The Heterogeneity of the Cigarette Price Effect on Body Mass Index

George L. Wehby* and Charles J. Courtemanche†

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Abstract:

Several previous studies have estimated the average effect of cigarette price on body mass index (BMI), with recent research showing that the different methodologies used in the literature all point to a negative effect after several years. This literature, however, ignores the possibility that the price of cigarettes may impact body weight differently throughout the weight distribution or across socioeconomic and demographic groups due to differences in underlying preferences for health or risk factors for obesity. We evaluate heterogeneity in the long-run effect of cigarette price on BMI by performing quantile regressions and stratifying the sample by race, education, sex and age. Cigarette price has a highly heterogeneous negative effect that is more than three times as strong at high levels of BMI – where weight loss is most beneficial for health – than at low levels. Stratifying by race reveals that the largest price effects are for severely obese black individuals, who respond to a permanent one dollar increase in cigarette prices by losing 0.8 units of BMI. This result suggests rising cigarette prices may have mitigated racial disparities in obesity. Education increases price responsiveness on average, though severely obese individuals without a high school degree are affected similarly to severely obese college graduates. Higher cigarette prices may therefore have increased obesity disparities by education. Price effects are largest for individuals 40-59 years of age and are generally insignificant for individuals 60 years or older. Finally, females are more price responsive than males.

Keywords: obesity, body mass index, racial disparities, smoking, cigarette prices, cigarette taxes, quantile regression

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* Corresponding author. Department of Health Management and Policy, College of Public Health, University of Iowa, 200 Hawkins Drive, E205 GH, Iowa City, IA 52242. Phone: 319- 384-5133. Email: george-wehby@uiowa.edu

† Department of Economics, College of Business, University of Louisville, Louisville, KY 40292 and National Bureau of Economic Research, Cambridge, MA. Phone: 502-852-4854. Email: cjcour02@louisville.edu

I. Introduction

Obesity has become one of the leading population-level health risks in the United States. Not only is the prevalence high, but obesity rates have increased significantly and steadily in recent decades, from 15% in the early 1970s to 34% in 2007-2008 (CDC, 2010; Flegal et al., 2010). Obesity-related illnesses such as heart disease and diabetes now lead to an estimated 112,000 deaths and $168.4 billion in medical expenditures per year (Cawley and Meyerhoefer, 2010; Flegal et al., 2010; Sturm, 2002).[1] This has prompted a major research effort to explain the rising incidence of obesity, including an investigation of whether changes in other health characteristics or behaviors may have played a role.

The most notable population-level health behavior change concurrent with the rise in obesity was a dramatic decline in cigarette smoking. Between 1965 and 2007, the smoking rate among adults in the US decreased from 42% to 20% (CDC, 2010). The simultaneous nature of the trends in smoking and obesity raises the question of whether the two are causally related. This question is further motivated by the potential biologic pathways through which smoking could affect body weight. Smoking may reduce appetite and enhance metabolism, leading to lower caloric intake and higher caloric expenditure (Pinkowish, 1999). This theory is supported by mice studies that show reductions in appetite, weight, and fat storage as well as biochemical changes in the brain with nicotine exposure (Chen et al., 2008; Chen et al., 2005). However, other factors suggest the opposite or no effect of smoking on obesity. Smoking may reduce the ability to exercise by impairing respiratory functioning (Hedenstrom et al., 1986). Also, quitting smoking could indirectly lead to healthier eating and exercise decisions by affecting expected longevity or general enthusiasm about health (Courtemanche, 2009). Furthermore, the drop in smoking is unlikely to explain the rise in childhood obesity unless changes in weight among adults caused by the decrease in smoking influence weight in children.

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[1] An individual is considered obese if her body mass index (BMI), or weight in kilograms divided by height in squared meters, is greater than or equal to 30.

Motivated by this theoretical ambiguity, several recent economic studies have attempted to determine the causal effect of cigarette costs on weight.[2] Chou et al. (2002; 2004) estimate positive relationships between state cigarette price and both body mass index and obesity using the Behavioral Risk Factor Surveillance System (BRFSS) and models that include state fixed effects, a quadratic time trend (or no time trend), and a set of control variables. Gruber and Frakes (2006) show that replacing cigarette price with state cigarette tax rate and the quadratic time trend with time period fixed effects switches the sign of the effect to negative. Rashad et al. (2006) use a methodology similar to Gruber and Frakes but a different dataset – the National Health and Nutrition Examination Survey (NHANES) – and estimate a small positive effect of cigarette taxes on weight. Nonnemaker et al. (2009) use the BRFSS and find that including linear state-specific time trends leads to the estimation of a small and insignificant relationship between cigarette costs and weight across the population using either price or tax as an instrument for price. Baum (2009) considers the National Longitudinal Survey of Youth (NLSY) and a difference-in-difference approach where the "treatment" group consists of individuals who have smoked at least 100 cigarettes in their life and are therefore most likely to be responsive to cigarette costs. He estimates a positive effect of cigarette costs on weight regardless of whether the other features of the model are similar to those of Chou et al. (2002; 2004) or Gruber and Frakes (2006). Most recently, Courtemanche (2009) notes that the aforementioned papers only study the impact of contemporaneous cigarette costs, which may be insufficient to capture the entire long-run effect since reductions in smoking may lag price increases while changes in eating and exercise habits may lag reductions in smoking. He uses both the NLSY and BRFSS and shows that all the different methodologies used in the literature point to a

