Taxing Tar and Nicotine

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Consumer misperception of health consequences is often invoked to justify government intervention in cigarette smoking. Rather than debating this issue here, I address a more practical problem. Suppose that government intervention is warranted by such misperceptions. What then is the most appropriate corrective action?

In particular, I analyze one form of corrective action—the taxation of cigarettes according to their tar and nicotine contents. I set up a benefit-cost framework in which smokers fail to perceive the health costs of cigarette use. Within this framework, I focus on the administratively simple case where different uniform tax rates apply to cigarette brands whose tar and nicotine contents exceed or fall below a specified cutoff value. The main regulatory design question is: What should determine our choice of these two tax rates and the cutoff value of tar and nicotine? The empirical answer below strikingly illustrates how biological and economic facts interrelate in the formulation of a discriminating public policy toward cigarette smoking.

I. Assumptions

The population contains a large number of cigarette smokers, who may differ in their cigarette preferences. In making their consumption decisions, these smokers fail to take account of the health damage produced by smoking. The purpose of the government's tax policy is to correct for these failures. The magnitude of this health damage depends upon the number and type of cigarettes smoked, but it is otherwise independent of tastes and incomes.

Social welfare is defined to be the sum of smokers' willingness to pay for cigarettes minus health damages, plus cigarette producers' profits and plus government tax revenues. This benefit-cost criterion is not sensitive to the distribution of benefits among consumers, government, and cigarette producers. It is also insensitive to the distribution of health damages across smokers.

I shall index smokers' cigarette tastes by the continuous scalar parameter n, which has probability density $f(n)$. Each smoker's consumption is characterized by x, the number of cigarettes smoked; and α, an index of the tar and nicotine (TN) delivery of the particular brand smoked. Smokers' tastes are ordered so that in equilibrium α increases with n. That is, $\alpha_n \geqq 0$, where subscripts stand for partial derivatives. Cigarette brands, I assume, are available over a continuum of values of α.

Let $H(x,\alpha)$ denote the individual health damage, in dollars, from smoking x cigarettes with TN content α, where $H_x > 0$ and $H_\alpha > 0$. Let c be the marginal cost of cigarettes, which is assumed to be constant and independent of α. Let Y and y be a smoker's gross income and his income available for all other goods, respectively. Let the utility function of a smoker with preferences of type n take the form

$$(1) \qquad V(x,\alpha,y,n) = U(x,\alpha,n) + y$$

where $U(x,\alpha,n)$ is concave in x and α. Given (1), a smoker's demand for cigarettes does not depend on his gross income or on the demands for other goods. Moreover, I assume that for all n, $U_\alpha(x,\alpha,n) = 0$ for some values of x and α. That is, smokers can be satiated with respect to the TN delivery of cigarettes. For purely notational convenience, and without loss of generality,

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all smokers are assumed to have the same gross income Y.

II. Uniform Price Case

First consider the case where the after-tax unit price p of cigarettes is independent of α. This case closely approximates current cigarette pricing and taxation.

Each smoker, failing to perceive the cost H, chooses (x,α,y) to maximize V subject to the budget constraint $px+y=Y$. From (1), this is equivalent to choosing (x,α) to maximize $U(x,\alpha,n)-px+Y$. A smoker's contribution to government tax revenues and cigarette producers' profits is $(p-c)x$. Social welfare is therefore

$$(2)\quad W=\int_R [V(x,\alpha,y,n)+(p-c)x - H(x,\alpha)]f(n)dn$$
$$=\int_R [U(x,\alpha,n)+Y-cx-H(x,\alpha)]f(n)dn$$

where the domain of integration is the real line R, and where x, α, and y depend upon p and n.

For each cigarette smoker of type n, the necessary first-order conditions for utility maximization include

$$(3)\qquad U_x(x,\alpha,n)=p$$
$$U_\alpha(x,\alpha,n)=0$$

Denote the utility-maximizing choices solving (3) by $x(p,n)$ and $\alpha(p,n)$. Although $x_p(p,n)\leqq 0$, all p,n, the sign of $\alpha_p(p,n)$ may be positive or negative. When $\alpha_p<0$, cigarette TN and smoking frequency are complements, and when $\alpha_p>0$, they are substitutes. Differentiate W with respect to p and substitute (3)

$$(4)\quad \frac{dW}{dp}=(p-c)\int_R x_p f\,dn - \int_R H_x x_p f\,dn - \int_R H_\alpha \alpha_p f\,dn$$

where I have omitted the arguments of $f(n)$, $x(p,n)$, $\alpha(p,n)$. The first term on the right-hand side measures the conventional deadweight loss resulting from an increase in price. Since $x_p\leqq 0$, the second term necessarily represents an offsetting decrease in health damage. The sign of the third term is in general indeterminate. But when $\alpha_p>0$, all n, the favorable health effect of a price-induced decrease in smoking frequency is counterbalanced by a compensating increase in TN. As we will see in Section IV, this is the important and realistic case.

