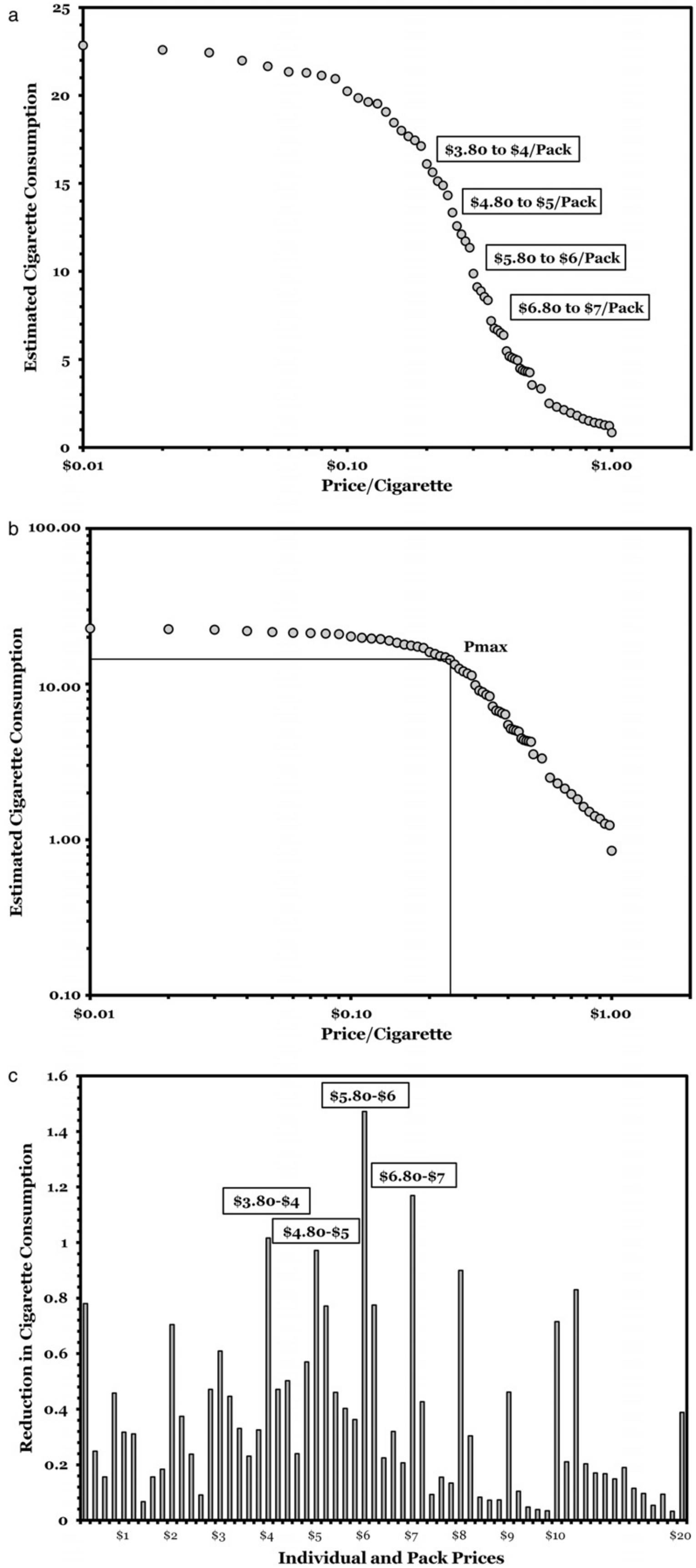

Figure 2 High-resolution tobacco demand in a large community sample of community smokers. (a) The overall empirical cigarette demand curve, $n = 1056$. All differences in consumption are statistically significant (*P*s < 0.05–0.00001). (b) The same data in proportionate (log–log) coordinates to clarify different phases of relative price sensitivity; the lines indicate the inflection point (P_{max}) of 24¢/cigarette. (c) Variation in the absolute magnitude of decreases in cigarette consumption across prices

Table 2 Illustrative effects of price increases on cigarette consumption across the demand curve, including changes across left-digit transitions, the two phases of the curve, and proportionate price doubling.