[2] See Courtemanche (2009) for a more detailed description of the models used by the different papers in the literature.

negative long-run effect of cigarette costs on weight if the effect is allowed to occur slowly over a six year period.[3]

A limitation common to all of these studies is a focus on the effects of cigarette costs on the mean of BMI or obesity status. While informative, focusing on "mean effects" may mask substantial heterogeneity in the effects of cigarette costs across the population. This heterogeneity may result from differences in biologic, demographic, socioeconomic, and environmental factors as well as in preferences for body weight. Evaluating if cigarette costs have heterogeneous effects is necessary to understand changes in the entire BMI distribution – as opposed to merely one moment of the distribution – and also to identify the groups that are most affected by these changes.

While heterogeneity by observed characteristics can be easily evaluated by stratifying the study sample, much of the heterogeneity may result from unobserved characteristics. Observable socioeconomic and behavioral characteristics explain only a small portion of the variation in body weight – generally less than 15%. Twin studies provide evidence of a high genetic heritability of about 80% for body mass index (BMI) and 73% for obesity (Hjelmborg et al., 2008; Watson et al., 2006). Some genes, such as *FTO* (Dina et al., 2007; Frayling et al., 2007; Kring et al., 2008; Scuteri et al., 2007; Villalobos-Comparan et al., 2008) and *MCR4* (Loos et al., 2008; Qi et al., 2008; Willer et al., 2009), have been found to have consistent effects on body weight but explain a very small percentage of the variation. Most of the variation in weight across individuals therefore can be attributed to unobserved family influences or person-specific factors.

Given that most of the determinants of obesity are still generally unknown, identifying the heterogeneity due to unobserved characteristics is critical to our understanding of how different types of people respond differently to changing cigarette costs. In this study, we identify the

[3] Other related research shows that overweight or obese female adolescents are more likely to initiate smoking, perhaps as a method of weight control (Cawley et al., 2004; Rees and Sabia, 2010).

heterogeneity in the effect of cigarette price on BMI due to unobservable characteristics by using quantile regression, a semi-parametric technique that estimates the impacts at different locations along the BMI distribution. We conduct quantile regressions for the total sample as well as for subsamples stratified by race, education, age, and sex, observable characteristics that have been shown to influence BMI. To our knowledge this is the first paper in the cigarette costs/body weight literature to either utilize quantile regression or examine heterogeneity on the bases of race, education, or age.[4]

Using a quantile version of Courtemanche's (2009) preferred specification, we find evidence that the long-run effect of cigarette price on BMI, while consistently negative, is more than three times as strong at high levels of BMI than at low levels. The health benefits from the reduction in population weight due to higher cigarette prices are therefore more substantial than estimates of mean effects would suggest. Stratifying by race shows that the largest responses occur among severely obese black individuals, who lose 0.8 units of BMI within six years following a permanent one-dollar increase in the price of a pack of cigarettes. Rising cigarette prices may therefore have helped to ameliorate racial disparities in obesity. Education strengthens the cigarette price effect on average but severely obese individuals without a high school degree respond similarly to severely obese college graduates. Nonetheless, increasing cigarette prices have worsened obesity disparities by socioeconomic status over the past two decades. Middle age (40-59) adults are most responsive to cigarette prices while older adults (≥60) are much less sensitive to price changes. Finally, females are slightly more sensitive to cigarette prices than males

[4] Fang et al. (2009) evaluated the effects of smoking on BMI quantiles using prices as instruments for smoking and data from China. However, the instrumental variable approach employed in that study is inconsistent for quantile regression (Chernozhukov and Hansen, 2004; Chernozhukov and Hansen, 2005) and the study does not report a reduced-form model that evaluates the effect of cigarette prices on BMI quantiles.

II. Methods

Data

The literature on the effect of cigarette cost on body weight utilizes three different individual-level datasets: the pooled cross-sectional BRFSS (Chou, 2002; Chou et al., 2004; Courtemanche, 2009; Gruber and Frakes, 2006; Nonnemaker, 2009), the NHANES (Rashad, 2006), and the panel National Longitudinal Survey of Youth (Baum, 2009; Courtemanche, 2009). The advantage of the BRFSS is its enormous sample size, which numbers in the millions as opposed to the tens-of-thousands for the NHANES and NLSY. A large sample is necessary for the precise estimation of the impacts of aggregate-level covariates such as state cigarette price. The advantage of the NHANES is its inclusion of actual, as opposed to merely self-reported, height and weight. The advantage of the NLSY is its panel nature, which enables the inclusion of individual (rather than just state) fixed effects and the tracking of movement between states over time, which reduces measurement error when creating lagged cigarette cost variables.