From (4), the first-order condition for a maximum of W is

$$(5)\quad p-c=\frac{\int_R H_x x_p f\,dn}{\int_R x_p f\,dn}+\frac{\int_R H_\alpha \alpha_p f\,dn}{\int_R x_p f\,dn}$$

This condition reveals two problems in implementing a uniform corrective tax. First, we have only one policy instrument (i.e., p) to influence two different dimensions of cigarette consumption (i.e., x and α), both of which may affect health. By taxing the quantity of cigarettes consumed, we may indirectly and adversely affect individuals' TN choices (see Jerry Green and Eytan Sheshinski). Second, the variability of smokers' cigarette tastes limits the discriminatory power of a uniform tax. Individuals who smoke different quantities of cigarettes with different TN contents will in general have different marginal health damages H_x and H_α. We cannot therefore set the markup $p-c$ equal to the marginal health damage for each smoker. Given this limitation, the price derivatives x_p and α_p tell us which smokers' marginal health damages should get the most weight (see Peter Diamond).

Now define

$$(6)\quad \mu(\alpha,p,n)=\max_x\{U(x,\alpha,n)-px+Y\}$$

The indirect utility function μ represents the maximum utility achieved at a uniform price p when α is constrained at a particular value. Let $x(p,\alpha,n)$ be the maximizing choice of x in (6). We have $x_p(\alpha,p,n)\leqq 0$, and when x and α are substitutes, $x_\alpha(\alpha,p,n)$ is negative. Define

$$v(p,n)=\max_{\alpha}\mu(\alpha,p,n) \tag{7}$$

The indirect utility function v represents the maximum utility achieved at a uniform price p when both x and α are unconstrained. The utility-maximizing choices in (7) are necessarily $x(p,n)$ and $\alpha(p,n)$.

III. Step-Function Price Schedule

Now consider the case where different uniform tax rates apply to cigarette brands whose TN contents exceed or fall below a specified cutoff value. Brands with TN content not exceeding the cutoff value α^* have after-tax price p. Brands with TN content exceeding α^* have after-tax price q. The graph of such a unit price schedule, in the typical case where $q>p$, is the step function of Figure 1. The more general case of multiple cutoffs is considered in Section VI.

The representative points denoted by D, E, F in Figure 1 illustrate the three kinds of responses of individual smokers. Individuals at D smoke cigarettes with TN content less than α^*. Those at E, by contrast, would smoke higher TN cigarettes if α^* were increased. But their desires for higher TN are not so great that they are willing to pay the higher price q. Finally, those at F are willing to pay the higher price q for higher TN. Hereafter, D, E, and F refer interchangeably to subsets of points in the (α,p) plane and to subsets of smokers.

In Figure 2, indifference curves for μ for a particular smoker are superimposed upon Figure 1. The direction of increasing utility is downward. For any uniform price schedule, this smoker's choice of α is determined by the point of tangency of his indifference curve to the horizontal price line. The expansion path corresponding to these tangency points is aa'. In the presence of a step-function price schedule, however, this particular smoker's utility μ is maximized at the corner solution E. Note that $\mu^1=v(q,n)$, $\mu^2=\mu(\alpha^*,p,n)$, and $\mu^3=v(p,n)$.

The subsets D, E, and F correspond to a partitioning of the domain of n into three intervals. The boundary points between these intervals, which I denote by n' and n'', are defined as follows: n' is the root of

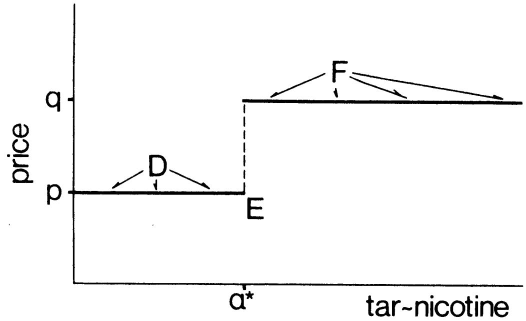

FIGURE 1. STEP-FUNCTION PRICE SCHEDULE

$$\alpha(p,n)=\alpha^* \tag{8}$$

and n'' is the root, for all $n\geqq n'$, of

$$\mu(\alpha^*,p,n)=v(q,n) \tag{9}$$

Individuals in subset D, for whom $n<n'$, smoke $x(p,n)$ cigarettes with TN delivery $\alpha(p,n)<\alpha^*$ and have utility $v(p,n)$. Those in subset E, for whom $n'<n<n''$, smoke $x(\alpha^*,p,n)$ cigarettes with TN content α^* and have utility $\mu(\alpha^*,p,n)$. Those in subset F, for whom $n>n''$, smoke $x(q,n)$ cigarettes with TN content $\alpha(q,n)$ and have utility $v(q,n)$. Smokers of type n' have an indifference curve tangent to the horizontal price line for p exactly at point E. Smokers of type n'' have an indifference curve that passes through point E and is tangent to the horizontal price line for q.

