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THE ECONOMICS OF SMOKING BANS

May 2010

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ABSTRACT

While the empirical literature on smoking bans is extensive, little theory has been developed. This paper examines the welfare impact of smoking bans in an economy where smokers' utility is reduced by a workplace/public place ban. The government has two instruments - increasing the price through taxation, or limiting when the product can be consumed through a ban. Its ability to reduce smoking through taxation is limited by a black market where cigarettes are not taxed. We show that the quantity instrument (ban) is always welfare-enhancing. The model has application to other addictive activities.

Key words: smoking, workplace ban, public place ban, government control, taxation

Suggested running title: Smoking Bans

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The authors wish to thank participants at the 2009 Canadian Public Economics Group workshop and the Canadian Health Economics Group workshop, and particularly Mike Hoy for his suggestions. Errors remain the responsibility of the authors.

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1. INTRODUCTION

Economists have long been interested in policy issues in which households make inefficient choices. A well-researched example is pollution in which an individual considers only her own benefit from her action and ignores the consequences of her action on others. An important policy issue is whether the individual's action is better controlled indirectly by changing the price (usually implemented by imposing a tax) or directly by limiting the quantity of the activity. With full information the two approaches are equivalent. However, when the government has less than full information, economists have traditionally stressed that there is likely to be an advantage in using the indirect or price route.[1]

Our research considers the case of the smoking, which the government wishes to limit because of the ill-health it causes. Smoking is furthermore addictive. One characteristic of the addiction is that the smoker prefers a steady flow of cigarettes (a.k.a. nicotine) to an unsteady flow; this suggests that the individual's utility from cigarettes may be modeled as having mean-variance form. If the government uses a price policy to reduce smoking, it levies a tax on cigarettes. However, the ability of the government to increase the tax on cigarettes to punitive levels is limited by the ability of the smoker to buy illegal, and untaxed, cigarettes.[2] Another government policy instrument is to ban smoking in the workplace, or public places. This policy works through the variance term. Although the smoker is able to offset the reduction of cigarettes he would otherwise smoke during the work period by increasing the cigarettes smoked at home, the forced elimination of cigarettes smoked at work creates an unsteady flow of nicotine, increasing the variance and making smoking less attractive. The overall effect is to reduce the number of cigarettes smoked. In our model, in which the government's use of taxes is limited, we show that the price policy and the smoking ban policy are not equivalent, and that the best policy always includes a smoking ban.

While smoking is our central consideration, we believe that the theory may be applied in many cases in which the government considers the product to be "a bad" (rather than a "good") and wishes to limit the extent to which the product is consumed. In addition to smoking bans at the workplace (or at restaurants or other public places), our theory explains licensing laws which limit alcohol purchases to particular times and laws which criminalize drugs, making their supply uncertain.

We believe our model is more general than the specific assumptions we make. We model addiction as a dislike of daily variance. In the classic "rational addiction" model of Becker and Murphy (1988), addiction implies that the utility flow from consumption depends on the accumulated stock of past consumption. While our model ignores this particular aspect of addiction, our results still apply. A workplace ban, by increasing the daily variance, makes smoking less attractive every day; therefore less cigarettes are smoked in each period, decreasing the accumulated stock of past consumption evaluated at a future date and improving future health.

Our government is paternalistic: it wants to limit smoking because smokers incorrectly perceive the ill-effects of smoking on their health. Of course there are other reasons the government may wish to limit smoking, prominent among them being the externality created by "second-hand" smoke. Apart from misperceiving the health impacts of smoking, smokers may smoke because they suffer from time inconsistency (Gruber and Koszegi (2004)) or projection bias (O'Donohue and Rabin (2001)), or they may make decision errors as a result of being exposed to certain cues (Bernheim and Rangell (2004)), or because they succumb to temptation (Gul and Pesendorfer 2001). This literature is reviewed extensively in Dela Vigna (2009). To maintain simplicity, the model development is based on the perceived costs of smoking: some individuals overestimate the costs while others underestimate. Viscusi (1990) gives credence to the idea that many non smokers actually overestimate health risks. What is critical in our model is that the smoker dislikes variance and that the government wants to limit smoking. Finally, we use the possibility of smokers switching to untaxed but illegal cigarettes as a device to limit the ability of the government to tax cigarettes. Another model might have political reasons or tax competition (as in de

Bartolome (2007)) preventing the government from setting taxes which are arbitrarily high. Whatever the devise, the government is unable to completely eliminate smoking by setting a punitive tax rate.

The paper is organized as follows. Section 2 summarizes the literature on smoking bans. Section 3 introduces the model by describing an individual's smoking decision and the reason for government's concern over the smoking level. Section 4 shows the effect of a smoking ban when cigarettes are untaxed. Section 5 shows how the potential to buy untaxed but illegal cigarettes limits the government's ability to reduce smoking using the tax instrument alone. Section 6 undertakes a positive discussion when the government simultaneously uses a tax and a smoking ban. Section 7 shows that the smoking ban is always a useful instrument by which to control smoking, even when the tax can be set optimally. Section 8 discusses the long-run consequences of a ban. Section 9 concludes

2. LITERATURE ON GOVERNMENT POLICY TOWARDS SMOKING

Bans on the use of tobacco in public and work places are widespread in all developed economies at the present time. They take many forms and are enacted by municipal, state/provincial and federal governments. They extend not only to the workplace, but also to the five B's (bars, bingo halls, bowling alleys, betting establishments, and billiard halls). Local governments frequently impose more restrictions than are required by higher-level legislation.

Prior to the 1990s, taxes were the main instrument by which governments sought to reduce tobacco use. Some of the earliest municipal ordinances were enacted in California around 1990 (see Moskowitz et al, 2000). The modern era has seen governments develop a larger array of anti-tobacco armaments: in addition to bans, health warnings on tobacco packages now appear in many countries, advertising of tobacco products has been severely curtailed; sponsorship of sports events by tobacco companies has been restricted and store displays have been outlawed.

In part bans have been introduced out of the recognition that the effectiveness of ever higher taxes is limited, on account of the incentive these latter provide for illegal production and trans-border shipment. For example, as of end 2007, approximately one third of cigarettes sold in Canada were supplied illegally. Additionally, bans are seen as a distinct measure in the fight against tobacco use, a measure that impacts the user in a different manner and that can therefore supplement the role of price disincentives. The group of non-price disincentives noted above form what is now termed the public health move to 'denormalize' smoking.

A substantive empirical literature documents the impact of smoking bans, and many econometric papers that estimate the impact of tax/price measures attempt to control for the impact of bans. Numerous studies have found lower tobacco prevalence and quantity in workplaces covered by complete or partial bans (Chapman *et al*, 1999, Fichtenberg and Glantz, 2002, or Gagné, 2008). While such correlations could reflect a choice of workplace in a high labor turnover economy, Evans, Farrelly and Montgomery (1998) controlled for the possible endogeneity of the choice of work place, and still found that bans reduced tobacco use. Furthermore, Cutler and Glaeser (2007) propose that smoking reductions achieved through bans may have a social multiplier impact.

While health groups universally support the implementation and extension of strictures on smoking, some research has been less than fully supportive. For example, Adams and Cotti (2008) propose that bans in bars have been found to encourage patrons to seek out bars in adjoining jurisdictions where smoking is not banned, with the consequence that road and vehicle accident rates increase as a result of driving further under the influence of some amount of alcohol.

The strength of bans (and the level of taxes) varies widely, depending upon the degree of anti-tobacco 'sentiment' in the jurisdiction in question (e.g. deCicca et al 2006). Sentiment against tobacco control is stronger in states or regions where tobacco is grown. For example, Kentucky and the Carolinas have lower tax rates on cigarettes than Massachusetts, because tobacco is a means of livelihood for many in the former states. At the same time, anti-tobacco sentiment may translate into more widespread bans on public place use.

Public policy interventions against smoking have received support from several recent theoretical developments (referenced above) that have addressed the implications of deviations from the assumptions of the traditional utility-maximizing model - time inconsistency, projection bias, the presence of cues and temptations. In the case of time inconsistency, problems arise because it is only in future periods that the negative consequences of current actions materialize, and a high discount rate applied to immediate decisions undervalues those consequences relative to a lower long-run discount rate. With projection bias, users miscalculate the future negative impacts associated with today's consumption. Cues are capable of triggering mistakes on the part of the brain's decision mechanism and temptation is important when the brain is subject to multiple decision modes. These models all stand in contrast to the rational addiction approach, where there is no role for a government in correcting individual decisions - unless externalities are present.

A critical element in smoking bans is the degree to which they induce substitution in time-of-day smoking: if individuals are restricted in the hours during which they are permitted to smoke, do such restrictions imply that smoking will fall (roughly) in line with the reduction in the proportion of the day during which smoking is not permitted? Or will substitution take place towards other non-restricted times of the day? Adda and Cornaglia (2007) propose that public-place smoking bans have led to an increase in the amount of smoking in the home, and that this in turn has increased the amount of second-hand smoke to which children and other non-smokers are exposed. Thus, substitution possibilities are critical. The model we develop in the next section permits smokers to increase their nicotine intake during non-restricted periods of the day in response to the imposition of a workplace ban.

