TAXING TAR AND NICOTINE*

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1. Introduction

Two decades of controversy have finally produced a "cure" for the cigarette problem. If you can't quit, so the new dictum goes, then switch.

Public propaganda designed to deter cigarette smoking has been partially successful. But the alternative goal of detoxifying the product seems more realistic. Within the past three years, in fact, the tobacco industry has brought forth so many new low-tar, low-nicotine cigarettes that these brands are expected to occupy over 20 percent of the 1977 cigarette market.¹

The debate over the medical benefits of these modifications is by no means settled. Evidence is accumulating, for instance, that carbon monoxide - rather than any particulate smoke constituent - was the main culprit all along. Despite this continuing scientific uncertainty, the shifting of consumption patterns toward safer cigarettes remains an attractive possibility.

This paper seeks to analyze one particular method of changing the pattern of cigarette consumption - namely, the levying of special taxes on dangerous cigarette components. This regulatory idea is far from fanciful.

A special tax on cigarette brands exceeding 17 milligrams of tar and 1.1 milligrams of nicotine has been in effect in New York City since 1971.²

The proposed Cigarette Health Protection Tax Act of 1977 (H.R. 3881) contains a entire schedule of tax surcharges based upon a special toxic dosage

scale. Although several authors have begun to analyze the administrative and legal mechanics of such a scheme, there has been no careful dissection of the scientific and economic principles underlying the use of this type of tax instrument. This is my current task.

The cigarette taxation problem is particularly interesting as a case study in market-based regulation. We are constantly discovering new dangers in the products and lifestyles we have always enjoyed. Because many of these things just cannot be outlawed, our government must determine how to get people to take these dangers into account. In a decentralized world of free individual choice, however, the appropriate corrective action is not so obvious.

The cigarette taxation problem is also a special case of the nonlinear pricing problem. Nonlinear pricing schemes have already been proposed as a useful method of economic regulation. Unfortunately, vending machines prevent us from tying the cigarette price to the quantity consumed. Attaching the price variation to a particular characteristic, however, may be a useful approximate method of achieving the same result, especially when this characteristic is correlated with the frequency of cigarette consumption.

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3 H.R. 3881, 95th Congress, 1st. Sess. (1977), was introduced by Congressman Drinan and 17 other cosponsors. This bill was substantially similar to H.R. 10612, 94th Congress, 2d. Sess. (1976), proposed by Senators Hart, Kennedy, and Moss as title XXII of the Tax Reform Act of 1976.

In the Drinan bill, the number of "toxic units" in each cigarette was calculated as the tar content (mg.) plus 10 times the nicotine content (mg.). The surcharge schedule was as follows.

<table>
<thead>
<tr>
<th>Toxic Units</th>
<th>Surcharge per Pack</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;10</td>
<td>.0</td>
<td>NOW(2.7)</td>
</tr>
<tr>
<td>10.0-19.9</td>
<td>.05</td>
<td>KENT GOLDEN LIGHTS(13.1)</td>
</tr>
<tr>
<td>20.0-29.9</td>
<td>.15</td>
<td>MARLBORO SOFT PACK(27.4)</td>
</tr>
<tr>
<td>30.0-39.9</td>
<td>.30</td>
<td>WINSTON 100S(31.7)</td>
</tr>
<tr>
<td>&gt;40</td>
<td>.50</td>
<td>PALL MALL KING(41.9)</td>
</tr>
</tbody>
</table>

My examples in this table are calculated from the most recent F.T.C. tar and nicotine measurements (June 1977).

4 See Drayton (1972) and Garner (1977).

5 See for example Weitzman (1976), Roberts and Spence (1976), Mirrlees (1976), and Spence (1977).
My analysis of the cigarette problem here is mathematically similar to the treatment of externalities. On the one hand, individuals derive satisfaction from cigarettes; firms make profits; governments obtain tax revenues. On the other hand, this consumption activity produces noxious health damage. Because of ignorance, addiction or social pressure, consumers of this product do not take these costs into account in their smoking decisions. The problem is to correct for this mistake. Some readers might object that only bonafide externalities - such as toxic sidestream smoke in poorly ventilated public places - should qualify for corrective taxation. However, such economic orthodoxy does not seem to confront the real public health problem facing our government.

After this introduction, Section 2 models an economy of individuals who make cigarette consumption and cigarette brand choice decisions. In order to focus the analysis, I will consider the case in which a single dimension of the product (tar content, for example) is to be regulated. As a further simplification, I will ignore income effects. There will be no explicit concern that these indirect taxes may be regressive.

Section 3 then uses this model to analyze the optimal uniform pricing rule. This pricing rule shows how the welfare effects of tax changes depend upon intercorrelations between individual price sensitivities and marginal dose-response effects of cigarette smoking.

Section 4 then focuses on the prototypical case in which a surcharge is added to the unit price of all cigarette brands whose tar/nicotine content exceeds a specific cutoff point. The main question is how best to manipulate the three parameters under the regulator's control: the base

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6 Most econometric studies have found the income elasticity of demand for cigarettes to be negligible. See for example Miller (1975) and Lyon and Spruill (1977). The 1975 Adult Use of Tobacco Survey, however, found that high income males are less likely to smoke than lower income males, while high income females are more likely to smoke. See U.S. Department of H.E.W. (1976). This question needs more investigation.

7 For a similar result, see Diamond (1975).
tax, the tar/nicotine cutoff, and the surcharge. Section 5 suggests how these results might be applied in practice. The available scientific evidence on cigarette-induced health damage, it turns out, leads us to a striking interpretation of the optimal tax rule.