Can this step-function price schedule solve the two conceptual problems posed by the implementation of a uniform corrective tax? For smokers in subset E, we now have as many policy instruments (that is, p and α^*) as dimensions of cigarette consumption (i.e., x and α). In fact, we can locate an individual anywhere to the left of his aa' curve in Figure 2 by appropriately choosing α^* and $p<q$ to form a corner E at that point. (To the right of aa', we would need $q<p$, a case which will not be important below.) Because smokers' cigarette tastes are heterogeneous, however, we cannot neces-

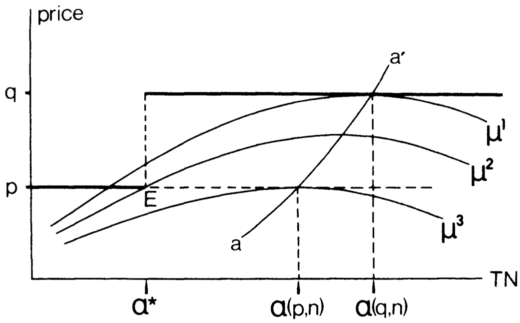

FIGURE 2. INDIFFERENCE CURVES FOR THE INDIRECT UTILITY FUNCTION μ

sarily get all smokers simultaneously to their individual optima at E. In that case, it may be preferable to bunch only some smokers at the corner E, permitting the remaining smokers in D and F to face two different uniform prices. Our regulatory design question becomes: Which cigarette smokers should end up in which subsets?

The social welfare function is

$$(10)\quad W=\int_D\left[v(p,n)+(p-c)x(p,n)-H(x(p,n),\alpha(p,n))\right]f(n)dn+\int_E\left[\mu(\alpha^*,p,n)+(p-c)x(\alpha^*,p,n)-H(x(\alpha^*,p,n),\alpha^*)\right]f(n)dn+\int_F\left[v(q,n)+(q-c)x(q,n)-H(x(q,n),\alpha(q,n))\right]f(n)dn$$

with partial derivatives

$$(11)\quad W_p=(p-c)\int_{D\cup E}x_p f\,dn-\int_{D\cup E}H_x x_p f\,dn-\int_D H_\alpha \alpha_p f\,dn-(J'-J'')n_p''$$

$$(12)\quad W_q=(q-c)\int_F x_q f\,dn-\int_F H_x x_q f\,dn-\int_F H_\alpha \alpha_q f\,dn-(J'-J'')n_q''$$

$$(13)\quad W_{\alpha*}=\int_E(U_\alpha+(p-c)x_\alpha)f\,dn-\int_E H_\alpha f\,dn-\int_E H_x x_\alpha f\,dn-(J'-J'')n''_{\alpha*}$$

where

$$(14)\quad J'=\left[H(x(\alpha^*,p,n''),\alpha^*)-H(x(q,n''),\alpha(q,n''))\right]f(n'')$$

$$(15)\quad J''=\left[(p-c)x(\alpha^*,p,n'')-(q-c)x(q,n'')\right]f(n'')$$

As in (4), changes in the policy parameters p, q, and α^* reflect the balancing of deadweight loss and health damage effects among the affected subsets of smokers. In contrast to (4), marginal changes in these parameters also produce discrete responses among those smokers of type n'' who jump between higher-priced higher TN brands in F and the lower-priced lower TN alternative at E. These additional welfare effects involve health damages (J'), and tax revenues and profits (J''), but not utilities. These discrete jumps cannot be dismissed as second-order magnitudes. In fact, they can dominate the other terms in the welfare gradient. Since the magnitudes of these jump effects depend on the number of smokers on the boundary between E and F (equations (14) and (15)), the welfare gradient may thus be sensitive to the underlying distribution of tastes $f(n)$. As we will see below, if $f(n)$ has many modes, then W may actually have many local optima.