A large sample size is of paramount importance when splitting the sample into race, age, and education groups and employing quantile regression, so we utilize the BRFSS in this study. Results from the literature suggest that this decision is unlikely to lead to inappropriate conclusions. Courtemanche (2009) found that the estimated average effects were similar using both the NLSY and BRFSS but that the BRFSS estimates were more precise. The NLSY regressions' use of individual as opposed to state fixed effects and tracking of between-state moves therefore did not meaningfully impact the results. This is not surprising, as the cigarette cost variables are state-level while only a fraction of individuals switch states over a six year period. The literature also shows that results from the BRFSS are not sensitive to the correction of self-reported height and weight for measurement error, so using the NHANES' actual height and weight does not appear to be necessary.[5]

We utilize the 1984 to 2005 waves of the BRFSS, a telephone survey of the health conditions and risky behaviors of randomly-selected individuals conducted by state health departments and the Center for Disease Control. Only 15 states participated in 1984, but this number steadily grew to 40 by 1989 and all 50 by 1996. The number of survey respondents also increased over time, from 12,258 in 1984 to 356,112 in 2005. We compute BMI based on the respondents' self-reported height and weight. The BRFSS also includes a variety of demographic information that we use to construct a set of control variables. These variables include age, age squared, income, income squared, and dummies for gender, race, marital status, and education.

We measure cigarette costs with annual state-level cigarette prices from *The Tax Burden on Tobacco* (Orzechowski and Walker 2006). These prices are retail and inclusive of state and federal excise taxes. After 1989, The Tax Burden on Tobacco reported prices both including and excluding generic brands. We follow convention in the literature and use the series excluding generics. We adjust prices for inflation using the Consumer Price Index for all urban consumers from the Bureau of Labor Statistics.

After merging the individual- and state-level datasets and dropping observations with missing variables, our sample size is 2,428,009. Table 1 gives descriptions and summary statistics for the study variables.

[5] Specifically, Cawley (1999) introduced a "correction" for self-reported BMI that involves using the NHANES to estimate actual BMI as a function of self-reported BMI. Gruber and Frakes' (2006) dataset does not employ this correction, but they show that their specification changes lead to virtually identical results using Chou et al.'s (2002 and 2004) data, which does use the correction. The conclusions reached using the BRFSS are therefore not sensitive to the utilization of the correction, so we do not use it in this paper.

Empirical Model and Estimation

We study the effect of cigarette price on body mass index (BMI) by modifying the preferred specification of Courtemanche (2009) to account for heterogeneity throughout the BMI distribution and by race, gender, age, and education. We adopt the approach of Courtemanche (2009) because he showed that the other methodologies used in the literature all point to negative long-run average effects of cigarette costs on BMI and probability of being obese once lagged costs are included in the model. He began by adding lagged costs to the models of Chou et al. (2002 and 2004) (cigarette price and a quadratic time trend) and Gruber and Frakes (2006) (cigarette tax and time period fixed effects) and showing that both methodologies estimated negative effects after six years. His initial regressions used NLSY data, included individual fixed effects plus demographic controls, and modeled cigarette costs with three two-year moving averages (price/tax in years *t* to *t-1*, *t-2* to *t-3*, and *t-4* to *t-5*). Continuing to use both the Chou et al. and Gruber and Frakes approaches to modeling cigarette costs and time, he then demonstrated the robustness of these results to a number of specification changes:

- Adding linear state-specific time trends (similarly to Nonnemaker et al. 2009);
- Adding per capita number of fitness and sports clubs in the state as a proxy for the state's demand for health;
- Accounting for unobserved heterogeneity with differencing methods instead of fixed effects;
- Implementing the difference-in-difference approach of Baum (2009) (using those who smoked 100 cigarettes in their life by the start of the panel as the treatment group);
- Modeling price/tax as only one moving average spanning years *t* to *t-5*;
- Modeling price/tax as only one moving average spanning years *t-4* to *t-5*;
- Allowing the effect to occur over 8, 10, or 12 years instead of 6;

- Using the BRFSS instead of the NLSY, necessitating the use of state instead of individual fixed effects; and
- Using the BRFSS and aggregating all variables to the state level.

He also conducted a back-of-the-envelope calculation to verify the plausibility of the magnitude of the estimated effect. Finally, he attempted to explain the direction and timing of the impact by using the BRFSS to link increases in cigarette prices to somewhat delayed declines in smoking and even more delayed increases in exercise and reductions in dietary fat intake.[6] He concluded that successfully quitting smoking may lead to a renewed interest in health that translates in the long run to improvements in eating and exercise habits. These indirect behavioral changes appear to eventually outweigh the direct biological changes that point in the direction of weight gain.

After establishing the robustness of the results to alternative specifications, Courtemanche (2009; p. 794) settled on a preferred model that includes as covariates average state cigarette prices over years *t* to *t-1*, *t-2* to *t-3*, and *t-4* to *t-5*; the demographic controls we describe in Table 1; and state and year fixed effects. We adopt this approach in our analysis of heterogeneity. Our only change is that, in order to enable clearer presentation of the quantile and subsample results, we use one six-year moving average spanning *t* to *t-5* rather than three two-year averages; this does not meaningfully impact the results.