Two final comments are in order before developing the model. First, we do not focus upon the possible impacts of second hand smoke in our welfare analysis; we are concerned with the well being of the aggregate of individual utilities where errors may be made as a result of incorrect priors on the health impact of smoking. An enormous literature exists in the medical journals on second hand smoke. Second, we do not introduce the complexity of 'intending quitters', who may favor bans because they are a type of commitment device (Gruber and Mullainathan, 2005 or Hersch, 2005).

3. THE MODEL

We introduce our model by considering the case when the government potentially imposes a tax on cigarettes but there is no ban. Smoking is addictive in both the long-run and in the short-run. The long-run effect is modeled by Becker and Murphy (1988); at time T the individual's utility from smoking is affected by his prior history of smoking, which we denote as $\Psi(T)$. While recognizing the long-run effect, we choose to focus on the short-run or within-the-day effect. When a cigarette is smoked, a shot of nicotine is released into the blood providing satisfaction to the smoker. As time moves forward within the day, this nicotine metamorphoses into cotinine and the nicotine level in the blood declines; this decline creates a longing to restore the nicotine to its pre-existing level and may induce the smoker to light up another cigarette. From the above discussion, it should be clear that within-the-day the smoker prefers a steady stream of nicotine to an unsteady stream.

We consider a day to have 3 periods; descriptively, the first period is the morning period before the individual goes to work, the second period is the period during which the individual works and the third period is the period after work. The exact number of periods is not critical provided there are at least two, so that substitution between periods is possible. The consumption of the numeraire in the day is x and cigarette consumption in period 1 is c_1, in period 2 c_2 and in period 3 is c_3. The individual's utility in day T depends on x, c_1, c_2, c_3, on his perceived health h and on the individual's prior smoking history, $\Psi(T)$ $U(x, c_1, c_2, c_3, h|\Psi(T))$. We assume a specific form for this function,

$$U(x, c_1, c_2, c_3, h | \Psi(T)) = x + V(c_1, c_2, c_3 | \Psi(T)) + h(c_1, c_2, c_3 | \Psi(T)).$$

The term $V(c_1, c_2, c_3 | \Psi(T))$ represents the direct utility the individual achieves from smoking the cigarettes c_1, c_2 and c_3 . We model this as having mean- variance form, with the smoker "enjoying" the mean level of cigarettes and the smoker's preference for a steady consumption of cigarettes being represented as a dislike of variance:

$$V(c_1, c_2, c_3 | \Psi(T)) = a(c_1 + c_2 + c_3) - b \operatorname{var}(c_1, c_2, c_3) .$$

The parameters a and b are positive; they are assumed to be functions of the smoking history $\Psi(T)$ but, as $\Psi(T)$ is given at day T, this dependance is suppressed. [3]

Any model of smoking with policy implications must explain why people choose to smoke when the induced health risks make it, to most outside observers, such a poor choice. The *true* health of the smoker is a negative function of the cigarettes he smokes- we model this as the quadratic function

$$- s(c_1 + c_2 + c_3) - t(c_1 + c_2 + c_3)^2$$

where the negative signs indicate that the health of the smoker declines with the cigarettes he smokes. The parameters s and t are assumed to be positive and to be functions of the smoking history $\Psi(T)$ but this dependance is also suppressed. However, the ill-health caused by cigarettes occurs in the future and so is not experienced by the individual when making his cigarette choice. In particular, the individual i *perceives* his future health to be:

$$h = -(1 + \alpha^i)(s(c_1 + c_2 + c_3) + t(c_1 + c_2 + c_3)^2)$$

where α^i is a parameter distributed on [-1, +1] with mean zero. Individuals with $\alpha^i > 0$ overestimate the negative effect of cigarettes on their future health (and do not smoke); individuals with $\alpha^i < 0$ underestimate the negative effect of cigarettes on their future health. It must be stressed that, although individuals are making errors in their perceptions, the error is two-sided so that there is no systematic bias: α^i has mean zero.

The individual's income is denoted M and the consumer price (which may include a tax) of a cigarette is denoted q. The individual potentially receives a lump-sum R from the government. Hence $x = M + R - q(c_1 + c_2 + c_3)$. Noting that the variance can be written as $\mathrm{var}(c_1, c_2, c_3) = \frac{2}{9}(c_1^2 + c_2^2 + c_3^2 - c_1c_2 - c_1c_3 - c_2c_3)$, the indivi

$$\max_{c_1\geq 0,\, c_2\geq 0,\, c_3\geq 0} M + R - q(c_1 + c_2 + c_3) + a(c_1 + c_2 + c_3) - b\frac{2}{9}(c_1^2 + c_2^2 + c_3^2 - c_1c_2 - c_1c_3 - c_2c_3)$$

$$- (1 + \alpha^i)(s(c_1 + c_2 + c_3) + t(c_1 + c_2 + c_3)^2)$$

The first-order condition for the choice of c_1 is:

$$\textit{either} \quad c_1 = 0 \qquad \text{and} - q + a - \frac{2}{9}b\left(2c_1 - c_2 - c_3\right) - (1 + \alpha^i)(s + 2t(c_1 + c_2 + c_3)) \,\Big|_{c_1 = 0} \leq 0$$

$$\textit{or} \quad c_1 > 0 \qquad \text{and} - q + a - \frac{2}{9}b\left(2c_1 - c_2 - c_3\right) - (1 + \alpha^i)(s + 2t(c_1 + c_2 + c_3)) = 0$$

Using the symmetry of the problem, $c_1 = c_2 = c_3$ and hence:

$$\textit{either} \quad a - (1 + \alpha^i)s - q \leq 0 \qquad c_1 = c_2 = c_3 = 0 \text{ and}$$

or $\quad a - (1 + \alpha^i)s - q > 0$ and $\quad c_1 = c_2 = c_3 = \dfrac{a - (1 + \alpha^i)s - q}{6(1 + \alpha^i)t}$

This is rewritten as:

If $\alpha^i \geq \dfrac{a - s - q}{s}$, the individual d $c_1 = c_2 = c_3 = 0$ (1) .

If $\alpha^i < \dfrac{a - s - q}{s}$, the individual smokes: $c_1 = c_2 = c_3 = \dfrac{a - (1 + \alpha^i)s - q}{6(1 + \alpha^i)t}$ (2)

We denote as $\alpha_1(q)$ the critical value of $\alpha^i(q)$ at which an individual is indifferent between not smoking and buying taxed cigarettes.

DEFINITION: the perception parameter of the individual who is indifferent between not smoking and smoking taxed cigarettes selling at consumer price q is $\alpha_1(q)$ *:*

$$\alpha_1(q) \equiv \frac{a - s - q}{s}.$$

The demand curve of an individual with parameter α^i is a straight line with price sensitivity

$$\frac{\partial(c_i + c_2 + c_3)}{\partial q} = -\frac{1}{2}\frac{1}{(1 + \alpha^i)t}.$$

Remembering that a traditional demand curve is drawn with the price on the vertical axis, the slope of the traditional demand curve is *-2(1+*α^i*)t* and the vertical intercept is $a - (1 + \alpha^i)s$. As α^i increases, the demand curve steepens and shifts down.

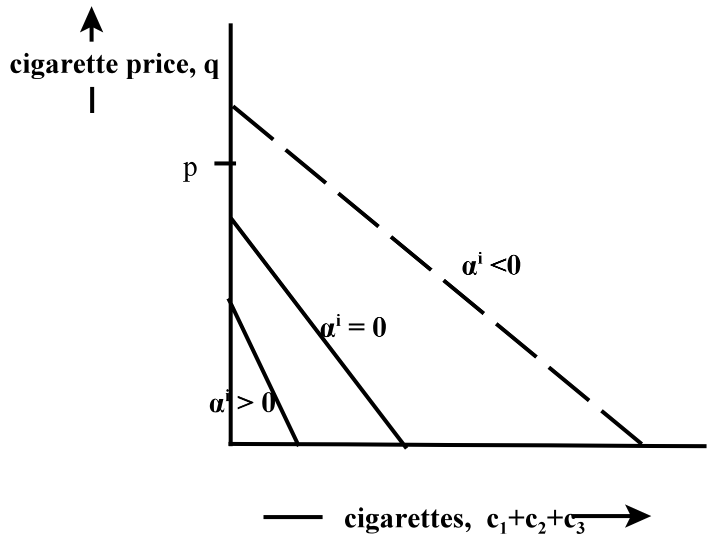

Fig 1: cigarette demand for individuals with different health perceptions

We assume that smoking is a "bad" in the strict sense that an individual who correctly perceives the ill-health does not choose to smoke even when cigarettes are untaxed or sell at their producer price *p*, or

if $\alpha^i = 0$ and $q = p$, $c_i = 0$

or

$$a - s - p < 0 .$$

In addition, we want there to be some smokers when cigarettes are sold at their producer price, or

$\alpha_1(p) > -1$ or

$$a - p > 0$$

ASSUMPTIONS: $a - s - p < 0 < a - p$.

4. GOVERNMENT POLICY

The government evaluates individual utility using the true effect of cigarettes on health or it calculates the welfare associated with an individual with perception α^i as:

$$W(\alpha^i,P) \equiv x(\alpha^i,P) + a(c_1(\alpha^i,P) + c_2(\alpha^i,P) + c_3(\alpha^i,P)) - b\,var(c_1(\alpha^i,P),c_2(\alpha^i,P),c_3(\alpha^i,P))$$

$$-(s(c_1(\alpha^i,P) + c_2(\alpha^i,P) + c_3(\alpha^i,P)) + t(c_1(\alpha^i,P) + c_2(\alpha^i,P) + c_3(\alpha^i,P))^2)]$$

where $x(\alpha^i, P)$ is the consumption of numeraire of an individual with perception bias α^i under policy P and $c_1(\alpha^i,P)$ is the consumption of cigarettes in Period 1 of an individual with perception bias α^i, etc.