The necessary first-order conditions for a welfare maximum are

$$(16)\quad p-c=\frac{\int_{D\cup E}H_x x_p f\,dn}{\int_{D\cup E}x_p f\,dn}+\frac{\int_D H_\alpha \alpha_p f\,dn}{\int_{D\cup E}x_p f\,dn}+\frac{(J'-J'')n_p''}{\int_{D\cup E}x_p f\,dn}$$

$$(17)\quad q-c=\frac{\int_F H_x x_q f\,dn}{\int_F x_q f\,dn}+\frac{\int_F H_\alpha \alpha_q f\,dn}{\int_F x_q f\,dn}+\frac{(J'-J'')n''_q}{\int_F x_q f\,dn}$$

$$(18)\quad \int_E (U_\alpha+(p-c)x_\alpha)f\,dn-J''n''_{\alpha^*}=\int_E (H_x x_\alpha+H_\alpha)f\,dn-J'n''_{\alpha^*}$$

where (16) and (17) are analogous to (5), and where (18) shows how the marginal benefit from an increase in α^* equals the marginal health cost.

IV. Cigarette Smoking Preferences

The analysis so far has imposed no specific form on the utility functions U. However, there is considerable scientific evidence that consumption x and TN delivery α are, to varying degrees, substitutes. In short-term behavioral experiments, for example, subjects increase their smoking frequency in response to controlled dilution of the cigarette smoke, and decrease their consumption frequency when cigarette tar and nicotine are increased (for example, see M. A. H. Russell et al.; Stanley Schachter; Murray Jarvik). In all of these experiments, smokers differ considerably in the magnitude of their total TN intake and in the extent of their compensation for changes in TN. Heavier smokers, it appears, compensate more for a controlled change in TN than light smokers. Yet no smoker appears to compensate completely for any given change in TN (see S. R. Sutton et al.). In general, there is no strong correlation between smoking frequency and TN choices across smokers (see also Section VI).

To reflect these facts, I assume that the utility functions U have the following form

$$(19)\quad U(x,\alpha,n,m)=-\frac{B}{n}(A\alpha x)^{-n}-\frac{B}{m}\alpha^m$$

where $1\geqq A>0$ and $B>0$ are fixed constants, and where both $n>0$ and $m\geqq 1$ are taste parameters which may vary among smokers. The unconstrained demand functions solving (3) are

$$(20)\quad x(p,n,m)=A^{mn/(m+n+mn)}\times(p/B)^{-(m+n)/(m+n+mn)}$$

$$(21)\quad \alpha(p,n,m)=A^{-n/(m+n+mn)}\times(p/B)^{n/(m+n+mn)}$$

The constrained demand function solving (6) is

$$(22)\quad x(\alpha,p,n,m)=(A\alpha)^{-n/(1+n)}(p/B)^{-1/(1+n)}$$

If $p>B$, then from (20) and (21), $x_n>0$, $\alpha_n>0$, $x_m>0$ and $\alpha_m<0$. Variations in the taste parameter n reflect heterogeneity in smokers' total TN preferences. Variations in the taste parameter m reflect the fact that some smokers want their total TN in frequent less-concentrated doses, while others want their total TN in infrequent more-concentrated doses.

From (21) and (22), $\alpha_p>0$ and $x_\alpha<0$, i.e., smoking frequency and TN content are substitutes. The elasticity of substitution between x and α (for a controlled change in α) is $\varepsilon=-(\alpha/x)x_\alpha=n/(1+n)$. Hence, the strength of substitution varies among smokers, with heavier (high n) smokers compensating for a controlled change in α more than lighter (low n) types. Since $\varepsilon<1$, no smoker will compensate completely. From (20), the unconstrained own-price elasticity of demand is $\eta=-(p/x)x_p=(m+n)/(m+n+mn)$. At any given uniform price, those who smoke a large number of cigarettes will have lower own-price elasticities.

Although Section III analyzed the case of a single taste characteristic, the step-function tax analysis of two taste parameters (n,m) is completely analogous. The subsets D, E, and F correspond to a partition of the (n,m) plane, where the boundaries between D and E and between E and F are two continuous curves. The welfare gradient is analogous to equations (11)–(15), with the corresponding jump terms J' and J'' reflecting discrete moves by smokers whose characteristics (n,m) lie on the curve separating subsets E and F.

V. Health Damage Function

The health damage due to cigarette smoking has been found to be an increasing function of both smoking frequency and TN content (for example, see E. Cuyler Hammond et al., 1976, 1977). The exact quantitative dose-response relations, however, have not been fully delineated.

If smoking affected only one stage of a disease process, then the disease incidence should be a linear function of total TN dosage. If smoking affected two independent stages, then the disease incidence should be proportional to the square of the total TN dosage. If the disease process itself reduced the potency of any given cigarette dosage, then the damage function would tend to be concave (for example, the loss of lung function resulting from increased smoking could diminish an individual's ability to inhale deeply.) Moreover, health damage need not depend only on total TN intake. In principle, smoking a large number of low TN cigarettes could be more or less damaging than consuming the same total TN in the form of a few high TN cigarettes (for example, the noxious effects of a particular smoke component might depend more on the peak blood level than the average exposure.) Although numerous studies have reported empirical dose-response relations between smoking frequency and disease incidence or mortality rates, their refined quantitative interpretation is known to be complicated by a variety of potential measurement biases (for example, poor health due to smoking affects smoking habits and in turn reported cigarette consumption). (See Richard Doll and Richard Peto; Hammond; Hammond et al., 1976, 1977; Peto.)