We evaluate the heterogeneity in the cigarette price effect at various locations of the BMI distribution by unobserved characteristics that affect BMI using quantile regression (QR). The QR model estimates the conditional distribution of BMI quantiles as a function of cigarette price and other covariates and identifies their effects on BMI at various quantiles. These quantile treatment effects (QTE) may be interpreted as effects at different levels of the net value of all

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[6] Specifically, average price over years *t* and *t-1* impacted cigarettes smoked per day among smokers but average price over years *t-4* and *t-5* had the strongest effects on probability of being a smoker. This suggests smokers initially respond to higher prices by cutting back but are not able to quit altogether until years later. Only average price over years *t-4* and *t-5* statistically impacted exercise or fruit and vegetable intake.

unobserved characteristics that determine the rank of an individual on the BMI distribution, conditional on the observed characteristics, and may include biologic/genetic, demographic, socioeconomic, and environmental factors. Our QR model can be characterized as follows:

$$W_{ist} = \mathrm{Q}(\overline{P}_{st}, \mathbf{X}_{ist}, \mathbf{S}_s, \mathbf{Y}_t, U_{ist}), \qquad (1)$$

where W_{ist} is the BMI of individual *i* living in state *s* in year *t*, while Q is the conditional quantile distribution. $\overline{P}_{st}$ is average inflation-adjusted state cigarette price, defined as

$$\overline{P}_{st} = \frac{P_{st} + P_{s,t-1} + P_{s,t-2} + P_{s,t-3} + P_{s,t-4} + P_{s,t-5}}{6}. \qquad (2)$$

$\mathbf{X}_{ist}$ is a vector of individual demographic and socioeconomic characteristics consisting of age (and age squared), race, sex, marital status, education, and inflation-adjusted household income (and income squared). $\mathbf{S}_s$ and $\mathbf{Y}_t$ denote dummy variables for state of residence and survey year. Finally, $U_{ist} \sim (0,1)$ is a uniformly distributed ranking variable that determines individual *i*'s rank on the BMI distribution, conditional on the control variables, and therefore represents the net level of all unobserved characteristics that are relevant for this rank. For each quantile *q* of BMI such that 0<*q*<1, $\mathrm{Q}(\overline{P}_{st}, \mathbf{X}_{ist}, \mathbf{S}_s, \mathbf{Y}_t, q)$ is the value of the conditional *q*th BMI quantile. Since the effects of cigarette prices on BMI are estimated holding *U*, the net level of the unobserved characteristics relevant to the individual's BMI rank, constant at *q,* the QTE at different *q* represent effects on BMI at different levels of these characteristics. In other words, the heterogeneity in effects of cigarette prices and other model variables on BMI by *U* can be evaluated by estimating the QTE at different quantiles as:

$$W_{ist} = \mathrm{Q}(\alpha_{0q} + \beta_q \overline{P}_{st} + \mathbf{X}_{ist}\boldsymbol{\gamma}_q + \mathbf{S}_s\boldsymbol{\lambda}_q + \mathbf{Y}_t\boldsymbol{\kappa}_q + \varepsilon_{ist}) \qquad (3)$$

where β_q represents the effects of cigarette prices at quantile q of BMI, $\boldsymbol{\gamma}_q$ is a vector of the effects of the control individual-level variables, $\boldsymbol{\lambda}_q$ and $\boldsymbol{\kappa}_q$ are vectors of the state and year fixed effects, respectively, and ε_{ist} is the error term.

The state and year fixed effects capture unobserved state-level determinants of BMI that are stable over time as well as unobserved year-to-year changes in BMI that are shared by all states. A natural concern with this model is whether changes over time in unobserved state-level characteristics, such as demand for health, could lead to omitted variable bias by influencing both cigarette prices and population weight. However, the large number of robustness checks performed by Courtemanche (2009) – especially the state trends and difference-in-difference models that explicitly accounted for time-variant unobservable state characteristics – help to rule out this possibility. Since our data span the same geographic area and time period, we do not recreate these robustness checks and instead refer the reader to Courtemanche (2009) for further detail.

QR is estimated by minimizing a weighted sum of the absolute deviations of the actual BMI values from conditional values for each *q* across all individuals in the sample (Koenker and Bassett 1978; Koenker and Hallock 2001):

$$\min[q \sum_{W_i \geq Q_i}^{n} |W_i - Q_i| + (1-q) \sum_{W_i < Q_i}^{n} |W_i - Q_i|] \quad (4),$$

where *n* is the total number of individuals.

We estimate the *QR* model for the following five BMI quantiles that are expected to provide adequate coverage of the entire BMI distribution: 0.1, 0.25, 0.5, 0.75 and 0.9. In order to test for differences in cigarette price effects between these quantiles, we estimate the variance-covariance matrices of the QR models simultaneously using 200 bootstrap replications, which are sufficient to obtain accurate estimates of the standard errors (Hao and Naiman 2007).

As a reference point, we also estimate the BMI reduced-form function using OLS in order to compare the cigarette price effects at the mean of BMI as has been calculated in previous studies to the effects at the five quantiles. For OLS, we estimate standard errors that are clustered by state (Moulton 1986). Probability sampling weights cannot be employed in the QR estimation. In unreported regressions, we estimate alternative OLS models that employ the probability sampling weights and find similar cigarette price effects to the unweighted models. We estimate all models for the total sample and stratified by race, education level, age, and sex.