We note that because the government knows the true effect of cigarettes on health, it pre-multiplies health by *1* not $(1+\alpha^i)$. The government calculates social welfare as the sum of all individual "true" utilities under policy P. If α^i is distributed on $[\underline{\alpha},\overline{\alpha}]$ with density $f(\alpha^i)$, social welfare W under policy P is

$$W(P) = \int_{\underline{\alpha}}^{\overline{\alpha}} [W(\alpha^i, P) f(\alpha^i) d\alpha^i$$

We normalize the population size to unity. If the government policy is a cigarette tax so that the consumer price is q, all tax revenue is returned as a lump-sum transfer R:

$$R = \int_{\underline{\alpha}}^{\overline{\alpha}} (q-p)(c_1(\alpha^i,q) + c_2(\alpha^i,q) + c_3(\alpha^i,q)) f(\alpha^i)\, d\alpha^i$$

and

$$x(\alpha^i,P) = M + R - q(c_1(\alpha^i,q) + c_2(\alpha^i,q) + c_3(\alpha^i,q)) .$$

We explore three possible government policies:

(1) a smoking ban in Period 2 where Period 2 corresponds to the work period or to the period when smoking by the individual can be monitored. Individuals spend Periods 1 and 3 "at home" where their cigarette consumption cannot be monitored.

(2) a cigarette tax. The government does not know the health perception α^i of the smoker and it does not know the period in which the cigarette is smoked. Therefore all cigarettes must have the same tax.

(3) a cigarette tax plus a smoking ban.

4. SMOKING BAN IN PERIOD 2

In this section we consider the case when the government imposes a smoking ban in Period 2. As the rule setting $c_2 = 0$ is introduced, at the pre-existing levels of c_1 c_3 and , there are two effects: (1) the effect of a marginal increase in c_1 c_3 on health is decreased and (2) the variance is increased. The first effect gives the possibility of the smoker offsetting the ban by substituting into Period 1 or Period 3 cigarettes; the second effect unambiguously lowers cigarette consumption and improves health.[4] This is formalized below.

We assume that there is no tax and hence $q = p$. The individual solves:

$$\max_{c_1 \geq 0,\, c_2 \geq 0,\, c_3 \geq 0} M - p(c_1 + c_2 + c_3) + a(c_1 + c_2 + c_3) - b\frac{2}{9}(c_1^2 + c_2^2 + c_3^2 - c_1c_2 - c_1c_3 - c_2c_3)$$

$$- (1 + \alpha^i)(s(c_1 + c_2 + c_3) + t(c_1 + c_2 + c_3)^2)$$

subject to the smoking ban: $c_2 = 0$;

or, substituting for c_2,

$$\max_{c_1 \geq 0,\, c_3 \geq 0} \; M - p(c_1 + c_3) + a(c_1 + c_3) - b\frac{2}{9}(c_1^2 + c_3^2 - c_1 c_3) \; - (1 + \alpha)(s(c_1 + c_3) + t(c_1 + c_3)^2)$$

The first-order condition is:

$$\text{either } c_1 = 0 \qquad \text{and} \; -p + a - \frac{2}{9}b\left(2c_1 - c_3\right) - (1 + \alpha^i)(s + 2t(c_1 + c_3)) \,\Big|_{c_1 = 0} \leq 0$$

$$\text{or} \quad c_1 > 0 \qquad \text{and} \; -p + a - \frac{2}{9}b\left(2c_1 - c_3\right) - (1 + \alpha^i)(s + 2t(c_1 + c_3)) \; = 0$$

By symmetry, set $c_1 = c_3$; hence

$$\alpha^i \geq \frac{a - s - p}{s} \qquad \text{and} \qquad c_1 = c_3 = 0$$

or

$$\alpha^i < \frac{a - s - p}{s} \qquad \text{and} \qquad c_1 = c_3 = \frac{a - (1 + \alpha^i)s - p}{\frac{2}{9}b + 4(1 + \alpha^i)t}$$

We make several observations. First, comparing Equations (1) and (2) with the above, we see that the ban does not change the value of α^i of the marginal smoker who is indifferent between not smoking and smoking, or does not cause any smoker to quit.[5] Why is this? Consider the change in utility from the first cigarette if there is a ban:

$$\frac{\partial U}{\partial c_1}\Big|_{c_1 = 0,\, c_2 = c_3 = 0} = -p + a - (1 + \alpha^i)s \qquad .$$

This is the same as if there is no ban. The variance created by the first cigarette is insufficient to deter the smoker. Technically, as $c_1 \to 0$, the variance term is going to zero "too fast". We summarize this observation below:

OBSERVATION 1: *the smoking ban does not cause any smoker to quit*.

The smoking ban in Period 2 may have the unintended consequence of inducing the smoker to increase his smoking in Periods 1 and 3. With no ban, the cigarettes smoked in Period 1 or 3 is:

$$c_1 = c_3 = \frac{a - (1 + \alpha^i)s - p}{6(1 + \alpha^i)t} .$$

With a ban, the cigarettes smoked in Period 1 or 3 is:

$$c_1 = c_3 = \frac{a - (1 + \alpha^i)s - p}{\frac{2}{9}b + 4(1 + \alpha^i)t} .$$

Therefore the ban induces positive substitution into cigarettes in Periods 1 and 3 if:

$$\frac{2}{9}b + 4(1 + \alpha^i)t < 6(1 + \alpha^i)t ;$$

or if

$$b < 9(1 + \alpha^i)t$$

i.e. provided the variance term is not "too strong". We summarize this observation:

OBSERVATION 2: *The smoking ban in Period 2 will increase the number of cigarettes smoked in Periods 1 and 3 unless the dislike of variance is "too strong."*

However, the ban lowers the total cigarettes smoked. With no ban, the total cigarettes smoked is:

$$c_1 + c_2 + c_3 = \frac{a - (1 + \alpha)s - p}{2(1 + \alpha)t} \qquad ;$$

With a ban, the total cigarettes smoked is:

$$c_1 + c_3 = \frac{a - (1 + \alpha)s - p}{\frac{b}{9} + 2(1 + \alpha)t} \qquad .$$

Hence, $b > 0$ ensures that the ban lowers the total number of cigarettes smoked by a smoker. This is formalized in the observation below:

OBSERVATION 3: The smoking ban - by increasing the variance - lowers the utility from smoking and reduces the total number of cigarettes smoked by a smoker.

The smoking ban improves health which increases the welfare of the smoker as calculated by the government. But it increases variance which decreases the smoker's utility and hence the welfare of the smoker as calculated by the government. Proposition 1 shows that the improvement in health dominates.

PROPOSITION 1: the smoking ban increases government welfare

PROOF: see Appendix A.

5. TAX ONLY

The government would like to stop smoking. Using Inequality (2), an individual i buys cigarettes provided $\alpha^i < (a - s - q)/s$ $-1 \le \alpha^i$. But . Putting these inequalities together, so are buying cigarettes provided;

$$-1 < \frac{a - s - q}{s}$$

or provided

$$q < a \qquad . \tag{4}$$

Hence, if the government can impose a sufficiently high tax, it can achieve its objective of stopping smoking. However, we believe that the government is limited in its ability to raise the tax rate and we model this restriction as coming from the possibility of individuals buying untaxed cigarettes on the "black" market.

The individual can either buy legal cigarettes at consumer price *q*, or can buy illegal untaxed cigarettes at a consumer price *p*. To participate in the illegal market, the individual must pay a fixed cost *F*. To close the model, any tax collected is returned to all individuals as a lump-sum transfer *R*.

We now describe the values of α^i as a function of *q* at which individuals choose not to smoke, to smoke legal cigarettes and to smoke illegal cigarettes. If the individual buys legal cigarettes, the consumer price is *q* and

$$c_1 = c_2 = c_3 = \frac{a - (1+\alpha)s - q}{6(1+\alpha)t} \qquad ;$$

his utility is:

$$M + R - q3\,\frac{a-(1+\alpha)s-q}{6(1+\alpha)t} + a3\,\frac{a-(1+\alpha)s-q}{6(1+\alpha)t} - (1+\alpha)\left(s3\,\frac{a-(1+\alpha)s-q}{6(1+\alpha)t} + t9\left(\frac{a-(1+\alpha)s-q}{6(1+\alpha)t}\right)^2\right)$$

If the individual buys illegal cigarettes, the consumer price is p and

$$c_1 = c_2 = c_3 = \frac{a - (1 + \alpha)s - p}{6(1 + \alpha)t} \qquad ;$$

he pays a fixed cost F (but still receives the lump-sum transfer R) and his utility is:

$$M - F + R - p3\frac{a - (1+\alpha)s - p}{6(1+\alpha)t} + a3\frac{a - (1+\alpha)s - p}{6(1+\alpha)t} - (1+\alpha)\left(s3\frac{a - (1+\alpha)s - p}{6(1+\alpha)t} + t9\left(\frac{a - (1+\alpha)s - p}{6(1+\alpha)t}\right)^2\right)$$