Unit prices	Pack prices	Means	Absolute decrease	% decrease	% price increase	%ΔC/%ΔP	Price sensitivity
		Illustrative left-digit transitions					
18–19¢	$3.60–3.80	17.45–17.12	0.32	1.86%	5.56%	0.34	Inelastic
19–20¢	$3.80–4.00	17.12–16.11	1.02	5.93%	5.26%	1.13	Elastic
23–24¢	$4.60–4.80	14.90–14.33	0.57	3.82%	4.35%	0.88	Inelastic
24–25¢	$4.80–5.00	14.33–13.36	0.97	6.78%	4.17%	1.63	Elastic
28–29¢	$5.60–5.80	11.72–11.36	0.36	3.09%	3.57%	0.87	Inelastic
29–30¢	$5.80–6.00	11.36–9.89	1.47	12.96%	3.45%	3.76	Elastic
33–34¢	$6.60–6.80	8.57–8.36	0.21	2.41%	3.03%	0.80	Inelastic
34–35¢	$6.80–7.00	8.36–7.19	1.17	13.98%	2.94%	4.75	Elastic
38–39¢	$7.60–7.80	6.52–6.38	0.13	2.05%	2.63%	0.78	Inelastic
39–40¢	$7.80–8.00	6.38–5.48	0.90	14.09%	2.56%	5.49	Elastic
43–44¢	$8.60–8.80	5.02–4.95	0.07	1.41%	2.33%	0.61	Inelastic
44–45¢	$8.80–9.00	4.95–4.49	0.46	9.32%	2.27%	4.10	Elastic
48–49¢	$9.60–9.80	4.30–4.27	0.03	0.79%	2.08%	0.38	Inelastic
49–50¢	$9.80–10.00	4.27–3.55	0.71	16.76%	2.04%	8.21	Elastic
		Two-phase demand curve price sensitivity					
1–24¢	20–4.80¢	22.84–14.33	8.52	37.28%	2300%	0.02	Inelastic
24–$1	$4.80–20	14.33–0.85	13.48	94.06%	316.67%	0.30	Inelastic
		Proportionate price doubling					
1–2¢	20–40¢	22.84–22.59	0.25	1.09%	100%	0.01	Inelastic
2–4¢	40–80¢	22.59–21.98	0.61	2.70%	100%	0.03	Inelastic
4–8¢	$80–1.60	21.98–21.13	0.85	3.87%	100%	0.04	Inelastic
8–16¢	$1.60–3.20	21.13–18.01	3.12	14.77%	100%	0.15	Inelastic
16–32¢	$3.20–6.40	18.01–8.89	9.12	50.64%	100%	0.51	Inelastic
32–62¢	$6.40–12.40	8.89–2.31	6.58	74.02%	94%	0.79	Inelastic

Note that rounding error makes the absolute decrease not always identical to the difference between two means.

strategy to make cigarettes less appealing by increasing pack prices into new whole-dollar amounts.

The second goal was to apply the data to a projected $1/pack tax increase in states that were most similar to the sample collected. These data converge with macroeconomic studies suggesting robust positive economic consequences of increasing tax rates (e.g. [14]). Projections suggested that the tax increase would generate substantial savings in health-care costs and lost productivity in all 10 states. Further, the tax increase was projected to increase tax revenue substantially in all 10 states in the year following the increase. In proportionate terms that adjust for state size, state tax revenues were predicted to at least double in all cases and, in some cases, more than triple. These data suggest that the short-term economic effects of this tax increase would yield a ‘win–win’ outcome by alleviating the economic burden of smoking and increasing tax revenue.

There are several important considerations that apply to the preceding findings. First, the primary assessment, the CPT, assessed estimated consumption, not actual consumption, raising the question of how well estimated consumption would reflect actual behavior if price changes were enacted. Previous behavioral economic studies have found evidence that there is a substantial overlap between choices for hypothetical and actual commodities [29–34]. This is putatively because the choices that are being made are for highly familiar commodities (e.g. cigarettes for daily smokers) that are organized in discrete and well-understood units (e.g. dollars, cigarettes). For these reasons, and based on the previous empirical studies [15–19], estimated consumption on the CPT is considered generally valid.

Importantly, however, close correspondence is not the same as perfect correspondence. At both individual level and the overall sample, the reported consumption preferences reflect *estimates* that, like other estimates in health economics, are assumed to be imperfect. For example, macroeconomic studies and computer simulations both include diverse sources of imperfect

Table 3 Projected effects of a $1 tax increase on tobacco-related economic-burden (health-care costs and lost productivity) and tax revenue in 10 US states based on the observed tobacco demand curve.