Section 6 then suggests some tentative generalizations of this type of analysis. One possible extension is to tax cigarettes according to a vector of multiple characteristics, such as the type of filter, the porosity of the paper, the presence of nontobacco additives, and so forth. Another extension involves the use of an incremental or stepwise schedule of tax increases rather than a single, one-shot surcharge. It is important to note, however, that there is no general quantum theoretical result in which smoothly nonlinear taxes are approximated in the limit. This conclusion is based upon a hidden non-convexity in the problem.

This first attempt to analyze tar and nicotine surcharges focuses mostly on the demand side of the cigarette problem. A more general model would take into account the consequences of these taxes on brand rivalry and pricing behavior in the oligopolistic cigarette market. The model described below, however, appears to lend itself naturally to such an extension. The tar and nicotine tax can force discrete jumps in smokers' cigarette consumption choices. Similarly, it may induce firms to alter product characteristics to find suitable nooks in the tar/nicotine spectrum.

I emphasize that taxing tar and nicotine is not entirely equivalent to the creation of a separate "market" in these product characteristics. Instead, a central authority is manipulating a price schedule which is inextricably tied to an existing market. Taxing chablis by alcohol content or cars by gas mileage or chow mein by MSG concentration are similar examples.
2. Notation

The population under consideration consists of a large number of individuals, indexed by the continuous parameter \( n \), which is distributed with density function \( f(n) \) over the interval \([0,1]\). Each individual's cigarette consumption is characterized by two variables: \( x \), the number of cigarettes smoked daily; and \( \alpha \), the tar/nicotine (T/N) content of the particular brand smoked. Individuals are, by convention, ranked so that their T/N consumption \( \alpha \) increases with \( n \). Our ability to make this rank ordering depends on the assumption that it is preserved as we change our cigarette taxation policies. As long as the relevant range of our cigarette tax variables is not too large, this assumption is realistic. Only direct empirical measurements, however, can test its validity.

In order to eliminate income effects, I assume that each consumer has a utility function of the form

\[
V(x,\alpha,y,n) = U(x,\alpha,n) + y \tag{1}
\]

where \( y \) is a numeraire good. \( U(x,\alpha,n) \) is assumed to be concave in \( x \) and \( \alpha \). Furthermore the partial derivative \( U_\alpha \) equals zero for some values of \( x \) and \( \alpha \). That is, individuals can be satiated with respect to tar and nicotine. Finally, I assume that each individual also has a health damage function \( H(x,\alpha) \), which is independent of \( n \).\(^8\) The damage function \( H \) is measured in dollar units. It is assumed to be nondecreasing in \( x \) and \( \alpha \).

Each individual maximizes utility subject to a budget constraint which has the general form

\[
R(x,\alpha) + y = Y \quad \tag{2}
\]

where \( Y \) is income. The consumer payments \( R(x,\alpha) \) are assumed to be distributed

---

\(^8\)The possibility of heterogeneous health damage effects could be introduced by appending an additional parameter \( m \) to the damage function as \( H(x,\alpha,m) \). The results below would then depend upon the joint probability density of \( m \) and \( n \).
in some way among tax revenues and cigarette company profits.\(^9\) Note that maximizing (1) subject to (2) is equivalent to maximizing \(U(x,\alpha) - R(x,\alpha) + Y\).

In making their smoking decisions, individuals ignore the health costs \(H(x,\alpha)\). The idea behind our tax policy is to correct for these omissions.

Let \(c\) be the marginal cost of production of cigarettes. For simplicity, I assume that \(c\) is constant and independent of \(\alpha\).\(^{10}\) Total profits plus tax revenues will therefore be

\[
\int_0^1 \left[ R(x,\alpha) - cx \right] f(n)dn \quad (3).
\]

Now define a social objective function which is the sum of individuals' utilities plus tax revenues plus profits minus total health damages. That is,

\[
W = \int_0^1 \left[ V(x,\alpha,y,n) + R(x,\alpha) - cx - H(x,\alpha) \right] f(n)dn
   = \int_0^1 \left[ U(x,\alpha,n) + Y - cx - H(x,\alpha) \right] f(n)dn \quad (4).
\]

This social welfare function is not sensitive to the distribution of benefits among consumers, tax revenues and cigarette company profits. It is also not sensitive to the distribution of health damages across individuals.

\(^9\)It is not necessary to assume that cigarette manufacturers are paid marginal cost. Only the deviation of the retail price from marginal cost will be relevant in this analysis. Of course we do have to worry that cigarette sellers will attempt to eliminate tax-induced retail price differences by manipulating their pretax prices. See Drayton (1972).

\(^{10}\)This simplification is intended to focus the analysis on the public health aspects of the corrective tax problem. If we introduced cost differences among cigarette brands, then the marginal cost \(c\) would be replaced by a weighted average of marginal costs, where the weights are price sensitivities of demand. The fact remains, however, that cigarettes vary considerably in the quality of tobacco, the looseness of tobacco packing, methods of sheet tobacco reconstitution, nontobacco additives, etc. The use of taxes to differentiate brands of different costs may therefore have important efficiency consequences, especially in an oligopolistic cigarette market where prices are uniform. See Note 11.