DEFINITION: The individual with perception $\alpha_2(q)$ *achieves equal utility by buying in the legal and illegal markets.*

Equating Expressions (5) and (6), we can show

$$\alpha_2(q) = \frac{1}{2}\frac{-q^2 + p^2 + 2(a-s)(q-p) - 4tF}{s(q-p) + 2tF} \qquad .$$

When $q = p$, $\alpha_2 = -1$. Differentitating

$$\frac{d\alpha_2}{dq} = \frac{1}{2}\frac{(s(q-p) + 2tF)(-2q + 2(a-s)) - (-q^2 + p^2 + 2(a-s)(q-p) - 4tF)s}{(s(q-p) + 2tF)^2}$$

Imposing the condition $\alpha_2 < \alpha_1$, we can show that

$$\alpha_2 < \alpha_1 \quad \text{implies} \quad \frac{d\alpha_2}{dq} > 0 \qquad .$$

Intuitively, as the consumer price increases, more people buy illegal cigarettes. In addition,

$$\alpha_2 = \alpha_1 \quad \text{implies} \quad \frac{d\alpha_2}{dq} = 0 \, .$$

At $\alpha_2 = \alpha_1$, the consumer price is $\hat{q}$, or

$$-(\hat{q} - p)^2 s + 4tF(a - \hat{q}) = 0 \, ,$$

This can be solved to give

$$\hat{q} = p + \frac{-2tF + 2\sqrt{tF(tF + (a-p)s)}}{s} \, .$$

The associated value of α_2 is

$$\alpha_2 = \alpha_1 = \frac{a - s - \hat{q}}{s} = \frac{(a - s - p)s + 2tF - 2\sqrt{tF(tF + (a-p)s)}}{s^2}$$

At prices exceeding $\hat{q}$, no smokers buy legal cigarettes. The relevant comparison is between not-smoking and smoking illegal cigarettes, and the value of α^i which makes the smoker indifferent between these choices does not depend on *q*.

Pulling this all together, the different α^i, q regions at which individuals do not smoke, smoke legal cigarettes and smoke illegal cigarettes is summarized in Figure 2 below.

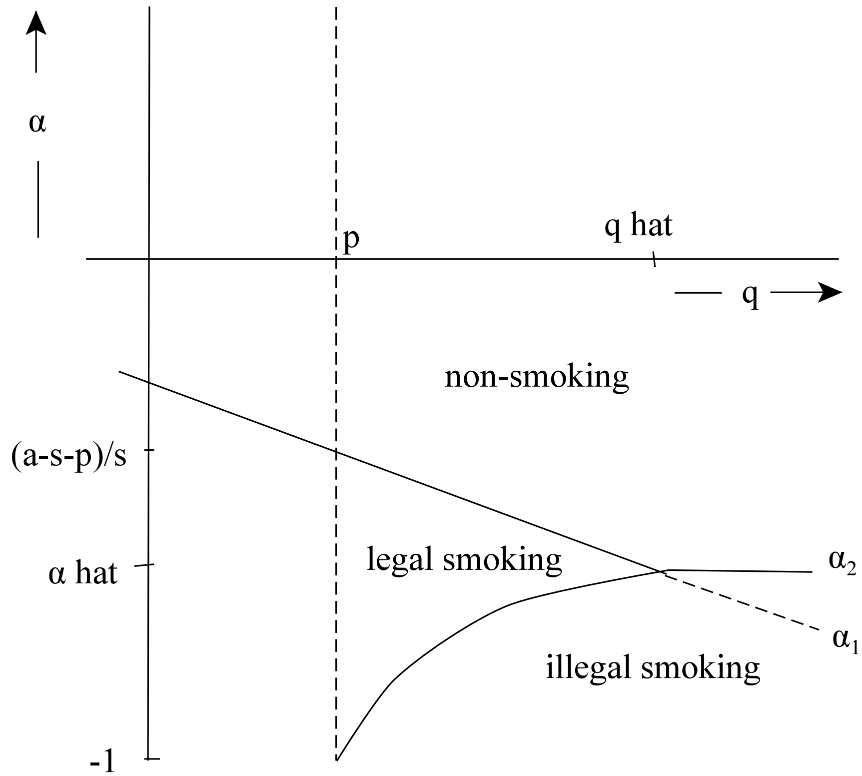

Figure 2: the division of individuals between non-smokers, smokers of legal cigarettes and smokers of illegal cigarettes

It is straight-forward to show that $\hat{q} < a$. Hence Inequality (4) is satisfied or the government is unable to eliminate smoking by raising the tax rate.

6. COMBINATION POLICY OF TAX AND BAN: POSITIVE ANALYSIS

We are interested in comparing welfare achieved without a smoking ban with welfare achieved with a smoking ban in the second period. In order to do calculus, we consider a partial ban in which an individual is allowed to smoke in the second period a fraction θ of the amount he smokes if there is no ban. The analysis then considers the effect of lowering θ from 1 to 0. We consider that an individual smoking legal cigarettes is restricted to smoke $\overline{c}_2^{legal}$ cigarettes in the second period,

$$\overline{c}_2^{legal} = \theta \frac{a - (1+\alpha)s - q}{6(1+\alpha)t} \quad ;$$

and an individual smoking illegal cigarettes is restricted to smoke $\overline{c}_2^{illegal}$ cigarettes in the second period,

$$\overline{c}_2^{illegal} = \theta \frac{a - (1+\alpha)s - p}{6(1+\alpha)t} \quad .$$

We note that when $\theta = 1$ it is "as if" the individual is unrestricted or there is no ban, and when $\theta = 0$ the individual is unable to smoke cigarettes in the second period, or the ban is total.

(i) Calculation of utility with legal purchases:

The individual's problem is:

$$\max_{c_1 \geq 0,\, c_3 \geq 0} M + R + (a - (1+\alpha^i)s - q)(c_1 + \overline{c}_2^{legal} + c_3)$$

$$- b\frac{2}{9}(c_1^2 + \overline{c}_2^{legal\,2} + c_3^2 - c_1\overline{c}_2^{legal} - c_1c_3 - \overline{c}_2^{legal}c_3) - (1+\alpha^i)t(c_1 + \overline{c}_2^{legal} + c_3)^2$$

s.t. $\overline{c}_2^{legal} = \theta \dfrac{a - (1+\alpha^i)s - q}{6(1 + \alpha)t}$.

The first-order condition for the choice of c_1 is:

either $c_1 = 0$ and

$$(a - (1+\alpha^i)s - q) - b\frac{2}{9}(2c_1 - \theta\frac{a - (1+\alpha^i)s - q}{6(1+\alpha^i)t} - c_3) - (1+\alpha^i)t2(c_1 + \theta\frac{a - (1+\alpha^i)s - q}{6(1+\alpha^i)t} + c_3) \le 0$$

or $c_1 > 0$ and

$$(a - (1+\alpha^i)s - q) - b\frac{2}{9}(2c_1 - \theta\frac{a - (1+\alpha^i)s - q}{6(1+\alpha^i)t} - c_3) - (1+\alpha^i)t2(c_1 + \theta\frac{a - (1+\alpha^i)s - q}{6(1+\alpha^i)t} + c_3) = 0$$

By symmetry, set $c_1 = c_3$, and simplifying

either $a - (1+\alpha^i)s - q \le 0 \quad c_1 = c_3 = 0$: ;

or $a - (1+\alpha^i)s - q > 0 \quad c_1 = c_3 = \dfrac{\dfrac{a - (1+\alpha^i)s - q}{6(1+\alpha^i)t}\left(6(1+\alpha^i)t + \dfrac{2}{9}b\theta - 2(1+\alpha^i)t\theta\right)}{\dfrac{2}{9}b + 4(1+\alpha^i)t}$:

Substituting into the smoker's utility function, the utility of the legal smoker with perception α^i is:

$$M + R + 3(a - (1+\alpha^i)s - q)\frac{(a - (1+\alpha^i)s - q)\left(\frac{2}{9}b\theta + 4(1+\alpha^i)t\right)}{6(1+\alpha^i)t\left(\frac{2}{9}b + 4(1+\alpha^i)t\right)}$$

$$- b\frac{2}{9}(a - (1+\alpha^i)s - q)^2 \frac{(1-\theta)^2}{\left(\frac{2}{9}b + 4(1+\alpha^i)t\right)^2} - 9(1+\alpha^i)t\,\frac{(a-(1+\alpha^i)s - q)^2}{\left(6(1+\alpha^i)t\right)^2}\,\frac{\left(\frac{2}{9}b\theta + 4(1+\alpha^i)t\right)^2}{\left(\frac{2}{9}b + 4(1+\alpha^i)t\right)^2}$$

(ii) *Calculation of utility with illegal purchases*:

The individual's problem is:

$$\max_{c_1 \geq 0,\, c_3 \geq 0} M + R - F + (a - (1+\alpha^i)s - p)(c_1 + \bar{c}_2^{illegal} + c_3)$$

$$- b\frac{2}{9}(c_1^2 + \bar{c}_2^{illegal\,2} + c_3^2 - c_1\bar{c}_2^{illegal} - c_1c_3 - \bar{c}_2^{illegal}c_3) - (1+\alpha^i)t(c_1 + \bar{c}_2^{illegal} + c_3)^2$$

s.t. $\bar{c}_2^{illegal} = \theta\,\dfrac{a - (1+\alpha^i)s - p}{6(1+\alpha)t}$.