III. Results

Table 2 reports the effect of cigarette price averaged over a six-year period on the mean of BMI and the five BMI quantiles, first for the total sample and then for the subsamples.[7] Cigarette price has a significant negative effect on BMI that monotonically increases (in absolute value) by the quantile order and is significantly larger at higher than lower quantiles in the total sample and most stratified samples. In the total sample, a one-dollar increase in prices reduces BMI by 0.12, 0.2, 0.28, 0.37 and 0.39 units at the 0.1, 0.25, 0.5, 0.75 and 0.9 quantiles, respectively; these effects are significantly different from each other (at $p<0.01$). The effect at the mean is generally similar to the effect at the median (0.5 quantile). Since the health benefits from weight loss are greatest for overweight and obese individuals, these results imply that higher cigarette prices are even more beneficial for health than focusing on mean effects alone would suggest.

Effects by Demographic and Socioeconomic Characteristics

Stratifying by race, the largest price effects are for black individuals, especially those at high BMI quantiles. A one-dollar increase in cigarette price reduces BMI by 0.76 and 0.58 units at the 0.9 and 0.75 quantiles, respectively, compared to a decrease of 0.17 units at the 0.1

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[7] The estimated effects of the control variables from the full sample regressions are given in Table A1 in the appendix.

quantile and 0.36 units at the median (0.36 unit decrease at the mean). Smaller cigarette price effects are observed for whites and those of a race other than white or black. Among whites, a one-dollar price increase reduces BMI by 0.32, 0.28 and 0.14 at the 0.9, 0.5 and 0.1 quantiles. Among individuals of another race, a one dollar increase in price reduces the 0.9 and 0.5 quantiles of BMI by 0.34 and 0.17 units, but has a smaller and insignificant effect at the 0.1 quantile. Effects are overall significantly different between the quantiles.

Stratifying by highest grade completed reveals that education increases price responsiveness at BMI quantiles 0.1 through 0.75 but not at the 0.9 BMI quantile. For example, cigarette prices have small and insignificant effects on BMI at the 0.1 quantile among individuals of high school education or less, but have a larger and significant effect at the 0.1 quantile for individuals of higher education with a one dollar increase in price reducing BMI by 0.13 units. Similarly, at the median cigarette prices have a small and insignificant impact on the BMI of individuals who did not complete high school, but have larger and significant effects for more educated individuals with a 0.23-0.26 decrease in BMI. In contrast, cigarette prices have the largest impacts at the 0.9 quantile for individuals who have less than a high school education and for college graduates, decreasing their BMI by 0.44-0.45 units per one-dollar price increase, compared to decreases of 0.2-0.3 units for individuals with intermediate education. The cigarette price effects are significantly different between the five quantiles for all education subgroups.

Cigarette prices have larger effects for younger (≤59) than older (≥60) adults at the mean and all evaluated quantiles. The largest cigarette price effects on BMI are at the 0.9 quantile for middle age adults (40-59), where a one-dollar price increase reduces BMI by 0.82 units, compared to a 0.6-unit BMI decrease for young individuals (<40) and a much smaller and insignificant decrease for older adults. The price effects at the mean are also largest for middle age adults, where BMI is reduced by 0.45 units with a one-dollar price increase, compared to a 0.36-unit decrease for individuals younger than 40 years. Except for a small effect at the 0.25

quantile, cigarette prices are generally not statistically associated with BMI for older adults. The price effects are significantly different between the five quantiles for ages of less than 59 years.

Finally, cigarette prices have slightly larger effects for females than males, with the largest difference at the BMI median, where a one-dollar price increase reduces BMI by 0.33 units for females and 0.23 units for males. Similarly to the total sample and other stratified samples, cigarette price effects are overall significantly larger at higher than lower quantiles for both females and males.

Implications for Disparities

The first column of Table 3 reports the sample obesity rates by race, education, age and sex. Significant disparities in obesity are observed by these characteristics. About 30.4% of black individuals are obese compared to 18.3% of whites. Obesity rates decrease with education, with 24.7% of individuals with less than a completed high school education being obese compared to 15.2% of college graduates. Obesity rates are highest for middle age adults (40-59) and lowest for young adults (<40), and are essentially the same for women and men.

Given the heterogeneity in the cigarette price effect observed across these groups, a natural question is whether rising cigarette prices have ameliorated or worsened these disparities. We attempt to quantify the impacts on disparities in the remaining columns of Table 3. For each group, we estimate a linear probability model for obesity using the same specification described above for the BMI function. From that regression, we predict the obesity rate in 2005 (the last year of our sample) at both 1984 (the first year of our sample) cigarette prices and 2005 cigarette prices (which are still averaged over current and past five-year prices). We then compute the predicted obesity rate disparity between each group and the group with the lowest obesity rate (e.g. blacks or other race versus whites) at both 2005 and 1984 prices. Finally, we calculate the difference in these predicted obesity rate disparities as a percentage of the disparity at 1984 prices. These estimates quantify the degree to which obesity disparities are larger or smaller than they would have been if cigarette prices had stayed at 1984 levels.