I therefore assume that the health damage function has the form

$$H(x,\alpha)=hx^{\kappa}\alpha^{\lambda} \tag{23}$$

where h, κ, and λ are positive constants. If $\kappa=\lambda$, then health damage depends only on the total TN intake $x\alpha$. If $\kappa>\lambda$, then smoking a large number of low TN cigarettes would produce more damage than obtaining the same total TN intake in the form of a few high TN cigarettes. If $\kappa<\lambda$, then a large number of low TN cigarettes would produce less health damage. Below I shall consider alternative values of 0.5, 1.0, and 2.0 for both κ and λ.

VI. Results

Hereafter, p is measured in dollars per pack, x is measured in packs per day, and α is measured in milligrams of tar per cigarette. Since the crude correlation coefficient between tar and nicotine contents across brands exceeds 0.9, the latter measurement convention involves little loss of generality.

Figure 3 depicts the distribution of tar per cigarette smoked by adult, current cigarette smokers in the United States in 1975. This distribution was derived from an appropriately weighted sample of 4,134 current smokers responding to the 1975 *Adult Use of Tobacco* survey. The central density in the 15–20 mg. tar range represents the conventional filter-tip brands, while the density beyond 20 mg. tar represents the conventional high TN, nonfilter brands. Those cigarettes below 15 mg. tar represent the relatively new low-tar and nicotine varieties. Table 1 shows the relation between cigarette tar content α and smoking frequency x among individuals in this sample. The crude correlation coefficient between x and α was 0.04.

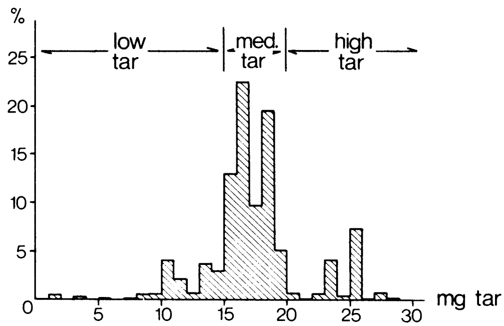

FIGURE 3. DISTRIBUTION OF TAR PER CIGARETTE; *U.S.* ADULT CURRENT SMOKERS, 1975

TABLE 1—JOINT DISTRIBUTION OF CIGARETTE TAR CONTENT AND SMOKING FREQUENCY (Shown in Percent)

Number of Packs Smoked Per Day	Cigarette Tar Content (mg.) Low Tar $\alpha \leqq 15$	Medium Tar $15 < \alpha \leqq 20$	High Tar $\alpha > 20$	Total
$x \leqq 0.5$	3.8	18.3	2.7	24.8
$0.5 < x \leqq 1.5$	9.3	41.8	9.0	60.1
$x > 1.5$	2.4	9.8	2.9	15.1
Total	15.5	69.9	14.6	100.0

These data describe only the distribution of cigarette consumption at the uniform prices prevailing in 1975, and not the underlying distribution of taste characteristics. However, for any uniform price p, the demand functions (20) and (21) specify a one-to-one map from (n,m) to (x,α), and therefore an inverse map from the image set of (x,α) back to (n,m). We can therefore uniquely determine an individual smoker's underlying taste parameters by observing his consumption frequency and TN choices at a particular uniform price. When I chose values of $A=0.01$ and $B=0.001$ in (19) to (22), this procedure yielded a mean own-price elasticity η among smokers equal to 0.44 (standard deviation, 0.07; range, 0.16–0.73), and a mean elasticity of substitution ε equal to 0.76 (standard deviation, 0.10; range, 0.37–0.99). For those smoking 0.5 packs per day or less, the mean value of η was 0.54 and the mean ε was 0.63. For those smoking more than 1.5 packs per day, the corresponding means of η and ε were 0.36 and 0.87, respectively. The results derived from these choices of A and B are consistent with previous experimental studies of smoking behavior (for example, Schachter's data yield mean values of ε for light and heavy smokers equal to 0.53 and 0.74, respectively) and with econometric estimates of the own-price elasticity of demand for cigarettes (for example, see Herbert Lyon and Julian Simon; Lyon and M. Lynn Spruill; Robert Miller).