After simplification, the first-order condition for the choice of c_1 is:

either $c_1 = 0$ and

$$(a - (1+\alpha^i)s - p) - b\frac{2}{9}\left(2c_1 - \theta\frac{a-(1+\alpha^i)s-p}{6(1+\alpha^i)t} - c_3\right) - (1+\alpha^i)t2\left(c_1 + \theta\frac{a-(1+\alpha^i)s-p}{6(1+\alpha^i)t} + c_3\right) \leq 0$$

or $c_1 > 0$ and

$$(a - (1+\alpha^i)s - p) - b\frac{2}{9}\left(2c_1 - \theta\frac{a-(1+\alpha^i)s-p}{6(1+\alpha^i)t} - c_3\right) - (1+\alpha^i)t2\left(c_1 + \theta\frac{a-(1+\alpha^i)s-p}{6(1+\alpha^i)t} + c_3\right) = 0$$

By symmetry, set $c_1 = c_3$, and hence *either* $a - (1+\alpha^i)s - p \le 0 \qquad c_1 = c_3 = 0$ and

or $a - (1+\alpha^i)s - p > 0 \qquad c_1 = \dfrac{\dfrac{a - (1+\alpha^i)s - p}{6(1+\alpha^i)t}\left(6(1+\alpha)t + \dfrac{2}{9}b\theta - 2(1+\alpha^i)t\theta\right)}{\dfrac{2}{9}b + 4(1+\alpha^i)t}$ and

Hence the utility of the illegal smoker with perception α is:

$$M + R - F + 3(a - (1+\alpha^i)s - p)\frac{(a - (1+\alpha^i)s - p)\left(\frac{2}{9}b\theta + 4(1+\alpha^i)t\right)}{6(1+\alpha^i)t\left(\frac{2}{9}b + 4(1+\alpha^i)t\right)}$$

$$- b\frac{2}{9}(a - (1+\alpha^i)s - p)^2\frac{(1-\theta)^2}{\left(\frac{2}{9}b + 4(1+\alpha^i)t\right)^2} - 9(1+\alpha^i)t\frac{(a - (1+\alpha^i)s - p)^2}{(6(1+\alpha^i)t)^2}\frac{\left(\frac{2}{9}b\theta + 4(1+\alpha^i)t\right)^2}{\left(\frac{2}{9}b + 4(1+\alpha^i)t\right)^2}$$

(iii) *Calculation of* α_1

Using Equation (7), the individual with perception parameter α_1 achieves the same utility from smoking legal cigarettes as from not smoking when:

$$M + R + 3(a - (1+\alpha_1)s - q)\frac{(a - (1+\alpha_1)s - q)\left(\frac{2}{9}b\theta + 4(1+\alpha_1)t\right)}{6(1+\alpha_1)t\left(\frac{2}{9}b + 4(1+\alpha_1)t\right)}$$

$$- b\frac{2}{9}(a-(1+\alpha_1)s-q)^2\frac{(1-\theta)^2}{\left(\frac{2}{9}b+4(1+\alpha_1)t\right)^2} - 9(1+\alpha_1)t\frac{(a-(1+\alpha_1)s-q)^2}{\left(6(1+\alpha_1)t\right)^2}\frac{\left(\frac{2}{9}b\theta+4(1+\alpha_1)t\right)^2}{\left(\frac{2}{9}b+4(1+\alpha_1)t\right)^2} = M+R$$

Solving:

$$\alpha_1 = \frac{a-s-q}{s} \quad .$$

(iv) Calculation of α_2 .

Using Equations (7) and (8), the individual with perception parameter α_2 achieves the same utility from smoking legal and illegal cigarettes when:

$$M+R+3(a-(1+\alpha_2)s-q)\frac{(a-(1+\alpha_2)s-q)\left(\frac{2}{9}b\theta+4(1+\alpha_2)t\right)}{6(1+\alpha_2)t\left(\frac{2}{9}b+4(1+\alpha_2)t\right)}$$

$$- b\frac{2}{9}(a-(1+\alpha_2)s-q)^2\frac{(1-\theta)^2}{\left(\frac{2}{9}b+4(1+\alpha_2)t\right)^2} - 9(1+\alpha_2)t\frac{(a-(1+\alpha_2)s-q)^2}{\left(6(1+\alpha_2)t\right)^2}\frac{\left(\frac{2}{9}b\theta+4(1+\alpha_2)t\right)^2}{\left(\frac{2}{9}b+4(1+\alpha_2)t\right)^2}$$

$$= M+R-F+3(a-(1+\alpha_2)s-p)\frac{(a-(1+\alpha_2)-p)\left(\frac{2}{9}b\theta+4(1+\alpha_2)t\right)}{6(1+\alpha_2)t\left(\frac{2}{9}b+4(1+\alpha_2)t\right)}$$

$$-b\frac{2}{9}(a-(1+\alpha_2)s-p)^2\frac{(1-\theta)^2}{\left(\frac{2}{9}b+4(1+\alpha_2)t\right)^2}-9(1+\alpha_2)t\frac{(a-(1+\alpha_2)s-p)^2}{(6(1+\alpha_2)t)^2}\frac{\left(\frac{2}{9}b\theta+4(1+\alpha_2)t\right)^2}{\left(\frac{2}{9}b+4(1+\alpha_2)t\right)^2}$$

The above equation may be simplified to:

$$2(1+\alpha_2)t\left(\frac{2}{9}b+4(1+\alpha_2)t\right)F-\left(2(q-p)(a-(1+\alpha_2)s)-q^2+p^2\right)\left(2(1+\alpha_2)t+\frac{2}{9}b\theta-\frac{b}{9}\theta^2\right)=0$$

Equation (9) is a quadratic equation in $1+\alpha_2$ which can be solved. We note:

(1) when q = p, this equation reduces to:

$$(1+\alpha_2)t\left(\frac{2}{9}b+4(1+\alpha_2)t\right)F=0 \quad .$$

But $\alpha_2 \geq -1$ and hence the above equation implies

$$\frac{2}{9}b+4(1+\alpha_2)t>0 \quad .$$

Therefore when $q=p$, $\alpha_2=-1$.

(2) If θ is held constant, differentiate Equation (9) with respect to q and rearrange

$$\frac{\partial\alpha_2}{\partial q} = \frac{2\left(2(1+\alpha_2)t + \frac{2}{9}b\theta\left(1-\frac{\theta}{2}\right)\right)(a-(1+\alpha_2)s-q)}{(1+\alpha_2)8t^2F + \left(\frac{2}{9}b+4(1+\alpha_2)t\right)2tF - (2(q-p)(a-(1+\alpha_2)s) - q^2+p^2)2t}$$

$$+\left(2(1+\alpha_2)t + \frac{2}{9}b\theta\left(1-\frac{\theta}{2}\right)\right)2(q-p)s \qquad .$$

If

$$\alpha_2 < \alpha_1 = \frac{a-s-q}{s} \qquad ,$$

then $a-(1+\alpha_2)s-q>0$ $\alpha_2 \geq -1$ $\theta \leq 1$ and and implies

$$-1 \leq \alpha_2 < \alpha_1 \quad : \quad \frac{\partial\alpha_2}{\partial q} > 0 \qquad .$$

When $\alpha_2 = \alpha_1$ $a-(1,+\alpha_2)s-q=0$ (the legal smoker would smoke no cigarettes) and

$$-1 < \alpha_2 = \alpha_1 \quad : \quad \frac{\partial\alpha_2}{\partial q} = 0 \qquad .$$

At larger values of q, the relevant boundary is between the non-smoker and the smoker of illegal cigarettes.

(3) If q is held constant, differentiate Equation (9) with respect to θ and rearrange:

$$\frac{\partial\alpha_2}{\partial\theta} = \frac{\left(2(q-p)(a-(1+\alpha_2)s) - q^2 + p^2\right)\frac{2}{9}b(1-\theta)}{(1+\alpha_2)8t^2F + \left(\frac{2}{9}b + 4(1+\alpha_2)t\right)2tF - (2(q-p)(a-(1+\alpha_2)s) - q^2 + p^2)2t + \left(2(1+\alpha_2)t + \frac{2}{9}b\theta\left(1-\frac{\theta}{2}\right)\right)2(q-p)s} .$$

Setting $\theta = 1$:

$$\frac{\partial\alpha_2}{\partial\theta}\Big|_{\theta=1} = 0 \quad ;$$

with no ban, the individual, whether smoking legal or illegal cigarettes, is indifferent to the last cigarette smoked and hence his utility is unchanged (to a first-order) if the ban is marginally tightened If $\alpha_2 = -1$, $q = p$ and

$$\frac{\partial\alpha_2}{\partial\theta}\Big|_{\alpha_2=-1} = 0 \quad ;$$

without the ban, the individual is smoking an infinite quantity of cigarettes. The ban allows the individual to smoke only a fraction θ of the infinite quantity, or the ban is ineffective.

More generally we can show that

if either $\theta = 1$ or $\alpha_2 = -1$: $\frac{\partial\alpha_2}{\partial\theta} = 0$;

otherwise: $\frac{\partial\alpha_2}{\partial\theta} > 0$.

Put differently, tightening the ban reduces the number of cigarettes smoked. Hence the pre-existing marginal smoker no longer finds it worthwhile to incur the cost *F* to buy illegal cigarettes.