	Alabama	*Georgia*	*Idaho*	*Kentucky*	*Louisiana*	*North Carolina*	*North Dakota*	*South Carolina*	*Virginia*	*West Virginia*
2010 pack cost	$4.48	$4.37	$4.56	$4.45	$4.34	$4.53	$4.24	$4.56	$4.43	$4.45
State tax	$0.425	$0.37	$0.57	$0.60	$0.36	$0.45	$0.44	$0.57	$0.30	$0.55
2010 packs (millions)	336.8	544.0	71.8	477.4	333.5	577.3	44.9	385.5	543.3	205.6
	Effects on smoking-related economic burden									
CDC economic cost/pack	$8.97	$9.02	$7.84	$5.07	$8.82	$7.18	$10.48	$7.66	$6.27	$8.94
Pack price (% reduction)	*Savings in health-care costs/lost productivity (millions)*									
$4.40–4.60 (1.58%)	$47.7	$77.5	$8.9	$38.2	$46.5	$65.5	$7.4	$46.7	$53.8	$29.0
$4.40–4.80 (5.35%)	$161.6	$262.5	$30.1	$129.5	$157.4	$221.8	$25.2	$158.0	$182.2	$98.3
$4.40–5.00 (11.76%)	$355.3	$577.0	$66.2	$284.6	$345.9	$487.5	$55.3	$347.3	$400.6	$216.2
$4.40–5.20 (16.86%)	$509.4	$827.3	$94.9	$408.1	$495.9	$698.8	$79.3	$497.9	$574.3	$309.9
$4.40–5.40 (19.90%)	$601.2	$976.5	$112.0	$481.7	$585.4	$824.9	$93.6	$587.6	$677.9	$365.8
	Effects on state tax revenue									
2010 revenue (gross)	$144.8	$201.3	$40.9	$286.4	$120.1	$259.8	$19.8	$219.7	$163.0	$113.1
Pack price (% reduction)	*Change in state tax revenue (millions)*									
$4.40–4.60 (–1.58%)	+$64.0	+$103.9	+$13.5	+$89.4	+$63.7	+$109.5	+$8.5	+$72.4	+$104.4	+$38.7
$4.40–4.80 (–5.35%)	+$119.9	+$195.2	+$25.0	+$165.4	+$119.8	+$204.7	+$15.9	+$134.2	+$197.0	+$71.8
$4.40–5.00 (–11.76%)	+$161.5	+$264.3	+$33.2	+$219.1	+$162.4	+$275.1	+$21.4	+$178.3	+$268.5	+$95.6
$4.40–5.20 (–16.86%)	+$199.9	+$327.9	+$40.9	+$269.2	+$201.6	+$340.2	+$26.5	+$219.4	+$333.9	+$117.7
$4.40–5.40 (–19.90%)	+$241.3	+$395.7	+$49.4	+$325.4	+$243.2	+$410.7	+$32.0	+$265.1	+$402.7	+$142.2
Pack price (% reduction)	*Change in state tax revenue (%)*									
$4.40–4.60 (–1.58%)	45%	52%	33%	31%	53%	42%	43%	33%	64%	34%
$4.40–4.80 (–5.35%)	84%	97%	61%	58%	100%	79%	81%	61%	121%	63%
$4.40–5.00 (–11.76%)	113%	131%	81%	76%	135%	106%	109%	81%	165%	85%
$4.40–5.20 (–16.86%)	140%	163%	100%	94%	168%	131%	134%	100%	205%	104%
$4.40–5.40 (–19.90%)	169%	197%	121%	114%	203%	158%	162%	121%	247%	126%

CDC: Centers for Disease Control and Prevention.

estimation [7,35]. Thus, in each domain, the estimates are recognized as reflecting a combination of signal and noise. Imperfect estimation is another reason that multiple projections are useful to characterize alternative outcomes. As illustrated, if a $1 tax increase had only 60% of the predicted effect (i.e. individuals overestimating the consequences of price increases), the economic savings and revenue increases would, nonetheless, be very substantial. Moreover, it will be important to verify these findings using methods that examine choices for actual outcomes and, more generally, to ascertain the parameters of relationship between choices for hypothetical cigarettes and actual cigarettes. In other words, even if hypothetical CPT choices correspond substantially with choices for actual cigarettes in relative terms, there is a need for future studies to determine whether there is systematic overestimation or underestimation in absolute terms.