The results suggest that the increase in cigarette price between 1984 and 2005 has decreased the disparity in obesity between blacks and whites by 5% and between those of another race and whites by 27%. In contrast, rising cigarette prices have increased the obesity disparity between college graduates and individuals with less than a high school degree, a high school degree but no college, and some college by 33%, 10%, and 10%, respectively. Finally, changes in cigarette prices decreased the obesity disparity between middle age and young adults by 23%, but increased the disparity between older (≥60) and young adults by 139% (though the latter of these numbers is misleadingly large because of the small initial disparity).

IV. Discussion

This study suggests strong complementarities between cigarette smoking and body weight that increase with body weight and vary across subgroups defined by race, sex, age, and education. Individuals who are at higher BMI quantiles are significantly more responsive to cigarette prices than those at lower BMI quantiles. Cigarette price increases therefore shift the entire BMI distribution to the left but bring significantly larger shifts in the right than the left side of the distribution. Since weight loss improves health most substantially for the obese, the health benefits from higher cigarette costs are greater than if the entire BMI distribution shifted left by the same amount.

This heterogeneity is masked by previous studies that focus on the impact at mean BMI, as the effect for a person at average BMI is clearly not representative of the effects for individuals at low or high BMI quantiles. In the total sample, “mean” effects underestimate the effects at the 0.9 percentile by about 24% and overestimate the effects at the 0.1 percentile by more than 100%. Larger differences between mean and quantile effects are observed in certain groups. For example, mean effects underestimate the effect at the 0.9 quantile for blacks by 50%.

Since the determinants of body weight are largely unknown, identifying the specific factors that result in the heterogeneity of the cigarette price effect across BMI quantiles is not possible at this point. The larger price-responsiveness among individuals at greater risks of being obese may be due to the larger benefits that these individuals reap from reducing their weight in the form of improvements in cardiovascular and respiratory health and decreased risk of chronic conditions such as diabetes or hypertension. This may also occur if individuals at higher BMI quantiles engage more intensively in behaviors that increase weight as a result of smoking such as consuming more food or alcohol and exercising less than individuals at lower BMI quantiles. Of course, differences in genetic and environmental factors may also play a role. Further research is needed to help unravel the exact sources of this heterogeneity.

The larger decreases in body weight among black individuals, particularly for those at high BMI quantiles, resulting from higher cigarette costs suggest that the large disparity in obesity rates between blacks and whites would have been even larger without the cigarette price increases in recent decades. Specifically, we estimate that the rising cigarette prices reduced this disparity by 5%.[8] In 2007-2008, about 44.1% of black adults (≥20 years) in the US were obese compared to 32.4% of whites (Flegal et al. 2010), and similar differences are observed in the study sample. Further increases in cigarette costs in the future may help to mitigate this disparity.

Significant disparities in body weight also exist by education. In our study sample, higher schooling significantly decreases body weight with significantly larger decreases at higher BMI quantiles. For example, graduating from college reduces the 0.9, 0.5 and 0.1 BMI quantiles by 2, 1.3 and 0.3 units compared to those who did not attend high school (see Table

[8] We also evaluate how average BMI disparities are affected with the rising cigarette prices, and find that the disparity in average BMI between blacks and whites decreased by about 10% due to the increase in cigarette prices between 1984 and 2005.

A1). The larger cigarette price responsiveness with higher education suggests that the increase in cigarette prices in recent decades increased weight/obesity disparities by education. In contrast, the effects of rising cigarette prices on age-related disparities in obesity are mixed, with decreasing obesity disparities between young and middle age adults but increasing disparities for older adults.

This study has important implications for policymakers. First, the results suggest that higher cigarette taxes may result in important secondary benefits to population health through weight losses among obese and severely obese individuals, or at least slowdowns in their rates of weight gain. Second, cigarette taxes may help mitigate racial disparities in obesity. While the fact that the majority of obese individuals are non-smokers suggests that cigarette taxes are limited in their ability to curb the rise in obesity, very few policy interventions are currently known to have the potential to bring large population-wide reductions in obesity, so a variety of interventions that all have modest effects might be the most feasible strategy. More conservatively, policymakers could also interpret our results as providing no justification for the fear that cigarette taxation might have the unintended consequence of increasing the obesity rate.

Consistent with the conclusions of Gruber and Frakes (2006), Nonnemaker et al. (2009), and Courtemanche (2009), our results suggest that the downward trend in smoking and upward trend in obesity are not causally related and are instead driven by coincidental population-level changes. The decrease in smoking rates is thought to have been primarily driven by a combination of increased knowledge of the health consequences of smoking and higher cigarette prices. The rise in obesity may have been the result of unrelated factors such as an increasingly sedentary lifestyle, greater fast-food and restaurant availability, food advertisements, improvements in food production technology, falling real food prices, and historically cheap gasoline.[9] Alternatively, the rise in obesity could have causally reduced smoking rates due to increasing concerns about health problems resulting from obesity such as hypertension and heart disease. While research suggests that obesity may increase smoking initiation among female adolescents (Cawley et al., 2004; Rees and Sabia, 2010), the causal effect of weight on smoking among adults remains unexplored.