Summarizing, Figure 3 shows how α_1 and α_2 vary with q and θ. The figure is drawn with $\theta_2 < \theta_1$.

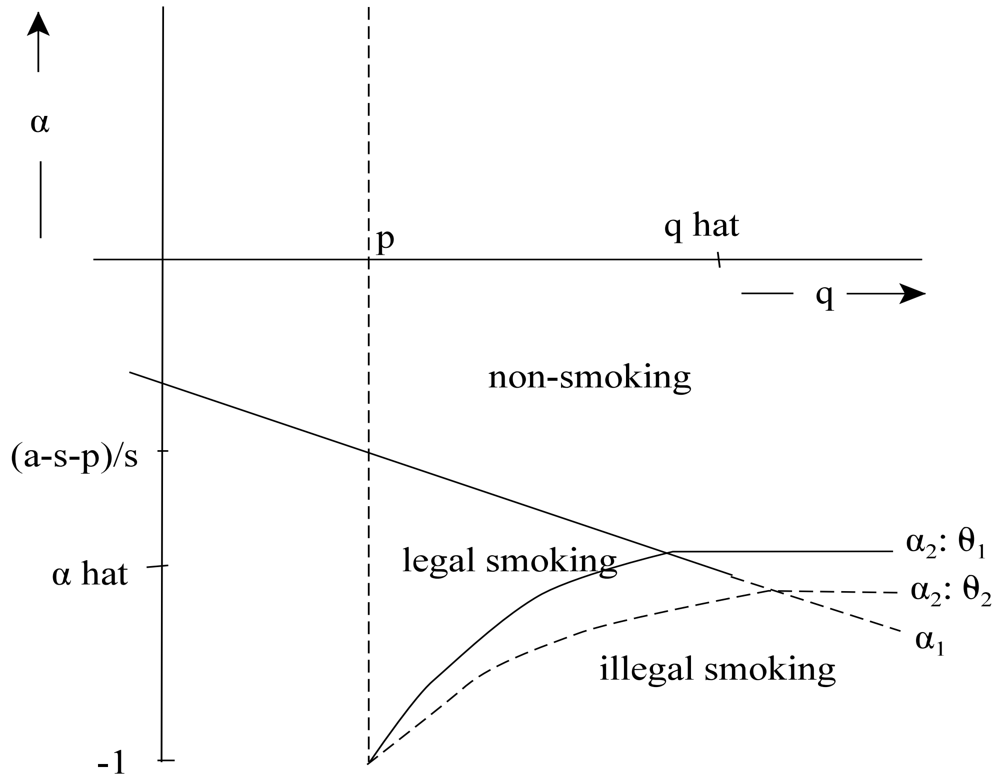

Figure 3: the division of individuals between non-smokers, smokers of legal cigarettes and smokers of illegal cigarettes as the ban in Period 2 is tightened

7. COMBINATION POLICY OF TAX AND BAN: NORMATIVE ANALYSIS

With the government policy P being its choice of q, the consumer price of cigarettes, and θ, the extent of the ban in the second period, the government's problem is to maximize the sum of welfare from smokers of illegal cigarettes, from smokers of legal cigarettes and from non-smokers. We note that without loss of generality we can restrict the government's choice of the consumer price to be between p and $\hat{q}$: if the government sets the consumer price to exceed $\hat{q}$, no legal cigarettes are bought and it is "as if" $q = \hat{q}$. Using Equation (3), the government's problem is:

$$\max_{\substack{p \leq q \leq \hat{q} \\ 0 \leq \theta \leq 1}} \int_{-1}^{\alpha_2(q,\theta)} W(\alpha, P=(q,\theta)) f(\alpha)\, d\alpha + \int_{\alpha_2(q,\theta)}^{\alpha_1(q)} W(\alpha, P=(q,\theta)) f(\alpha)\, d\alpha + \int_{\alpha_1(q)}^{1} W(\alpha, P=(q,\theta)) f(\alpha)\, d\alpha$$

Instead of calculating the optimum values of q and θ , we instead proceed sequentially. The government is assumed to first choose the optimal consumer price q conditional on θ ;

$$W(\theta) = \max_{p \leq q \leq \hat{q}} \int_{-1}^{\alpha_2(q,\theta)} W(\alpha, P=(q,\theta)) f(\alpha)\, d\alpha + \int_{\alpha_2(q,\theta)}^{\alpha_1(q)} W(\alpha, P=(q,\theta)) f(\alpha)\, d\alpha + \int_{\alpha_1(q)}^{1} W(\alpha, P=(q,\theta)) f(\alpha)\, d\alpha$$

PROPOSITION 2: *With q being set optimally conditional on θ, q(θ),*

$$\frac{dW(\theta)}{d\theta} < 0$$

PROOF: See Appendix B.

Proposition 2 is the central result of this paper. Even when the tax rate can be set optimally, welfare increases when the smoking ban in the second period is tightened from $\theta = 1$ to $\theta = 0$. Put differently, Proposition 2 implies that it is always desirable to have a full ban in the second period, or to set $\theta = 0$.

8. DISCUSSION OF HISTORY- DEPENDENCE

In Section 2 we noted that addiction has both long-term and short-term aspects. Our model focuses on short-run addiction and is static. The long-term addictive properties of smoking imply that an individual's smoking taste at time *T* is heavily dependent on his smoking history. We interpret the state variable $\Psi(T)$ to be the accumulated stock of cigarettes smoked prior to time T; inc $\Psi(T)$ increases the smoker's taste for cigarettes at time *T* and lowers his health. We suggested that this should be modeled by making the taste parameters *a* and *b*, and the health parameters *s* and *t* increasing functions of $\Psi(T)$. We note in passing that any policy that lowers the cigarettes smoked at time *T* lowers future values of the accumulated stock, thereby lowering $\Psi(T : T > T)$ and long-run addiction. Put differently, a policy which lowers smoking in the short-run will do likewise in the long-run.

9. CONCLUSION

We have considered how government intervention can limit the consumption of a product that it perceives is injurious to health and in addition has addictive properties - in this case cigarettes. Addiction takes the form of a strong preference for an even consumption flow during any time period and the injurious nature of the product is underestimated by those who consume it. The (paternalist) government is limited in its ability to set tax rates punitively because of the availability of an illegal market where consumers can purchase the product untaxed, but incur a (fixed) cost in doing so. We show that a ban on the consumption of the product during part of the day, because it increases the individual's variance in consumption, induces the individual to lower his total consumption of the product. In addition, although the ban makes the individual worse off, welfare as calculated by the government increases. By showing that a tax plus a ban is the best policy, we hope this finding adds to the "price *v.* quantity" debate on how to best control socially undesirable activities. The model may have particular attraction in the debate over the legalization of marijuana, where it has been proposed that high taxes and high penalties may form an alternative policy to making the product illegal. Quantity restrictions in this context may may further increase welfare.

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ENDNOTES

1. A notable exception is Weitzman (1974).

2. In Canada the presence of the illegal market accounts for at least one quarter of the national market, and a much higher share in Quebec and Ontario.

3. The effect of policy on $\Psi(T)$ and long-run addiction is discussed in Section 8.

4. If c_1 and c_3 were increased to fully offset the fall in c_2, health would be unchanged but the variance would be increased, implying that the smoker would want to lower consumption.

5. Introducing a fixed cost of smoking would lead a ban to cause some smokers to quit (the critical value of α^i decreases.

APPENDIX A: PROOF OF PROPOSITION A

With no ban and no cigarette tax (R= 0) , the welfare of a smoker as calculated by the government is:

$$M - p\frac{a - (1 + \alpha^i)s - p}{2(1 + \alpha^i)t} + a\frac{a - (1 + \alpha^i)s - p}{2(1 + \alpha^i)t}$$

$$- 1\left(s\frac{a - (1 + \alpha^i)s - p}{2(1 + \alpha^i)t} + t\left(\frac{a - (1 + \alpha^i)s - p}{2(1 + \alpha^i)t} \right)^2 \right)$$

With a ban, the welfare of the smoker as calculated by the government is:

$$M - p\frac{a - (1 + \alpha^i)s - p}{\frac{b}{9} + 2(1 + \alpha^i)t} + a\frac{a - (1 + \alpha^i)s - p}{\frac{b}{9} + 2(1 + \alpha^i)t} - \frac{2}{9}b\left(\frac{a - (1 + \alpha^i)s - p}{\frac{2}{9}b + 4(1 + \alpha^i)t} \right)^2$$

$$- 1\left(s\frac{a - (1 + \alpha^i)s - p}{\frac{b}{9} + 2(1 + \alpha^i)t} + t\left(\frac{a - (1 + \alpha^i)s - p}{\frac{b}{9} + 2(1 + \alpha^i)t} \right)^2 \right)$$

where the variance is calculated setting $c_1 = c_3$ c_2 and 0 . The ban increases the welfare of the individual as calculated by the government as:

$$\Delta U = (a - s - p)\left(\frac{a - (1 + \alpha^i)s - p}{\frac{b}{9} + 2(1 + \alpha^i)t} - \frac{a - (1 + \alpha^i)s - p}{2(1 + \alpha^i)t}\right) - \frac{2}{9}b\frac{1}{4}\left(\frac{a - (1 + \alpha^i)s - p}{\frac{b}{9} + 2(1 + \alpha^i)t}\right)^2$$

$$- t\left(\left(\frac{a - (1 + \alpha^i)s - p}{\frac{b}{9} + 2(1 + \alpha^i)t}\right)^2 - \left(\frac{a - (1 + \alpha^i)s - p}{2(1 + \alpha^i)t}\right)^2\right)$$

We note that, when b = 0, $\Delta U = 0$.