It is also worth noting that this formulation does not impose any constraints on minimum tax revenues. Including such a constraint, unfortunately, would turn this into a general equilibrium problem. One way of avoiding this difficulty in practice is to calculate \(c\) as the marginal cost of production plus an "optimal" tax markup. Thus, in the absence of health damage the "first best" solution would be to set price at marginal cost plus a separately calculated optimal tax rate. Such an approach assumes that our current tar/
3. The Uniform Price Case

We now consider the case where the unit price of cigarettes is independent of \(x\) and \(\alpha\). We can think of this price as being the sum of the cigarette manufacturer's uniform price plus a uniform cigarette tax.\(^{11}\) The consumer's objective function is thus \(U(x,\alpha,n) = px + Y\). The first order conditions for utility maximization are

\[
\begin{align*}
U_x(x,\alpha,n) &= p \\
U_\alpha(x,\alpha,n) &= 0
\end{align*}
\]

where subscripts stand for partial derivatives. Denote the utility maximizing values of \(x\) and \(\alpha\) solving (5) by \(x(p,n)\) and \(\alpha(p,n)\). Because we have eliminated income effects, \(x_p(p,n) \leq 0\). However \(\alpha_p(p,n)\) may be positive or negative. The former corresponds to the case where tar/nicotine \(\alpha\) and consumption \(x\) are substitutes. The latter corresponds to the case where \(\alpha\) and \(x\) are complements.

The derivative of \(W\) with respect to \(p\) is

\[
\frac{dW}{dp} = \int_0^1 \left[ U_x x_p + U_\alpha \alpha_p - c_x x_p - H x_p - H_\alpha \alpha_p \right] f \, dn
\]

(Footnotes continued from page 7) 

nicotine tax surcharge has little effect on the optimal structure of direct and indirect taxation in the economy. See Harris (1977).

\(^{11}\) The assumption that the uniform price \(p\) is independent of \(\alpha\) is consistent with current pricing behavior in the cigarette industry. Although cigarette retail prices do vary by size (regular, king, 100mm) and by type of sale (counter, vending machine, carton lot), these differences are not correlated with tar/nicotine content. I am indebted to June Sears of the Tobacco Tax Council for providing data on this point.

\(^{12}\) Strictly speaking, we should write \(U_x \leq p\) (with \(U_x = p\) for \(x > 0\)) to include the possibility of corner solutions. This refinement, however, will not affect the optimal tax rules below.
where I have omitted the arguments of the functions f(n), x(p,n), a(p,n), U(x,α,n) and H(x,α). Substituting (5) into (6), we get

\[
\frac{dW}{dp} = (p-c)\int_0^1 x_p f \, dn - \int_0^1 H_x x_p f \, dn - \int_0^1 H_α x_p a \, dn \tag{7}
\]

The first expression in (7) is a conventional dead-weight loss term. The other two expressions are health damage effects. The expressions indicate why individual heterogeneity may be so important in the analysis of corrective taxes. As the second term in (7) suggests, the health effect of a small price increase will depend on the correlation between marginal health damage $H_x$ and price sensitivity $x_p$. If those individuals who are most damaged by a marginal increase in consumption are also those who are the most price sensitive, then a small cigarette tax increase could be a "good hit." This effect may be quantitatively significant even if the average price sensitivity $\int x_p f \, dn$ in the population is quite low. Similarly, the third term in (7) suggests that a relatively small price increase may have a very favorable public health effect if those individuals with the highest marginal tar/nicotine damage $H_α$ are also those who regard tar/nicotine $α$ and consumption $x$ as complements. The necessary conditions for a maximum of $W$ are\(^\text{13}\)

\[
p - c = \frac{\int_0^1 H_x x_p f \, dn}{\int_0^1 x_p f \, dn} + \frac{\int_0^1 H_α x_p a \, dn}{\int_0^1 x_p f \, dn} \tag{8}
\]

This corrective pricing rule is similar to that derived by Diamond (1975). The excess of price over marginal cost consists of two terms. The first is a weighted average of individual marginal health damages, where the weights are individuals' price sensitivities of demand. The second term picks up

\(^\text{13}\)For discussion of the second-order conditions, see below.
the possible substitution or complementarity effects of a price change on tar/nicotine consumption $\alpha$.

In applying this rule, we are attempting to find the "best linear approximation" to the dose-response curve for cigarette damage. The problem is that we are using one uniform tax variable ($p$) to capture the algebraic effects of two related dose-response relations - one for cigarette consumption $x$ and the other for tar/nicotine $\alpha$. Even in the scientifically controversial case where the dose-response curve for cigarette consumption $x$ is linear through the origin, its slope $H_x$ may still depend upon each individual's T/N consumption $\alpha$.

Before we leave the uniform price case, it will be useful to define two types of indirect utility functions. Let

$$\mu(\alpha,p,n) = \max_x \{U(x,\alpha,n) - px + Y\}$$

(9).

The indirect utility function $\mu$ represents the maximum utility achieved at a uniform price $p$ when $\alpha$ is fixed at a particular value. Let $x(\alpha,p,n)$ be that choice of $x$ in (9) which maximizes $U(x,\alpha,n) - px + Y$. We see that $x_p(\alpha,p,n) \leq 0$ but that $x_\alpha(\alpha,p,n)$ has ambiguous sign. Now let

$$v(p,n) = \max_\alpha \mu(\alpha,p,n)$$

(10).

The indirect utility function $v$ represents the maximum utility achieved at a uniform price $p$ when both $x$ and $\alpha$ are chosen optimally. By the envelope theorem, these utility-maximizing choices will be $x(p,n)$ and $\alpha(p,n)$.

4. The Tar/Nicotine Surcharge

We are now in a position to analyze the effect of a surcharge on cigarette brands with high tar/nicotine (T/N) content. Cigarette brands with T/N content in excess of some cutoff level $\alpha^*$ will have price $q$. Those brands with T/N contents not exceeding $\alpha^*$ will have price $p < q$. The graph of this price schedule in the $(\alpha,p)$ plane is depicted in Figure 1.
Figure 1
The points D, E and F crudely characterize the three kinds of responses we would expect from cigarette smokers. Those at point D consume cigarettes with T/N not exceeding α*. Consumers at point E, by contrast, would be willing to smoke higher T/N cigarettes if the cutoff point α* were increased. But their desires for higher T/N are not so great that they would be willing to pay the higher price q. Finally, those at F are willing to pay the higher price for higher T/N.