Our results appear inconsistent with the evidence from mice studies showing increased caloric intake, weight gain, and fat accumulation with nicotine exposure (Chen et al. 2004; Chen et al. 2008). However, our hypothesis for why quitting smoking reduces weight in humans in the long run is behavioral, not biological. Successfully quitting smoking may improve dietary and exercise habits by enhancing a person's motivation and commitment to engage in a healthy lifestyle. Over time, these indirect behavioral effects accumulate and eventually outweigh the immediate biological effects on metabolism and appetite. Our results highlight the need for future research to test our hypothesis more directly by examining the mechanisms through which changes in smoking status influence body weight.

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[9] For a sample of research exploring these possibilities, see Lakdawalla and Philipson (2002), Philipson and Posner (2003), Cutler et al. (2003), Chou et al. (2004), Rashad (2006), Eid et al. (2007), Chou et al. (2008), Currie et al. (2010), Dunn (2010), Zhou and Kaestner (2010), Courtemanche and Carden (2011), Anderson and Matsa (forthcoming), Andreyeva et al. (forthcoming), Courtemanche (forthcoming), and Goldman et al. (forthcoming).

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Table 1. Distribution of Study Variables

Variable	Description	Mean (Std. Dev.)
BMI	Body mass index	26.28 (5.32)
Obese	0/1 indicator for BMI ≥ 30	0.195 (0.396)
Price	Average cigarette price in years t to t-5	2.81 (0.8)
Age	Age in years	46.88 (16.99)
Age squared	Age in years squared	2486.84 (1735.11)
Female	0/1 indicator for females	0.57 (0.49)
Black	0/1 indicator for black race	0.08 (0.27)
Other	0/1 indicator for non-white and non-black race	0.1 (0.3)
Married	0/1 indicator for being married	0.55 (0.5)
Some high school	0/1 indicator for attending but not graduating from high school	0.08 (0.26)
High school graduate	0/1 indicator for graduating from high school but not attending college	0.32 (0.47)
Some college	0/1 indicator for attending but not graduating from college	0.27 (0.45)
College graduate	0/1 indicator for graduating from college	0.29 (0.46)
Income	Household income adjusted for inflation	44952.72 (25286.67)
Income squared	Household income squared	2.66×10^9 (2.49×10^9)

Table 2. Effects of Cigarette Price on BMI Quantiles and Mean

Model	Quantile 0.1	0.25	0.5	0.75	0.9	"Mean" Effect
Total sample [a]	-0.12*** (0.02)	-0.20*** (0.02)	-0.28*** (0.02)	-0.37*** (0.03)	-0.39*** (0.05)	-0.28*** (0.06)
Stratified by race						
Black [c, d]	-0.17** (0.08)	-0.24*** (0.07)	-0.36*** (0.09)	-0.58*** (0.13)	-0.76*** (0.21)	-0.37*** (0.11)
White [a]	-0.14*** (0.02)	-0.20*** (0.02)	-0.28*** (0.02)	-0.34*** (0.03)	-0.32*** (0.05)	-0.27*** (0.06)
Other [a]	-0.07 (0.06)	-0.17*** (0.05)	-0.17*** (0.06)	-0.43*** (0.08)	-0.34** (0.15)	-0.19 (0.12)
Stratified by education						
Incomplete HS or less [b]	0.04 (0.07)	-0.10 (0.08)	-0.09 (0.07)	-0.14 (0.11)	-0.45*** (0.16)	-0.12 (0.08)
HS graduate [a]	-0.03 (0.04)	-0.13*** (0.03)	-0.23*** (0.04)	-0.30*** (0.06)	-0.30*** (0.08)	-0.21*** (0.08)
Some [b] college	-0.13*** (0.04)	-0.19*** (0.04)	-0.26*** (0.04)	-0.35*** (0.06)	-0.21** (0.10)	-0.25*** (0.08)
College graduate [a]	-0.13*** (0.03)	-0.18*** (0.03)	-0.26*** (0.03)	-0.37*** (0.05)	-0.44*** (0.08)	-0.29*** (0.07)
Stratified by age						
Less than 40 years old [a]	-0.12*** (0.03)	-0.22*** (0.03)	-0.37*** (0.03)	-0.59*** (0.05)	-0.60*** (0.08)	-0.36*** (0.07)
40 to 59 years old [a]	-0.13*** (0.03)	-0.26*** (0.03)	-0.40*** (0.03)	-0.53*** (0.06)	-0.82*** (0.09)	-0.45*** (0.09)
60 years and older	-0.03 (0.05)	-0.1** (0.04)	-0.04 (0.04)	-0.1* (0.05)	-0.09 (0.09)	-0.06 (0.06)
Stratified by sex						
Males [a]	-0.11*** (0.03)	-0.15*** (0.03)	-0.23*** (0.03)	-0.32*** (0.04)	-0.38*** (0.07)	-0.23*** (0.06)
Females [a]	-0.13*** (0.02)	-0.22*** (0.03)	-0.33*** (0.03)	-0.41*** (0.05)	-0.39*** (0.08)	-0.30*** (0.07)

Note: Standard errors in parentheses. ** indicates p<0.05; *** indicates p <0.01. [a], [b] and [c] indicate that the coefficients were significantly different between the five quantiles at p < 0.01, p < 0.05 and p < 0.1 respectively. [d] indicates that the coefficients were significantly different between the 0.1 and 0.9 quantiles at p < 0.01 (only evaluated when the differences across the five quantiles were insignificant or marginally significant at p<0.1).