Several economic and policy considerations also apply. First, one assumption was that the tobacco industry would fully pass through the tax increase to consumers. This is generally consistent with empirical studies [7], but it is also possible that the industry would pass on more or less than the tax increase [36–38]. Table 3 also addresses how estimates would change if the tobacco industry absorbed some of the tax increase (for example, to avoid left-digit transitions in a market) and suggests that even if much of the tax increase was not passed through (i.e. undershifted), substantial savings and added tax revenue will remain. Secondly, for savings in health-care costs and lost productivity, another factor that may play a role is that a portion of smokers may not reduce consumption but switch to low-cost brands. However, previous studies do not suggest this happens extensively and increased taxation reduces price differences between brands [39,40], thus actually reducing the probability of brand substitution. Nonetheless, as with the previous consideration, the data suggest that even if this happens to an extent, the alleviation of tobacco-related economic burden would be substantial. Thirdly, with regard to generalizability, it is important to keep in mind that these data are most applicable to smokers in the United States and other high-income countries and may not apply to low- or middle-income countries. For example, the pack-level left-digit effects may be specific to catchment areas where the pack is the most common unit of purchase. Similarly, a CPT presumes an approximately 7th grade level of literacy and may not be viable in samples with low levels of literacy, regardless of the overall country income level. Finally, a consequence of increasing taxes is the prospect of increased black market sales, such as inter-jurisdictional trafficking (e.g. smuggling cigarettes across state lines for resale). Although this is a legitimate concern, the empirical evidence suggests that risk of extensive cross-border smuggling, at least in developed countries, is both exaggerated by the tobacco industry [41] and can be substantially controlled [42].

These issues also raise the important point that although tax policy is one of the most powerful tobacco control tools, it is not a finely calibrated instrument. Tobacco taxation optimally ought to take place as part of a coordinated tobacco control strategy that also includes comprehensive clean air laws, strategies to minimize black market sales and availability of efficacious prevention and treatment programs. Indeed, low-cost access to efficacious treatment may be critical for low-income or otherwise marginalized individuals [43,44]. Thus, although increased tobacco taxes may generate additional revenue, an optimal multi-pronged tobacco control strategy will also require funding for enforcement and resources for prevention and cessation. From the standpoint of Pigouvian taxation (i.e. taxes to offset unaddressed costs associated with consumption of the commodity), for which a tobacco tax can be considered prototypic, a logical use of additional revenue would be in these domains, but that is ultimately a policy decision.

The current study applied behavioral economics to understand tobacco demand more clearly and to inform tobacco tax policy. The high-resolution CPT brought the tobacco demand curve into sharp relief and revealed particular regions of sensitivity, especially at the pack-level interface between whole-dollar amounts. When extrapolated to a potential tax increase, the data suggested substantial reductions in the economic burden of smoking and substantial increases in short-term tax revenue. Finally, the need for applying behavioral economic methodologies to public policy is increasingly discussed [45] and the current study provides proof-of-concept that scaling-up behavioral economic paradigms is both feasible and may indeed yield novel insights.

Declarations of interest

All authors declare they have no conflicts of interest. JM currently receives grant funding from NIH and the National Center for Responsible Gaming and serves as a consultant to NIH grants. JGM currently receives grant funding from NIH and serves as a consultant to NIH grants. FC currently receives grant funding from NIH, the Robert Wood Johnson Foundation, the Bill and Melinda Gates Foundation, the YMCA of the USA, the US Department of Agriculture, Canadian Institute of Health Research, the National Institutes on Cancer (Canada), and the American Legacy Foundation.

Acknowledgements

This project was supported partially by grants from the Substance Abuse Policy Research Program of the

Robert Wood Johnson Foundation (J.M.) and the National Institutes of Health (NIH) (K23 AA016936; J.M.). The sponsors played no role in study design, data collection, data analysis, interpretation or manuscript preparation. The authors thank University of Georgia Health Economics Workgroup and Dr Keith Campbell for constructive input on an early presentation of these data.