We can also get a rough idea of the separate effects of small changes in our three control parameters, p, q and α*. A small increase in p, for example, will cause consumers in group D to decrease their cigarette consumption. Whether these individuals switch brands will depend on their particular preferences. Note also that an increase in p will shift some consumers from group E into group F. Such individuals would no longer be willing to save money by purchasing low T/N cigarettes. They respond to this marginal change in p by a discrete jump to a higher tar level. Although their consumption responses are not a priori predictable, they will also be discrete. Note finally that marginal changes in p will not affect consumers already in group F.

A similar type of analysis can be applied to marginal changes in our two other control variables, α* and q. It turns out that a marginal decrease in q will induce marginal responses among consumers in group F, discrete responses among consumers in group E, and no response among those in group D. On the other hand, marginal changes in α* will affect only those in group E.

In fact, these individuals may quit smoking altogether. This observation raises an interesting speculative possibility. We might get people to quit smoking by first using a surcharge to drive them to the low-tar brands, and then raising the base tax to crowd them out of the market.
In Figure 2, "indifference curves" for the indirect utility function \( u \) are superimposed upon the price schedule of Figure 1. The indifference curves are drawn in this example to correspond to an individual at the corner solution \( E \) in Figure 1. The direction of increasing utility is downward and to the right. When faced with a uniform price, this individual selects that indifference curve which is just tangent to a horizontal price line. The expansion path corresponding to these tangency points is the curve \( AA' \). In this example, \( AA' \) slopes downward, i.e. \( x \) and \( x \) are complements. The points, \( \alpha(q,n) \) and \( \alpha(p,n) \) indicate the \( T/N \) levels which this consumer would have purchased if faced with uniform price schedules at \( q \) and \( p \) respectively. In the presence of a tar/nicotine surcharge, however, the price schedule is now a single step function. It is therefore possible that \( \mu \) will be maximized at the corner \( E \), as in Figure 2. Note that \( \mu^1 = v(p,n), \mu^2 = \mu(\alpha^*,p,n), \) and \( \mu^3 = v(q,n) \).

We can now formally characterize the three types of responses suggested by Figure 1. Those individuals \( n \) for whom \( \alpha(p,n) \leq \alpha^* \) correspond to point \( D \). They will consume \( x(p,n) \) and \( x(p,n) \) and have utility \( v(p,n) \). Those individuals \( n \) for whom \( \alpha(p,n) > \alpha^* \) and \( \mu(\alpha^*,p,n) \geq v(q,n) \) correspond to point \( E \). They will consume \( x(\alpha^*,p,n) \) and \( \alpha^* \) and have utility \( \mu(\alpha^*,p,n) \). Finally, those individuals \( n \) for whom \( \alpha(p,n) > \alpha^* \) and \( \mu(\alpha^*,p,n) < v(q,n) \) correspond to point \( F \). They will consume \( x(q,n) \) and \( \alpha(q,n) \) and have utility \( v(q,n) \). We can thus partition our population according to two indices, \( n' \) and \( n'' \), where \( n' \) is the root of

\[
\alpha(p,n) = \alpha^* \tag{11}
\]

and \( n'' \) is the root, for all \( n > n' \), of

\[
\mu(\alpha^*,p,n) = v(q,n) \tag{12}
\]
Figure 2
If \( n < n' \), then consumer \( n \) is in the D group. If \( n' < n < n'' \), then consumer \( n \) is in the E group. If \( n'' < n \), then consumer \( n \) is in the F group.

Consumers \( n' \) and \( n'' \) are right on the margins between groups.

Total welfare is now

\[
W = \int_0^{n'} \left[ v(p,n) + (p-c)x(p,n) - H(x(p,n),\alpha(p,n)) \right] f(n)dn
+ \int_{n'}^{n''} \left[ \mu(\alpha^*,p,n) + (p-c)x(\alpha^*,p,n) - H(x(\alpha^*,p,n),\alpha^*) \right] f(n)dn
+ \int_{n''}^{1} \left[ v(q,n) + (q-c)x(q,n) - H(x(q,n),\alpha(q,n)) \right] f(n)dn
\]

(13).

Setting \( W_p = 0 \), \( W_q = 0 \) and \( W_{\alpha^*} = 0 \) yields

\[
p - c = \frac{\int_0^{n'} [ H_x p + H_\alpha p ] f dn + J_{n''}}{\int_0^{n'} x_p f dn}
\]

(14),

\[
q - c = \frac{\int_{n''}^{1} [ H_x q + H_\alpha q ] f dn + J_{n''}}{\int_{n''}^{1} x_q f dn}
\]

(15),

and

\[
\int_{n'}^{n''} [ U_\alpha - c x_\alpha ] f dn = \int_{n'}^{n''} [ H_\alpha + H_x x_\alpha ] f dn + J_{n''}\]

(16),

where

\[
J = \left[ H(x(\alpha^*,p,n''),\alpha^*) - H(x(q,n''),\alpha(q,n'')) \right] f(n'')
+ \left[ (q-c)x(q,n'') - (p-c)x(\alpha^*,p,n'') \right] f(n'')
\]

(17).
These conditions tell us to do the following. For groups D and F respectively, set tax rates $p$ and $q$ so that these price-cost margins are approximately equal to the weighted marginal health damages for their respective populations. I use the term "approximately" because there are additional "jump terms" (involving $J$) which capture the discrete moves from group E to group F resulting from marginal changes in these control parameters. The magnitude of these jump terms must be evaluated with respect to a specific set of demand functions and a health damage function. In general, we cannot assume that these jump terms are negligible. Finally, condition (16) tells us that for group E, the marginal benefit of tar/nicotine should be equal on average to the marginal health damage.