And

$$\frac{d\Delta U}{db} = (a - (1 + \alpha^i)s - p)\left[-(a - s - p)\frac{1}{\left(\frac{b}{9} + 2(1 + \alpha^i)t\right)^2}\frac{1}{9}\right.$$

$$+ (a-(1+\alpha^i)s-p)\left(\frac{b}{18} 2 \frac{1}{\left(\frac{b}{9}+2(1+\alpha^i)t\right)^3} \frac{1}{9} - \frac{1}{18} \frac{1}{\left(\frac{b}{9}+2(1+\alpha^i)t\right)^2} \right)$$

$$+ t(a-(1+\alpha^i)s-p) \frac{2}{\left(\frac{b}{9}+2(1+\alpha^i)t\right)^3} \frac{1}{9} \quad \Bigg]$$

$$= \frac{1}{18} \frac{a-(1+\alpha^i)s-p}{\left(\frac{b}{9}+2(1+\alpha^i)t\right)^3}$$

$$\left[-2(a-s-p)(\frac{b}{9}+2(1+\alpha^i)t) \;+\; (a-(1+\alpha^i)s-p)\left(\frac{2}{9}b-(\frac{b}{9}+2(1+\alpha^i)t))+4t \right) \right]$$

$$> 0$$

where the last inequality follows from: $a - s - p < 0$; we are considering a smoker or

$a - (1 + \alpha^i)\, s - p > 0$ and

$$\frac{2}{9}b - \frac{b}{9} - 2(1 + \alpha^i)t + 4t \;=\; \frac{b}{9} + 2t(1 - \alpha^i) > 0$$

and the last inequality follows that fact that *for a smoker* $\alpha^i \leq 0$.

APPENDIX B: PROOF OF PROPOSITION 2

$$W(\theta) = \max_{p \le q \le \hat{q}} \int_{-1}^{\alpha_2(q,\theta)} W(\alpha, P=(q,\theta)) f(\alpha)\, d\alpha$$

$$+ \int_{\alpha_2(q,\theta)}^{\alpha_1(q)} W(\alpha, P=(q,\theta)) f(\alpha)\, d\alpha + \int_{\alpha_1(q)}^{1} W(\alpha, P=(q,\theta)) f(\alpha)\, d\alpha$$

To evaluate $dW(\theta)/d\theta < 0$ we use the envelope condition:

$$\frac{dW(q(\theta),\theta)}{d\theta} = \frac{\partial W(q(\theta),\theta)}{\partial\theta}$$

$$= \int_{-1}^{\alpha_2(q,\theta)} \frac{\partial W(\alpha, P=(q,\theta))}{\partial\theta} f(\alpha)\, d\alpha + W(\alpha_2, P=(q,\theta), illegal) f(\alpha_2) \frac{\partial\alpha_2}{\partial\theta}$$

$$+ \int_{\alpha_2(q,\theta)}^{\alpha_1(q)} \frac{\partial W(\alpha, P=(q,\theta))}{\partial\theta} f(\alpha)\, d\alpha - W(\alpha_2, P=(q,\theta), legal) f(\alpha_2) \frac{\partial\alpha_2}{\partial\theta}$$

$$+ \int_{\alpha_1(q)}^{1} \frac{\partial W(\alpha, P=(q,\theta))}{\partial\theta} f(\alpha)\, d\alpha$$

where we note α_1 is a function of q but not of θ per se, and hence $\partial\alpha_1(q)/\partial\theta = 0$.

Evaluating each term:

(1) the contribution to welfare for the smoker of illegal cigarettes is:

$$-1 \le \alpha \le \alpha_2 \qquad W(\alpha, P=(q,\theta)) = M + R - F + 3(a - s - p) \frac{(a - (1+\alpha)s - p)\left(\frac{2}{9}b\theta + 4(1+\alpha)t\right)}{6(1+\alpha)t\left(\frac{2}{9}b + 4(1+\alpha)t\right)}$$

$$- b\frac{2}{9}(a - (1+\alpha)s - p)^2 \frac{(1-\theta)^2}{\left(\frac{2}{9}b + 4(1+\alpha)t\right)^2}$$

$$- 9t\frac{(a - (1+\alpha)s - p)^2}{(6(1+\alpha)t)^2}\frac{\left(\frac{2}{9}b\theta + 4(1+\alpha)t\right)^2}{\left(\frac{2}{9}b + 4(1+\alpha)t\right)^2}$$

This can be simplified to

$$-1 \le \alpha \le \alpha_2 \quad \frac{\partial W(\alpha, P=(q,\theta))}{\partial\theta}$$

$$= \frac{\partial R}{\partial\theta} + \frac{a-(1+\alpha)s-p}{(6(1+\alpha)t)^2\left(\frac{2}{9}b+4(1+\alpha)t\right)^2}\frac{2}{9}b\Bigg(3(a-s-p)6(1+\alpha)t\left(\frac{2}{9}b+4(1+\alpha)t\right)$$

$$+ (a-(1+\alpha)s-p)\,18t\left(4(1+\alpha)^2t(1-\theta) - \frac{2}{9}b\theta - 4(1+\alpha)t\right)\Bigg)$$

(2) The contribution to welfare from the smoker of legal cigarettes is

$$\alpha_2 \le \alpha \le \alpha_1: \quad W(\alpha, P=(q,\theta)) = M + R + 3(a-s-q)\frac{(a-(1+\alpha)s-q)\left(\frac{2}{9}b\theta+4(1+\alpha)t\right)}{6(1+\alpha)t\left(\frac{2}{9}b+4(1+\alpha)t\right)}$$

$$- b\frac{2}{9}(a - (1+\alpha)s - q)^2 \frac{(1-\theta)^2}{\left(\frac{2}{9}b + 4(1+\alpha)t\right)^2}$$

$$- 9t\frac{(a-(1+\alpha)s-q)^2}{(6(1+\alpha)t)^2}\frac{\left(\frac{2}{9}b\theta+4(1+\alpha)t\right)^2}{\left(\frac{2}{9}b+4(1+\alpha)t\right)^2}$$

Differentiating with respect to θ and rearranging

$$\alpha_2 \le \alpha \le \alpha_1 : \frac{\partial W(\alpha, P=(q,\theta))}{\partial\theta}$$

$$= \frac{\partial R}{\partial\theta} + \frac{a-(1+\alpha)s-q}{(6(1+\alpha)t)^2\left(\frac{2}{9}b+4(1+\alpha)t\right)^2}\frac{2}{9}b\left(3(a-s-q)6(1+\alpha)t\left(\frac{2}{9}b+4(1+\alpha)t\right)\right.$$

$$\left.+(a-(1+\alpha)s-q)\,18t\left(4(1+\alpha)^2t(1-\theta)-\frac{2}{9}b\theta-4(1+\alpha)t\right)\right)$$

(3)To determine $W(\alpha_2, illegal) - W(\alpha_2, legal)$ $c_1^{illegal}, \bar{c}_2^{illegal}$ Subs $c_3^{illegal}$ for determine $W(\alpha_2, illegal)$ $c_1^{legal}, \bar{c}_2^{legal}$ ıd fo c_3^{legal} $W(\alpha_2, legal)$ to determine rearrangement

$$W(\alpha_2, illegal) - W(\alpha_2, legal)$$

$$= 3\alpha_2 s\big((a-(1+\alpha_2)s-p)-(a-(1+\alpha_2)s-q)\big)\frac{\left(\frac{2}{9}b\theta+4(1+\alpha_2)t\right)}{6(1+\alpha_2)t\left(\frac{2}{9}b+4(1+\alpha_2)t\right)}$$

$$+ 9\alpha_2 t\frac{(a-(1+\alpha)s-p)^2-(a-(1+\alpha)s-q)^2}{(6(1+\alpha)t)^2}\frac{\left(\frac{2}{9}b\theta+4(1+\alpha)t\right)^2}{\left(\frac{2}{9}b+4(1+\alpha)t\right)^2}$$

(4) The non-smoker is affected by the change in θ only because the size of his transfer R is affected:

$$\alpha_1 \leq \alpha \leq 1 : \quad \frac{\partial W(\alpha, P=(q,\theta))}{\partial\theta} = \frac{\partial R}{\partial\theta}$$