References

1. Centers for Disease Control and Prevention. Smoking-attributable mortality, years of potential life lost, and productivity losses—United States, 2000–2004. *Morb Mortal Wkly Rep* 2008; **57**: 1226–8.
2. World Health Organization. *WHO Report on the Global Tobacco Epidemic 2011: Warning about the Dangers of Tobacco*. Washington, DC: World Health Organization; 2011.
3. Mokdad A. H., Marks J. S., Stroup D. F., Gerberding J. L. Actual causes of death in the United States, 2000. *JAMA* 2004; **291**: 1238–45.
4. Centers for Disease Control and Prevention. Cigarette smoking among adults—United States, 2000. *Morb Mortal Wkly Rep* 2002; **51**: 642–5.
5. Centers for Disease Control and Prevention. *National Center for Health Statistics with Chartbook on Trends in the Health of Americans*. Hyattsville, MD: US Department of Health and Human Services; 2004.
6. Chaloupka F. J., Straif K., Leon M. E.; Working Group, International Agency for Research on Cancer. Effectiveness of tax and price policies in tobacco control. *Tob Control* 2011; **20**: 235–8.
7. Chaloupka F. J., Hu T., Warner K. E., Jacobs R., Yurekli A. The taxation of tobacco products. In: Jha P., Chaloupka F. J., editors. *Tobacco Control in Developing Countries*. Oxford: Oxford University Press; 2000, p. 237–72.
8. Johnson M. W., Bickel W. K. The behavioral economics of cigarette smoking: the concurrent presence of a substitute and an independent reinforcer. *Behav Pharmacol* 2003; **14**: 137–44.
9. Johnson M. W., Bickel W. K. Replacing relative reinforcing efficacy with behavioral economic demand curves. *J Exp Anal Behav* 2006; **85**: 73–93.
10. DeGrandpre R. J., Bickel W. K., Hughes J. R., Higgins S. T. Behavioral economics of drug self-administration: III. A reanalysis of the nicotine regulation hypothesis. *Psychopharmacology (Berl)* 1992; **108**: 1–10.
11. Bickel W. K., Marsch L. A., Carroll M. E. Deconstructing relative reinforcing efficacy and situating the measures of pharmacological reinforcement with behavioral economics: a theoretical proposal. *Psychopharmacology (Berl)* 2000; **153**: 44–56.
12. Mackillop J., Murphy J. G., Tidey J. W., Kahler C. W., Ray L. A., Bickel W. K. Latent structure of facets of alcohol reinforcement from a behavioral economic demand curve. *Psychopharmacology (Berl)* 2009; **203**: 33–40.
13. Hursh S. R., Galuska C. M., Winger G., Woods J. H. The economics of drug abuse: a quantitative assessment of drug demand. *Mol Interv* 2005; **5**: 20–8.
14. Chaloupka F. J., Yurekli A., Fong G. T. Tobacco taxes as a tobacco control strategy. *Tob Control* 2012; **21**: 172–80.
15. MacKillop J., Murphy J. G., Ray L. A., Eisenberg D. T., Lisman S. A., Lum J. K. *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**: 57–65.
16. Murphy J. G., MacKillop J., Tidey J. W., Brazil L. A., Colby S. M. Validity of a demand curve measure of nicotine reinforcement with adolescent smokers. *Drug Alcohol Depend* 2011; **113**: 207–14.
17. Jacobs E. A., Bickel W. K. Modeling drug consumption in the clinic using simulation procedures: demand for heroin and cigarettes in opioid-dependent outpatients. *Exp Clin Psychopharmacol* 1999; **7**: 412–26.
18. Mackillop J., Tidey J. W. Cigarette demand and delayed reward discounting in nicotine-dependent individuals with schizophrenia and controls: an initial study. *Psychopharmacology (Berl)* 2011; **216**: 91–9.
19. Few L. R., Acker J., Murphy C., MacKillop J. Temporal stability of a cigarette purchase task. *Nicotine Tob Res* 2012; **14**: 761–5.
20. Armour B. S., Campbell V. A., Crews J. E., Malarcher A., Maurice E., Richard R. A. State-level prevalence of cigarette smoking and treatment advice, by disability status, United States, 2004. *Prev Chronic Dis* 2007; **4**: A86.
21. Centers for Disease Control and Prevention. State smoke-free laws for worksites, restaurants, and bars—United States, 2000–2010. *Morb Mortal Wkly Rep* 2011; **60**: 472–5.
22. Heatherton T. F., Kozlowski L. T., Frecker R. C., Fagerström K. O. The Fagerstrom Test for Nicotine Dependence: a revision of the Fagerström Tolerance Questionnaire. *Br J Addict* 1991; **86**: 1119–27.
23. Tabachnick B. G., Fidell L. S. *Using Multivariate Statistics*, 5th edn. Needham Heights, MA: Allyn & Bacon; 2004.
24. Hursh S. R., Silberberg A. Economic demand and essential value. *Psychol Rev* 2008; **115**: 186–98.
25. Murphy J. G., MacKillop J. Relative reinforcing efficacy of alcohol among college student drinkers. *Exp Clin Psychopharmacol* 2006; **14**: 219–27.
26. Boonn A. *State Cigarette Tax Rates and Rank, Date of Last increase, Annual Pack Sales and Revenues, and Related Data*. Washington, DC: Campaign for Tobacco-Free Kids; 2011.
27. Manning K. C., Sprott D. E. Price endings, left-digit effects, and choice. *J Consum Res* 2009; **36**: 328–35.
28. Thomas M., Morwitz V. Penny wise and pound foolish: the left-digit effect in price cognition. *J Consum Res* 2005; **32**: 54–64.
29. Johnson M. W., Bickel W. K. Within-subject comparison of real and hypothetical money rewards in delay discounting. *J Exp Anal Behav* 2002; **77**: 129–46.
30. Madden G. J., Begotka A. M., Raiff B. R., Kastern L. L. Delay discounting of real and hypothetical rewards. *Exp Clin Psychopharmacol* 2003; **11**: 139–45.
31. Madden G. J., Raiff B. R., Lagorio C. H., Begotka A. M., Mueller A. M., Hehli D. J. *et al*. Delay discounting of potentially real and hypothetical rewards: II. Between- and within-subject comparisons. *Exp Clin Psychopharmacol* 2004; **12**: 251–61.
32. Lagorio C. H., Madden G. J. Delay discounting of real and hypothetical rewards III: steady-state assessments, forced-choice trials, and all real rewards. *Behav Processes* 2005; **69**: 173–87.
33. Bickel W. K., Pitcock J. A., Yi R., Angtuaco E. J. Congruence of BOLD response across intertemporal choice conditions: fictive and real money gains and losses. *J Neurosci* 2009; **29**: 8839–46.