5. Analyzing the Optimal Tax Rules

Let us now examine the first order conditions (14), (15), and (16) in detail. Panel A of Figure 3 displays the distribution of tar content of cigarettes in 1976.\(^{15}\) The great fraction of the current market is claimed by the conventional filter-tipped brands in the 15-19mg. range, such as Marlboro, Winston, and Kent. The small peak in the 24-26mg. range represents the established nonfilter brands such as Chesterfield King and Lucky Strike Regular. A significant fraction of the market has now moved into the 0-15mg. range, with such brands as Carlton, Vantage, and Decade. From the viewpoint of brand competition, it appears that the low-tar varieties have not yet found their own nook in the tar distribution.

\(^{15}\)I calculated this distribution from the F.T.C. tar measurements and John Maxwell's data on the sales of various cigarette brands. See Federal Trade Commission (1977) and Maxwell (1976). Unfortunately, Panel A represents the sales-weighted distribution of tar. Yet our theory requires the distribution of tar content among individuals. This distribution would accurately reflect the distribution of tar among smokers only if $x$ and $\alpha$ were independent across individuals. Although Waingrow et al (1968) in fact found that the number of cigarettes smoked per day was uncorrelated with a tar-related cigarette toxicity measure, I suspect that this finding would not be confirmed if repeated on the recent 1975 Adult Use of Tobacco data.
Figure 3

A

B

TAR PER CIGARETTE (mg.)

α*
Panel B displays the hypothetical effect of a surcharge on all cigarette brands with content exceeding $\alpha^* = 11$mg. Those consumers in the 11-16mg. range and an additional 5% in the 16-17mg. range have moved to the $\alpha^*$ brands. Those below $\alpha^*$ are unaffected. Those remaining above $\alpha^*$ would rather pay the higher price $q$ than adhere to the $\alpha^*$ limit.

Note that the distribution of tar consumption among those individuals above $\alpha^*$ is not necessarily identical to that in Panel A. In this example, the higher price $q$ faced by these individuals has pushed some of them back to the high-tar, nonfilter brands. These smokers, regarding $x$ and $\alpha$ as substitutes, are buying stronger cigarettes to make up for their necessarily diminished consumption at the higher price. An analogous consumption effect applies to the group bunched at $\alpha^*$. Some of these individuals may have increased their cigarette smoking frequency to compensate for the low-tar intake. The quantitative behavioral responses of these groups are in principle empirically testable. But this example at least raises the worrisome possibility that many of the smokers bunched at $\alpha^*$, who formerly smoked regular filter-tipped 16 mg. cigarettes, are now puffing away to compensate for the switch.

Panel B also illustrates why the jump terms $J_n^p$, $J_n^q$ and $J_n^\alpha$ may not be trivial. The magnitudes of these terms depend in part upon the number of smokers ready to jump to $\alpha^*$ in response to a marginal increase in this cutoff level. Although we cannot be certain without an explicit calculation, the example in Panel B suggests that a large fraction of 16-17mg. smokers are ready to make this jump. On the other hand, as we continue to increase $\alpha^*$ to past the 16mg. level, we may be able to bunch all of the conventional

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My restrictive assumption that $\alpha$ is an increasing function of $n$ requires that we clear out all those in the 11-16mg. range before we start moving those in the 16-17mg. range.
filter smokers at the new cutoff. At that point, there may be very few smokers left to jump to \( \alpha^* \), since the nonfilter smokers in the high 20's are too far off to be affected. Hence the jump terms in (14) - (16) at \( \alpha^* = 16 \text{mg} \) may be very small.

We see that the cutoff \( \alpha^* \) has properties quite similar to a regulatory standard. In economic terms, the surcharge \( q-p \) can be interpreted as the penalty paid per unit of cigarette consumption in violation of this standard.\(^17\) As the surcharge \( q-p \) becomes very large, the high tar brands approach the point of prohibition. The illustration in Figure 3 shows how a policymaker can titrate the effect of this standard by monitoring changes in the distribution of \( \alpha \) in the market.

The appropriate choice for this cutoff standard depends not only upon these discrete jump effects, but also upon the conjunction of certain scientific and economic relationships. Provided that individual's preferences for the cigarette component \( \alpha \) are not too narrow,\(^18\) the first order conditions (16) suggests that we should seek a value of \( \alpha^* \) right around any possible "threshold" on the tar/nicotine dose-response curve. This makes intuitive sense. If we are going to bunch individuals at \( \alpha^* \), then we should pick a tar/nicotine cutoff which is in some sense "safe". Such a threshold level would correspond to a point at which \( H_{\alpha} + H_{x^*} \) is rapidly

\(^17\)This is probably a good way of looking at any regulatory standard. One recent F.D.A. order, for example, permitted a maximum of 2 rodent hairs per 100gm. of peanut butter. In effect a manufacturer of peanut butter is actually facing a step-function tax schedule at \( \alpha^* = 2 \) hairs/100gm. The surcharge \( q \) is the expected cost of abatement plus fines if a violation is discovered.

\(^18\)By this I mean that the magnitude \( \int \nabla_x f d\eta \phi_{\alpha} \) is not too negative. If individual preferences were strongly peaked around a particular tar/nicotine level, then this effect might dominate in the choice of \( \alpha^* \) in equation (16).
Increasing as we increase $\alpha^*$, that is, where the curvature of the dose-response curve is largest.