Hence:

$$\frac{dW(\theta)}{d\theta} = \int_{-1}^{\alpha_2}\Bigg[\frac{\partial R}{\partial\theta} + \frac{a-(1+\alpha)s-p}{(6(1+\alpha)t)^2\left(\frac{2}{9}b+4(1+\alpha)t\right)^2}\frac{2}{9}b\Bigg(3(a-s-p)6(1+\alpha)t\left(\frac{2}{9}b+4(1+\alpha)t\right)$$

$$+(a-(1+\alpha)s-p)\,18t\left(4(1+\alpha)^2t(1-\theta)-\frac{2}{9}b\theta-4(1+\alpha)t\right)\Bigg)\Bigg]f(\alpha)\,d\alpha$$

$$\int_{\alpha_2}^{\alpha_1}\Bigg[\frac{\partial R}{\partial\theta} + \frac{a-(1+\alpha)s-q}{(6(1+\alpha)t)^2\left(\frac{2}{9}b+4(1+\alpha)t\right)^2}\frac{2}{9}b\Bigg(3(a-s-q)6(1+\alpha)t\left(\frac{2}{9}b+4(1+\alpha)t\right)$$

$$+(a-(1+\alpha)s-q)\,18t\left(4(1+\alpha)^2t(1-\theta)-\frac{2}{9}b\theta-4(1+\alpha)t\right)\Bigg)\Bigg]f(\alpha)\,d\alpha$$

$$+\Bigg(3\alpha_2 s\big((a-(1+\alpha_2)s-p)-(a-(1+\alpha_2)s-q)\big)\frac{\left(\frac{2}{9}b\theta+4(1+\alpha_2)t\right)}{6(1+\alpha_2)t\left(\frac{2}{9}b+4(1+\alpha_2)t\right)}$$

$$+9\alpha_2 t\frac{(a-(1+\alpha)s-p)^2-(a-(1+\alpha)s-q)^2}{(6(1+\alpha)t)^2}\frac{\left(\frac{2}{9}b\theta+4(1+\alpha)t\right)^2}{\left(\frac{2}{9}b+4(1+\alpha)t\right)^2}\Bigg)f(\alpha_2)\frac{\partial\alpha_2}{\partial\theta}$$

$$+ \int_{\alpha_1}^{1} \frac{\partial R}{\partial \theta} f(\alpha)\, d\alpha \qquad .$$

But with the population normalized to unity,

$$\int_{-1}^{\alpha^2} \frac{\partial R}{\partial \theta} f(\alpha)\, d\alpha \; + \int_{\alpha_2}^{\alpha^1} \frac{\partial R}{\partial \theta} f(\alpha)\, d\alpha \; + \int_{\alpha_1}^{1} \frac{\partial R}{\partial \theta} f(\alpha)\, d\alpha \; = \; \frac{\partial R}{\partial \theta}$$

Tax revenue is:

$$R \; = \int_{\alpha_2(q,\theta)}^{\alpha_1(q)} (q - p)\, 3\, \frac{(a - (1+\alpha)s - q)\left(\frac{2}{9} b\theta + 4(1+\alpha)t\right)}{6(1+\alpha)t\left(\frac{2}{9} b + 4(1+\alpha)t\right)} f(\alpha)\, d\alpha$$

and hence

$$\frac{\partial R}{\partial \theta} \; = \int_{\alpha_2(q,\theta)}^{\alpha_1(q)} 3\,(q-p)\, \frac{(a - (1+\alpha)s - q)}{6(1+\alpha)t\left(\frac{2}{9} b + 4(1+\alpha)t\right)} \frac{2}{9} b\, f(\alpha)\, d\alpha$$

$$- \, 3\,(q-p)\, \frac{(a - (1+\alpha_2)s - q)\left(\frac{2}{9} b\theta + 4(1+\alpha_2)t\right)}{6(1+\alpha_2)t\left(\frac{2}{9} b + 4(1+\alpha_2)t\right)} f(\alpha_2) \frac{\partial \alpha_2}{\partial \theta}$$

Substituting into *dW(θ)/dθ* and rearranging terms:

$$\frac{dW(\theta)}{d\theta} \; = \int_{-1}^{\alpha_2} \frac{a - (1+\alpha)s - p}{\left(6(1+\alpha)t\right)^2 \left(\frac{2}{9} b + 4(1+\alpha)t\right)^2} \frac{2}{9} b \left(3(a - s - p)6(1+\alpha)t\left(\frac{2}{9} b + 4(1+\alpha)t\right) \right. .$$

$$+\,(a-(1+\alpha)s-p)\;18t\left(4(1+\alpha)^2 t(1-\theta)\;-\;\frac{2}{9}b\theta\;-\;4(1+\alpha)t\right)\Bigg)\,f(\alpha)\,d\alpha$$

$$+\int_{\alpha_2}^{\alpha_1}\frac{a-(1+\alpha)s-q}{(6(1+\alpha)t)^2\left(\frac{2}{9}b+4(1+\alpha)t\right)^2}\,\frac{2}{9}b\left(3(a-s-q)6(1+\alpha)t\left(\frac{2}{9}b+4(1+\alpha)t\right)\right.$$

$$+\,(a-(1+\alpha)s-q)\;18t\left(4(1+\alpha)^2 t(1-\theta)\;-\;\frac{2}{9}b\theta\;-\;4(1+\alpha)t\right)\Bigg)\,f(\alpha)\,d\alpha$$

$$+\int_{\alpha_2}^{\alpha_1}(q-p)\;3\,\frac{(a-(1+\alpha)s-q)}{6(1+\alpha)t\left(\frac{2}{9}b+4(1+\alpha)t\right)}\,\frac{2}{9}b\,f(\alpha)\,d\alpha$$

$$-\,3\,(q-p)\,\frac{(a-(1+\alpha_2)s-q)\left(\frac{2}{9}b\theta+4(1+\alpha_2)t\right)}{6(1+\alpha_2)t\left(\frac{2}{9}b+4(1+\alpha_2)t\right)}\,f(\alpha_2)\,\frac{\partial\alpha_2}{\partial\theta}$$

$$+\left(3\alpha_2 s\big((a-(1+\alpha_2)s-p)-(a-(1+\alpha_2)s-q)\big)\frac{\left(\frac{2}{9}b\theta+4(1+\alpha_2)t\right)}{6(1+\alpha_2)\,t\left(\frac{2}{9}b+4(1+\alpha_2)t\right)}\right.$$

$$\left.+\,9\alpha_2 t\,\frac{(a-(1+\alpha)s-p)^2-(a-(1+\alpha)s-q)^2}{(6(1+\alpha)t)^2}\,\frac{\left(\frac{2}{9}b\theta+4(1+\alpha)t\right)^2}{\left(\frac{2}{9}b+4(1+\alpha)t\right)^2}\right)f(\alpha_2)\,\frac{\partial\alpha_2}{\partial\theta}$$

We can sign this as:

1. Knowing that $-1<\alpha\le\alpha_2<0$ implies $a-(1+\alpha)s-p>0$ and that $4(1+\alpha)t>4(1+\alpha)^2 t(1-\theta)$; in addition we know $a-s-p<0$. Henc

negative.

2. Combine the second and third integrals:

$$+\int_{\alpha_2}^{\alpha_1} \frac{a-(1+\alpha)s-q}{(6(1+\alpha)t)^2\left(\frac{2}{9}b+4(1+\alpha)t\right)^2}\frac{2}{9}b\left(3(a-s-q)6(1+\alpha)t\left(\frac{2}{9}b+4(1+\alpha)t\right)\right.$$

$$+(a-(1+\alpha)s-q)\,18t\left(4(1+\alpha)^2t(1-\theta)-\frac{2}{9}b\theta-4(1+\alpha)t\right)$$

$$\left.+3\,(q-p)\,6(1+\alpha)t\left(\frac{2}{9}b+4(1+\alpha)t\right)\right)f(\alpha)\,d\alpha$$

$$=\int_{\alpha_2}^{\alpha_1} \frac{a-(1+\alpha)s-q}{(6(1+\alpha)t)^2\left(\frac{2}{9}b+4(1+\alpha)t\right)^2}\frac{2}{9}b\left(3(a-s-p)6(1+\alpha)t\left(\frac{2}{9}b+4(1+\alpha)t\right)\right.$$

$$\left.+(a-(1+\alpha)s-q)\,18t\left(4(1+\alpha)^2t(1-\theta)-\frac{2}{9}b\theta-4(1+\alpha)t\right)\right)f(\alpha)\,d\alpha$$

This is negative because $\alpha_2 \leq \alpha < \alpha_1 < 0$ implies that $a-(1+\alpha)s-q > 0$ and th $4(1+\alpha)t > 4(1+\alpha)^2t(1-\theta)$, and in addition we know that $a-s-p<0$.

3. Combine the last terms:

$$\left(-3\,(q-p)\frac{(a-(1+\alpha_2)s-q)\left(\frac{2}{9}b\theta+4(1+\alpha_2)t\right)}{6(1+\alpha_2)t\left(\frac{2}{9}b+4(1+\alpha_2)t\right)}\right.$$

$$+3\alpha_2 s\big((a-(1+\alpha_2)s-p)-(a-(1+\alpha_2)s-q)\big)\frac{\left(\frac{2}{9}b\theta+4(1+\alpha_2)t\right)}{6(1+\alpha_2)t\left(\frac{2}{9}b+4(1+\alpha_2)t\right)}$$

$$+ 9\alpha_2 t \frac{(a-(1+\alpha)s-p)^2-(a-(1+\alpha)s-q)^2}{(6(1+\alpha)t)^2} \frac{\left(\frac{2}{9}b\theta+4(1+\alpha)t\right)^2}{\left(\frac{2}{9}b+4(1+\alpha)t\right)^2} \Bigg) f(\alpha_2)\frac{\partial\alpha_2}{\partial\theta}$$

.

But we know that $a-(1+\alpha_2)s-q>0$; and $q > p$ implies that $a-(1+\alpha_2)s-p>a-(1+\alpha_2)s-q>0$ $\alpha_2<0$; and . Hence each negative. In addition, $\partial\alpha_2/\partial\theta>0$ so that the whole term is negative.

Summarizing,

$$\frac{dW(\theta)}{d\theta}<0$$