Now consider the constant h in (23). Bryan Luce and Stuart Schweitzer have estimated the total $U.S.$ health damage in 1975 attributable to cigarette smoking to be \$25.7 billion, including \$7.5 billion in health care costs and \$18.2 billion in lost earnings due to sickness and death. It is not obvious, however, what fraction of this total health damage should be counted as an unperceived cost (see Anthony Atkinson). We could assume that anyone who smokes is necessarily misinformed or shackled by addiction, and then count the entire \$25.7 billion as the unperceived cost. More conservatively, we could assume that smokers ignore only those health costs subsidized by public and private insurance plans, which overwhelmingly do not distinguish smoking status or the number and type of cigarettes smoked. If about two-thirds of smoking related illness is covered by health insurance, and if about one-quarter of smoking-related lost earnings is covered by disability, pension, and life insurance plans, then the total unperceived cost in 1975 would be about \$10 billion or, given 52.9 million regular smokers in 1975, a mean of \$190 per smoker annually. I shall adjust h to yield this latter aggregate cost estimate.

Finally, I measure the markups $p-c$ and $q-c$ as increases in the price of cigarettes beyond observed 1975 values. In effect, I assume that current prices are those which would prevail at the optimum in the absence of unperceived health damages (see Efraim Sadka). Such an approach ignores the possibility of noncompetitive pricing by cigarette manufacturers. Because of geographic variations in cigarette excise taxes, the observed current prices in this sample ranged from \$0.36 to \$0.60 per pack.

Figure 4 illustrates the welfare effects of varying the cutoff α^* from 5 to 25 mg. tar, with constant taxes of $p-c=\$0.15$ and $q-c=\$0.30$, and with health damage parameters

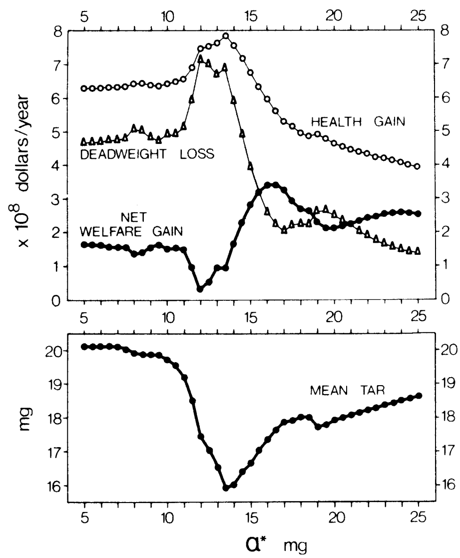

FIGURE 4. EFFECT OF VARYING α^*

$p-c=\$0.15; q-c=\$0.30; \kappa=\lambda=1$

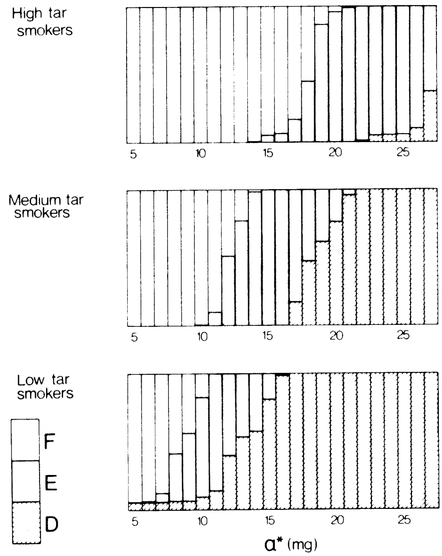

FIGURE 5. DISTRIBUTION OF LOW, MEDIUM, AND HIGH TAR SMOKERS AMONG SUBSETS D, E, AND F AS α^* VARIES

$p-c=\$0.15; q-c=\$0.30; \kappa=\lambda=1$

$\kappa=\lambda=1$. The top panel depicts the predicted net decrease in health costs, the deadweight loss, and the net welfare gain, measured in \$0.1 billions annually for the United States in 1975. The bottom panel shows the predicted mean tar per cigarette. The cutoff value $\alpha^*=13.5$ mg. yields a maximum health gain of \$0.78 billion annually, at the point of minimum average tar per cigarette. But this health gain is counterbalanced by an equally substantial deadweight loss. At the welfare maximum $\alpha^*=16.5$ mg. tar, the net welfare gain is \$0.34 billion annually. The health gain is \$0.56 billion annually, and the deadweight loss is \$0.22 billion, which represents a \$3.24 billion annual increase in tax revenues, minus a \$3.46 billion annual loss in consumer surplus.