As (16) suggests, our calculations of this "safe" level of tar/nicotine require that we do not hold consumption $x$ constant. This is because the curvature of the dose-response curve at $\alpha^*$ is not $H_{\alpha \alpha}$ but rather

$$\frac{d^2H}{d\alpha^2} = H_{\alpha \alpha} + [H_{xx}x^2 + 2H_{\alpha x}x \alpha + H_{x}x \alpha]$$ \hspace{1cm} (18).$$

In effect, we are finding the point of highest curvature of a behavioral rather than a scientific dose-response curve. The distinction between these two types of dose-response curves is that the former allows consumption $x$ to vary as $\alpha$ changes. The latter is the pure ceteris paribus relationship. When measuring the damage function for the purpose of regulation, we should not hold constant any parameter which we cannot control in practice.

Figure 4 interprets what little information is available on the damage curve for tar/nicotine.\(^{19}\) These results are derived from prospective matched group analyses performed by Hammond et al (1976) for subjects during the period 1966-1972.\(^{20}\)

\(^{19}\) These are also some earlier retrospective studies which suggest that smokers of filter cigarettes have lower mortality risks than smokers of nonfilter cigarettes. See, for example, Bross and Gibson (1968).

\(^{20}\) The idea behind these matched group analyses is to aggregate the mortality experience of smokers in such a way that age, occupational exposures, smoking frequency, and other factors are held constant. In the points displayed in Figure 4, I have combined the mortality ratio results of two such analyses for the 1966-1972 period - one comparing all smokers to the low-tar/nicotine group, the other comparing the low-tar/nicotine group to nonsmoking controls. Combining these ratios is valid only if one assumes that the effects of tar and nicotine on death rates are purely multiplicative and independent of age, smoking frequency, etc. The mean ages of male and female subjects in both matched groups, however, were very close.
Constructed Mortality Ratio (All Causes of Death)

Source: Hammond et al (1976)
Although our analysis requires that health damage be measured in dollar units, I have displayed the results in terms of the mortality ratios - that is, the ratio of age-adjusted annual probability of death in each T/N smoking group to the age-adjusted annual mortality in the nonsmoking controls. For purposes of analysis, these authors classed cigarettes into three T/N groups. The lowest T/N group represented those who smoked cigarettes with generally no more than 17.6 mg. of tar per cigarette. Unfortunately, finer distinctions could not be made in the very low T/N range. Hence, with no other justification than the need to make a point, I have extrapolated (dotted line) the dose-response curve to the origin. I emphasize that in the construction of this curve, we should not control for the possibility that low-α individuals will smoke more heavily. For example the hypothetical threshold at 4mg. tar/cigarette might reflect the fact that low-tar smokers are also very low frequency smokers. The point, however, is that the optimal regulatory cutoff α* will very likely be in this threshold range.

"Tar" is not the only acknowledged dangerous component in cigarette smoke. Carbon monoxide, in fact, may be a far more deleterious constituent. If we could measure the carbon monoxide (CO) delivery of various brands routinely, then a surcharge could be equally well imposed upon higher levels of this component. To illustrate this point, Figure 5 displays a similar dose-response curve constructed for CO. The curve is derived from some tentative results of Wald et al (1973) in which blood carboxyhemoglobin concentrations in various subjects were related to physical examination and historical evidence of atherosclerosis (heart

21 The Federal Trade Commission intends to begin routine CO measurements on all brands by 1980. See also Ross(1976).
Figure 5: Constructed dose-response relation for carbon monoxide delivery per cigarette at approximately 30 cigarettes daily.

Sources: Wald et al. (1973), Sillett et al. (1976).
attack, angina, ischemic electrocardiographic changes, claudication). Although the study attempted to measure the joint effect of both cigarette smoking frequency and CO, the number of subjects in each cell was too small to make any definite inferences. In order to get a stronger result, I have combined the data on all sexes and smoking frequencies. On an additional dosage axis, I have made some rough calculations of the cigarette CO content corresponding to the measured carboxyhemoglobin concentrations.\footnote{See Sillett et al (1976), Table 1, p. 346. These results were used to get a rough idea of the relation between CO delivery per cigarette and carboxyhemoglobin level in various subjects in the steady state. The mean cigarette consumption for these subjects was 29 per day, close to the 1976 U.S. average daily intake per smoker. The problem with any translation of this sort is that CO delivery per cigarette is very sensitive to the smoker's ventilatory parameters (puffs per cigarette, puff flow rate, depth of inhalation, alveolar ventilation rate, etc.) while the half-life of blood carboxyhemoglobin will depend on the smoker's level of physical activity. In principal, the mapping between CO delivery for a standardized method of smoking and carboxyhemoglobin level should not hold constant any parameters out of the regulator's control. Nevertheless, there is considerable uncertainty about the significance of these measurements. See Wald et al (1976).}

This dose-response curve is particularly important because of recent suggestions that some of the lower tar filter cigarettes actually produce a higher level of CO delivery.\footnote{See Wald et al (1976), Ross (1976).} In this case, the evidence suggests increasing marginal damage beyond a carboxyhemoglobin saturation of 3
percent. This threshold is particularly interesting because atmospheric carbon monoxide contamination alone rarely produces carboxyhemoglobin concentrations beyond 2 to 4 percent. On the lower dosage scale, this apparent threshold would correspond to about 7ml. CO per cigarette, a level which was satisfied only by two of the very lowest of the low-tar, low-nicotine cigarettes reported by Reader's Digest.\footnote{See Ross(1976). These brands were Now Kings and Carlton 70s.} Although I can only speculate, this damage curve for CO may be the underlying explanation for the shape of the T/N curve of Figure 4. The loose tobacco packing and higher porosity paper of the very low T/N cigarettes also make them low CO deliverers. Beyond this T/N range, the presence of a filter may prevent the complete combustion necessary to reduce CO.