Table 3: Obesity Rates by Demographic and Socioeconomic Characteristics and Disparity Changes with Cigarette Prices

Group	Sample Obesity Rate	Cigarette price effect on probability of being obese	Predicted Average Obesity Rate in 2005 at 1984 Cigarette Price	Predicted Average Obesity Rate in 2005 at 2005 Cigarette Price	Obesity Rate Disparity at 1984 Cigarette Price	Obesity Rate Disparity at 2005 Cigarette Price	% Difference in Obesity Disparity Because of Higher Cigarette Price
Stratified by race							
Black	0.304	-0.021*** (0.007)	0.440	0.390	0.151	0.143	-5.34
Other	0.204	-0.021** (0.009)	0.318	0.269	0.030	0.021	-27.45
White	0.183	-0.017*** (0.004)	0.289	0.247	--	--	--
Stratified by education							
Incomplete HS or less	0.247	-0.004 (0.005)	0.328	0.317	0.076	0.114	33.10
HS graduate	0.213	-0.016*** (0.006)	0.330	0.290	0.078	0.086	9.74
Some college	0.20	-0.017*** (0.007)	0.320	0.280	0.069	0.077	10.47
College graduate	0.152	-0.02*** (0.005)	0.252	0.204	--	--	--
Stratified by age							
Less than 40 years old	0.157	-0.024*** (0.005)	0.291	0.233	--	--	--
40 to 59 years old	0.234	-0.031*** (0.007)	0.363	0.289	0.072	0.056	-22.78
60 years and older	0.197	-0.005 (0.004)	0.258	0.246	-0.033	0.013	139.41
Stratified by sex							
Males	0.194	-0.02*** (0.005)	--	--	--	--	--
Females	0.196	-0.019*** (0.005)	--	--	--	--	--

Note: Standard errors in parentheses. ** indicates p<0.05; *** indicates p <0.01

Appendix

Table A1. Regression Coefficients of the BMI Function

	Quantile Regression / Quantiles					Mean Effect-OLS
	0.1	0.25	0.5	0.75	0.9	
Price	-0.12*** (0.02)	-0.20*** (0.02)	-0.28*** (0.02)	-0.37*** (0.03)	-0.39*** (0.05)	-0.28*** (0.06)
Age	0.17*** (0.001)	0.21*** (0.001)	0.28*** (0.001)	0.37*** (0.002)	0.47*** (0.003)	0.32*** (0.0004)
Age squared	-0.002*** (0.00001)	-0.002*** (9.2×10^{-6})	-0.002*** (0.00001)	-0.003*** (0.00001)	-0.005*** (0.00002)	-0.003*** (0.00004)
Female	-2.02*** (0.01)	-1.99*** (0.01)	-1.65*** (0.01)	-0.91*** (0.01)	0.04** (0.02)	-1.14*** (0.04)
Black	1.03*** (0.01)	1.41*** (0.01)	1.88*** (0.01)	2.30*** (0.02)	2.65*** (0.04)	1.94*** (0.07)
Other	0.15*** (0.01)	0.29*** (0.01)	0.33*** (0.01)	0.31*** (0.02)	0.23*** (0.03)	0.30*** (0.07)
Married	0.29*** (0.01)	0.32*** (0.01)	0.33*** (0.01)	0.27*** (0.01)	0.08*** (0.02)	0.24*** (0.02)
Some high school	-0.06** (0.03)	-0.11*** (0.02)	-0.16*** (0.03)	-0.20*** (0.03)	-0.26*** (0.05)	-0.17*** (0.04)
High school graduate	0.01 (0.02)	-0.21*** (0.02)	-0.47*** (0.02)	-0.72*** (0.03)	-0.91*** (0.04)	-0.51*** (0.05)
Some college	-0.01 (0.02)	-0.29*** (0.02)	-0.59*** (0.02)	-0.82*** (0.03)	-0.93*** (0.04)	-0.57*** (0.05)
College graduate	-0.33*** (0.02)	-0.78*** (0.02)	-1.27*** (0.02)	-1.72*** (0.03)	-2.02*** (0.04)	-1.31*** (0.07)
Income	0.00002*** (5.64×10^{-7})	4.78×10^{-6}*** (4.96×10^{-7})	-0.00001*** (5.97×10^{-7})	-0.00004*** (9.04×10^{-7})	-0.0001*** (1.55×10^{-6})	-0.00003*** (1.13×10^{-6})
Income squared	-1.54×10^{-10}*** (5.27×10^{-12})	-7.93×10^{-11}*** (4.69×10^{-12})	3.11×10^{-11}*** (5.52×10^{-12})	1.90×10^{-10}*** (8.22×10^{-12})	3.51×10^{-10}*** (1.41×10^{-11})	8.56×10^{-11}*** (9.45×10^{-12})

Note: The table reports the regression coefficients with standard errors in parentheses from QR and OLS for the total sample. The year and state fixed effects are suppressed from the table for brevity. ** p<0.05; *** p <0.01.