Figure 5 displays the corresponding distribution of smokers among subsets D, E, and F. The figure depicts separately the responses of those individuals originally smoking low-tar ($\alpha \leqq 15$), medium-tar ($15 < \alpha \leqq 20$), and high-tar ($\alpha > 20$) cigarettes at current prices. The marked decline in mean tar as α^* increases from 10 to 14 mg. (Figure 4) corresponds to medium-tar smokers' jumping from F to E, that is, switching to lower-priced brands. At the welfare optimum, the low, medium, and high-tar smokers are almost exactly sorted between subsets D, E, and F. At this point, the medium-tar smokers reduce both x and α by about 5 percent, while the high-tar smokers reduce their smoking frequency by about 15 percent, without switching brands. As α^* increases beyond 16.5 mg. tar, the high-tar smokers jump into E. Because x and α are substitutes, their resulting decline in tar is counterbalanced by a 20 percent increase in smoking frequency.

Table 2 displays the optimal uniform and optimal step-function taxes for different values of κ and λ. As long as health damage is a function only of total TN intake (that is, $\kappa=\lambda$), the optimal cutoff α^* is 16–17 mg. tar, a value which almost exactly sorts low, medium, etc., and high-tar smokers between D, E, and F. The optimal step-function tax achieves a welfare gain twice that of the optimal uniform tax by bunching medium-tar smokers (who constitute 70 percent of smokers) at the corner E, where they decrease both their smoking frequency and cigarette tar.

TABLE 2—OPTIMAL UNIFORM AND STEP-FUNCTION TAXES

Damage Function Parameters		Optimal Uniform Tax		Optimal Step-Function Tax			
κ	λ	Tax ($/pack)	1975 Welfare Gain (billions of $)	Low-Tar Tax ($/pack)	High-Tar Tax ($/pack)	Cutoff Tar (mg.)	1975 Welfare Gain (billions of $)
0.5	0.5	0.10	0.07	0.17	0.21	16.6	0.13
	1.0	−0.07	0.04	0.18	0.78	15.0	0.49
	2.0	−0.24	1.13	0.06	0.69	12.7	2.78
1.0	0.5	0.36	0.76	0.40	0.44	18.0	0.78
	1.0	0.18	0.22	0.31	0.43	16.3	0.44
	2.0	−0.14	0.24	0.02	0.40	14.1	1.85
2.0	0.5	0.64	2.61	0.65	0.66	20.5	2.61
	1.0	0.57	1.91	0.60	0.64	19.5	1.95
	2.0	0.29	0.51	0.45	0.70	16.0	1.00

When $\kappa<\lambda$, a uniform increase in price diminishes welfare, because the health gain achieved by a price-induced decrease in consumption is completely offset by the compensating price-induced increase in *TN* (recall (4) above). The optimal step-function strategy is to impose a price differential of $q-p=\$0.38$–$0.63$ around a cutoff of $\alpha^*=$ 12.7 to 15.0 mg. tar. This price differential is so large that smoking brands with *TN* content above α^* is effectively prohibited. In this case, the welfare gain derives from brand switches of both medium- and high-tar smokers. (For example, at $\kappa=1$, $\lambda=2$, all medium-tar smokers and 99.6 percent of high-tar smokers are bunched at *E*. The total annual welfare gain of $1.85 billion reflects a $0.98 billion annual gain among medium-tar smokers and a $0.86 billion annual gain among high-tar smokers, with a negligible welfare effect on low-tar smokers.) Finally, when $\kappa>\lambda$, the step-function tax yields a net welfare gain which is indistinguishable from that achieved by a uniform tax.

Although Section III discussed only the case of two tax rates (p and q) and a single cutoff (α^*), the quantitative analysis of a step-function tax with multiple cutoffs is completely analogous. In particular, the two-cutoff case (with the population of smokers partitioned into five subsets) yielded the following results. For $\kappa=\lambda=1$, the optimal tax scheme was $0.40 per pack on brands not exceeding 16 mg. tar, $0.60 per pack on brands over 16 mg. tar but not exceeding 25 mg. tar, and $1.00 per pack on brands exceeding 25 mg. tar. The net welfare gain was $0.58 billion, as compared to $0.44 for the optimal single cutoff tax. This additional welfare gain was extracted primarily from high-tar smokers, who were induced to cut back their consumption without switching to low-tar brands. Moreover, by locating the high-tar smokers at a separate corner solution in the (α,p) plane, we can impose a higher tax on the medium-tar smokers. When $\kappa=\lambda=2$, in fact, the incremental welfare gain derived from an additional *TN* cutoff was even more substantial, because the damage function is then convex in total *TN* intake. In the $\kappa=1$, $\lambda=2$ case, however, a second *TN* cutoff yields almost no incremental welfare gain, because we already want everyone to switch to low-tar brands. When $\kappa=2$, $\lambda=1$, a second *TN* cutoff is likewise superfluous, adding little to the welfare gain achieved by a nondiscriminating uniform tax.