Examining conditions (14) and (15), we see that the use of a tar/nicotine surcharge represents a form of price discrimination. Its superiority over a uniform price instrument will depend in part on the degree to which the weighted marginal damage terms on the right hand sides of (14) and (15) differ across high-\(\alpha\) and low-\(\alpha\) individuals. One might think of the choice of \(\alpha^*\) as the best place to split up these high-\(\alpha\) and low-\(\alpha\) portions of the market.

These two market fractions may differ not only in relation to health damage effects, but also in relation to the price responsiveness of each set of consumers. The contention that the price elasticity of demand for
cigarettes is very low is actually somewhat misleading in this respect. It may be perfectly accurate to say that the "average smoker" has a price elasticity of demand of no more than (say) 0.5. But this does not rule out the possibility that some smokers may be very price sensitive while others are extremely price insensitive.

Although data on this question are virtually nonexistent, it is useful to trace out the implications of some reasonable possibilities. The high-α end of the market [n",1] most likely consists of intensely habituated smokers who have the highest cigarette consumption x and the lowest price responsiveness x_p. These individuals are also likely to regard smoking frequency x and tar/nicotine α as strong substitutes. That is, a price increase among this group of individuals might shift them from (say) a regular and king to a higher tar 100mm. and 120mm. brand. On the other hand, the low-α end of the market [0,1] most likely consists of price-sensitive individuals with lower cigarette consumption. These individuals, one might postulate, are less likely to regard x and α as strong substitutes.

25 There has actually been considerable debate over this point. Studies of cigarette demand have yielded price elasticity estimates ranging from zero to 1.5, with most estimates hovering around 0.5. The observed variations may be the result of differences in data, methods of estimation, model specification, etc. See Lyon and Spruill (1977). In cross-section studies, a negative correlation between tax rates and consumption may merely mean that tax increases are politically more feasible in states where cigarettes are less popular. In time series studies, it has been very difficult to sort out the relative contributions of price changes, various health scares, advertising bans, and so forth. The exchange among Russell (1973), Atkinson and Skegg (1974) and Peto (1974) in the British literature illustrates very clearly how small changes in model specification or measurement conventions yield large changes in price elasticity estimates.

26 An unpublished 1970 follow-up of smokers in the 1966 Adult Use of Tobacco Survey suggests that smokers who have decreased their T/N consumption have also decreased their smoking frequency. However, those who decreased their T/N by more than 25% did increase their consumption by 15%. (Daniel Horn, personal communication).
The main consequence of these assumptions is an interesting parity between the price variables \( p \) and \( q \) and the dosage parameters \( x \) and \( \alpha \). That is, the term \( H_x x_p \) will dominate in equation (14), while the term \( H_\alpha \alpha_p \) will dominate in equation (15). The base tax rate \( p \) thus picks up the frequency-sensitive health effects, while the tax-plus-surcharge picks up the \( T/N \)-sensitive health effects.

The dose-response curve for consumption frequency \( x \) in Figure 6 lends even more credence to this interpretation. I measure health damage in this case as the difference between mean life expectancy for nonsmokers and mean life expectancies for various smoking frequencies.\(^{27}\) The most striking feature of these curves is their apparent concavity. There may be a threshold for female smokers below 10 cigarettes per day. But in the range beyond one-half pack - which accounts for about 90% of male smokers and 85% of female smokers - the dose-response curve displays diminishing marginal damage. Although there may be some subtle artifacts in the measurement of this dose-response relation, it is nevertheless a consistent finding in the major studies of cigarette smoking and excess mortality.\(^{28}\) It also turns up when some anatomic or behavioral correlate of disease has been

\(^{27}\)All of these health measures are mean values of a probability distribution of health damage. I am therefore assuming that the relevant decisionmaker is risk neutral. Although this assumption would hardly be tenable for individual decision, it is reasonable for the present social decisionmaking context. The life expectancies in Figure 1 are calculated from various Appendix tables in Hammond (1966). My method calculating these life expectancies from tables of age-specific death rates reproduces that of Hammond (1969). For further discussion of possible artifacts and problems of interpreting life expectancy data of this sort, see Harris (1977).

\(^{28}\)Actually, the concavity of the consumption related dose-response curve is not characteristic of all smoking pathology. It is concave for coronary artery disease and chronic obstructive pulmonary disease, but actually shows increasing marginal damage for lung cancer. The former causes of death, however, are far more frequent than lung cancer. There are many possible artifacts in the construction of this curve. For example, reported smoking frequency may be biased by recent health experience. See Harris (1977) for a more complete discussion.
LOST YEARS OF LIFE EXPECTANCY

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Figure 6: Relation between daily cigarette consumption and life expectancy at age 35 for men and women.

Source: Calculated from Hammond (1966)

Appendix Tables 2a, 2b, 3a, 3b.
measured as the endpoint rather than death rates.  

If in fact the low- \( \alpha \) smokers are the low- \( x \), high- \( H_x \), high- \( x_p \) types, then a relatively small tax may have a large welfare effect. We can thus view the base tax \( p \) as being set to crowd the casual smokers, near-quitters and teenage starters out of the market. At the other high- \( \alpha \) extreme, individuals with high- \( x \), but low- \( x_p \) will be frequency insensitive but possibly quite sensitive to changes in particular cigarette constituents. The surcharge \( q \) at this end is designed to pick up the \( \alpha \)-sensitivity of these smokers.