34. Amlung M. T., Acker J., Stojek M. K., Murphy J. G., 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**: 716–24.
35. Levy D. T., Chaloupka F., Gitchell J., Mendez D., Warner K. E. The use of simulation models for the surveillance, justification and understanding of tobacco control policies. *Health Care Manag Sci* 2002; **5**: 113–20.
36. Keeler T. E., Hu T. W., Barnett P. G., Manning W. G., Sung H. Y. Do cigarette producers price-discriminate by state? An empirical analysis of local cigarette pricing and taxation. *J Health Econ* 1996; **15**: 499–512.
37. Hanson A., Sullivan R. The incidence of tobacco taxation: evidence from geographic micro-level data. *Natl Tax J* 2009; **62**: 677–98.
38. Harding M., Leibtag E., Lovenheim M. F. The heterogeneous geographic and socioeconomic incidence of cigarette taxes: evidence from Nielsen homescan data. *Am Econ J Econ Policy*; in press; 2012.
39. Jha P., Chaloupka F. *Curbing the Epidemic Governments and the Economics of Tobacco Control*. Washington, DC: World Bank; 1999.
40. World Health Organization. *Building Blocks for Tobacco Control: A Handbook*. Geneva, Switzerland: World Health Organization; 2004.
41. Warner K. E. The economics of tobacco: myths and realities. *Tob Control* 2000; **9**: 78–89.
42. Joossens L., Raw M. Progress in combating cigarette smuggling: controlling the supply chain. *Tob Control* 2008; **17**: 399–404.
43. Bitton A., Eyal N. Too poor to treat? The complex ethics of cost-effective tobacco control. *Public Health Ethics* 2011; **4**: 109–20.
44. West R., McNeill A., Britton J., Bauld L., Raw M., Hajek P. *et al*. Should smokers be offered assistance with stopping? *Addiction* 2010; **105**: 1867–9.
45. Amir O., Ariely D., Cooke A., Dunning D., Epley N., Koszegi B. *et al*. Psychology, behavioral economics, and public policy. *Mark Lett* 2005; **16**: 443–54.

Supporting information

Additional Supporting Information may be found in the online version of this article:

Table S1 Demographics by site.
Table S2 Comprehensive cigarette consumption by price data.

Please note: Wiley-Blackwell are not responsible for the content or functionality of any supporting materials supplied by the authors. Any queries (other than missing material) should be directed to the corresponding author for the article.