Would the optimal tax change if low-tar cigarettes became more popular? To test this possibility, I increased the sampling weights on all low-tar smokers in the data base and then recalculated the optimal single cutoff tax. For the $\kappa=\lambda=1$ case, increasing the effective proportion of low-tar smokers from 16 percent (Table 1) up to 62 percent had no effect on the optimal cutoff α^*. When the effective proportion of low-tar smokers exceeded 62 percent, the optimal α^* shifted to 13.4 mg. tar. Because the marginal health damages of low-tar smokers are small relative to medium- and high-tar smokers, our targeting the tax structure toward low-tar smokers yields little health gains until they reach a critical proportion of the smoking population. This critical proportion currently exceeds the projected one-third market share of low-tar cigarettes for 1979 (see my paper).

VII. Discussion and Conclusions

I have shown how the design of a *TN*-based cigarette tax hinges critically on the health tradeoff between smoking frequency and cigarette *TN* delivery. If smoking a few high-*TN* cigarettes produces more health damage than smoking many low-*TN* cigarettes, then the best policy is the prohibitively high tax on brands delivering more than 13–15 mg. tar. If smoking many low-*TN* cigarettes is more damaging, then the best policy is a relatively high, uniform tax on all brands. If health damage depends only upon total *TN* intake, then the best policy is to tax all brands, with a moderate price differential at 16–17 mg. tar. This policy induces medium-tar filter-tip smokers to reduce both *TN* and smoking frequency, while high-tar nonfilter smokers reduce their smoking frequency without switching to the lower-*TN* brands. This health tradeoff also determines the incremental welfare gains to be achieved by additional gradations in the tax scheme. These potential gains must be balanced against the administrative cost of maintaining an array of price gradations for different *TN* deliveries (see William Drayton; Donald Garner).

The annual net benefit derived from the simple step-function tax ranged from \$0.1 to \$2.8 billion in 1975. These results, however, were based upon a conservative interpretation of the unperceived health costs of smoking. Under a broader definition, the net welfare gains could be substantially greater. As long as the social cost of smoking is construed in terms of health damages which smokers inflict upon themselves, then the damage function can be derived from the biological dose-response curve. If the effects of sidestream smoke on nonsmokers or bandwagon effects on teenagers were at issue, however, then these dose-response relationships do not necessarily apply.

For the class of damage functions considered above, the optimal *TN* cutoff ranged from 12 to 21 mg. tar. However, if the true damage function displays a no-damage threshold at very low values of *TN*, then the optimal cutoff may fall in the very low range. At present, however, there is no evidence for the existence of such a threshold. My inclusion of only smoking frequency and cigarette *TN* delivery in the health damage function ignores other factors contributing to the health damage from smoking (for example, the synergistic effect of cigarettes and certain occupational exposures). In principle, we could write the damage function as $H(x,\alpha,r)$ where r is an additional characteristic which varies among smokers. The critical question in that case is the possible covariation between r and the taste characteristics n and m (for example, asbestos-handling smokers might be high-*TN* types). Moreover, the index α may not adequately characterize the dosage of various smoke consitituents. For example, certain medium-tar cigarettes with unventilated filters may have greater carbon monoxide deliveries than certain high-tar nonfilter cigarettes (see R. A. Jenkins, R. B. Quincy, and M. R. Guerin). In the optimal tax results above, however, high-tar smokers did not switch to these medium-tar brands and therefore did not increase their cigarette carbon monoxide content. In the $\kappa<\lambda$ case, both high-tar and medium-tar smokers switched to brands below 13–15 mg. tar, a range where carbon monoxide deliveries are generally lower (see Jenkins, Quincy, and Guerin, Figure 1). In the $\kappa>\lambda$ case, the uniform tax induced some medium-tar smokers to switch to high-tar nonfilter brands, thus decreasing their carbon monoxide content.

On the supply side, this analysis assumed that the marginal cost of cigarettes was constant and independent of *TN*. Accurate information concerning the allocation of various tobacco manufacturing, product development, and promotional costs across brands is not currently available. The effect of alternative tax schemes on the magnitude and distribution of cigarette advertising expenditures is a critical issue in this respect.

On the demand side, this analysis omitted certain aspects of cigarette consumption other than brand choice and smoking frequency. When smokers switch to lower *TN* cigarettes, for example, they may compensate by inhaling more deeply or smoking them further down to the end (see, for example, Sutton et al.; the author). It is difficult to imagine how we could devise an additional policy instrument to control this aspect of consumption. Moreover, by assuming a fixed population of smokers, I have ignored the possibility that changes in taxes may affect initiation of smoking among teenagers or cessation of smoking among adults.

Finally, this analysis has not squarely confronted the addictive nature of smoking. Although my welfare criterion incorporates the consumer benefit from smoking, it may not be appropriate to measure this benefit in terms of willingness to pay. This is the subject of a later paper.

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