If the magnitude  
\[
\int_0^{n'} H_x x_p f \, dn
\]

is actually very large relative to the health damage effects in the \((n'',1]\) range, then the optimal tax structure may be a very high base price \( p \) and a small tar/nicotine surcharge. In the extreme case, it is even possible that we should merely set a very high uniform tax, with \( p = q \). Rather than using a surcharge to push smokers to \( \alpha^* \), we would be hitting the potential quitters and new starters with full force, leaving the rest of the market to its own devices.

6. Future Directions

The difficulty underlying those limiting cases where the two-tier tax collapses to a uniform tax is that the second-order conditions are breaking down. The dose-response curve \( H \) is so strongly concave in the consumption dimension that our marginal cost-benefit methodology is invalidated. Note that it is perfectly possible for the second-order conditions to be satisfied in the uniform tax case, while they are violated in the two-tiered tax case.  

\[\int_0^1 (x_p \alpha_p) \left[ H_{**}(\alpha_p) \right] f \, dn \]

Intuitively, individuals' economic responses

\[29\text{See for example Auerbach et al (1976) and Wilson (1973).}\]

\[30\text{The reason is that the quadratic form}\]

\[\int_0^1 (x_p \alpha_p) \left[ H_{**}(\alpha_p) \right] f \, dn \]


are sufficiently heterogeneous to remove any nonconvexities in the problem. However, as we begin to chop up the market into homogeneous segments by means of discriminating taxes, these nonconvexities start to show up.

This problem could become particularly important when we consider the natural extension of our two-tiered tax to a multi-tiered tax system. If we set up an entire schedule of tar/nicotine cutoff levels and surcharges, then the optimal tax rule would look very similar to the first-order conditions (14) - (16). We would merely have a series of optimal surcharge and optimal cutoff rules and a corresponding multiplicity of jump terms. However, as we add more T/N cutoffs and surcharges, then at some point the second-order conditions may be violated. At this point, it pays to chop up the market no further.

This difficulty with the use of a decentralized nonlinear tax scheme is actually more basic than are possible nonconvexity of dose-response curve. Even in the case where \( H(x,a) \) is everywhere convex, we may not be able to achieve a smoothly nonlinear tar/nicotine tax. In the limiting case where there are no bunching effects at various cutoff points and no discrete jump terms, the step-wise tax schedule will be replaced by a smoothly differentiable function \( p(a) \). That is, the unit price of cigarettes will vary continuously with the T/N level. But we cannot regard this price schedule as completely mimicking the damage function \( H(a,x) \). The reason for this is that we are stuck with a linear approximation in the x-dimension. Nonlinearities in the cigarette price schedule which derive from

(footnote 30 continued) where \( \left[ H_{**} \right] \) is the Hessian matrix of second-order partial derivatives of \( H \), may be negative when the domain of integration is \([0,1]\). However, this integral may be positive when the domain of integration is some subinterval of \([0,1]\).
specific cigarette characteristics cannot in general make up for this uniform price constraint.

The multiplicity of separate cutoff points and surcharges will naturally be limited by the costs of administering such complex tax schedules. After all, there is a point at which we would need special vending machines with integrated circuitry. My own feeling is that no more than one or two surcharge levels are feasible. The more interesting possibility, it seems, is to extend the concept of specific surcharges to other cigarette constituents. The simplest way to do this is to base the surcharge upon a single index of cigarette toxicity. As long as CO levels of cigarettes are correlated with T/N levels, this procedure may be adequate.

On the other hand, there is some evidence that carbon monoxide levels of some filter cigarettes are actually higher than those of nonfilter brands. In that case, we will need to have a 2-dimensional tax structure. It would not be necessary, however, to set 4 different prices. For example, if $\alpha^* = 5$mg. were the cutoff level for tar and $\beta^* = 6$ml. were the cutoff level for CO, we could have a schedule of the form

\[
p(\alpha, \beta) = \begin{cases} 
0.0 & \text{if } \alpha \leq \alpha^* \text{ and } \beta \leq \beta^* \\
0.05 & \text{if } \alpha > \alpha^* \text{ and } \beta \leq \beta^* \\
0.25 & \text{otherwise.}
\end{cases}
\]

In this case, we are placing most emphasis on bunching smokers at the CO regulatory standard. Adhering to both regulatory limits receives a small additional payoff.

Such simple, two-dimensional systems may be particularly useful in a regime of constantly changing scientific evidence, for they allow the regulator the flexibility of adjusting the parameters as new facts turn up. The effect of such a scheme upon the nature of competition in the cigarette
industry is hard to predict. One could easily imagine a scenario in which manufacturers are constantly second-guessing next year's cutoffs. The regulatory interaction could develop into a dangerous bilateral monopoly problem in which haggling and deception are the dominant strategies. We might even need administrative courts to decide if the aldehydes in Fact or the laser-made filter in Decade merits a special tax exemption.

7. Conclusion

A special surcharge on cigarettes with high tar and nicotine content may have particularly attractive regulatory properties. The base tax would be adjusted to reflect consumption-sensitive health damages among light smokers. The surcharge would capture the tar/nicotine-sensitive health effects among heavy smokers. The cutoff point would have properties very much like a regulatory standard. Such a standard should be set to bunch individuals near possible thresholds in the dose-response curve. For public policy purposes, the measurement of such dose-response curves for cigarette-induced health damage should allow unregulated consumption parameters to vary.

Nonconvexities in the dose-response curve have important implications for the use of marginal cost-benefit analysis. They also present difficulties in the design of decentralized methods of regulation. Such non-convexities, I suspect, are commonplace in the damage function of many noxious substances. The cigarette problem discussed here illustrates how misleading it would be to limit our attention to cases of increasing marginal damage.

The most promising generalization of the tar/nicotine tax discussed here is its extension to include carbon monoxide. We must also further investigate the effects of such tax manipulations on oligopolistic pricing and brand competition in the cigarette industry.


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