We Should Drink No Wine Before Its Time

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We Should Drink No Wine Before Its Time

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Abstract: We consider the impact of taxes on the quantity and quality produced of goods for which market value accrues with age, such as wine. Provided society values both quality and quantity, an optimal tax system would never distort marketed product quality, though it necessarily reduces quantity. Any two-tax system that includes a \textit{volumetric sales tax} and any one of three other types of tax – an \textit{ad valorem sales tax}, an \textit{ad valorem storage tax}, or a \textit{volumetric storage tax} – spans the quality/revenue space and can support an optimal tax system. Any tax system that reduces quality relative to the market equilibrium with no taxes could increase tax revenues and reduce the quality distortion without increasing the quantity distortion. This finding suggests that social preferences regarding alcohol may be guiding the use of taxation schemes that reduce both the quantity and quality of wine.
1. Introduction

The tendency for an excise tax to increase the average quality of a consumed good is often referred to as the Alchian-Allen effect (Alchian and Allen, 1964). Barzel (1976) explained this effect in terms of product attributes; an ad valorem tax is based on all product attributes, while an excise tax affects only certain product attributes. Many authors have refined and expanded these initial analyses (Gould and Segall, 1969; Borcherding and Silberberg, 1978; Umbeck, 1980; Leffler, 1982; Kaempfer and Brastow, 1985; Cowen and Tabarrok, 1995; James and Alston, 2002; Razzonlini, Shughart and Tollison, 2003).

Most—though not all—all of these articles focus on consumption rather than production decisions and none have addressed the time dimension of the quality-tax relationship. Many products, such as wine, aged cheese, cultured pearls, timber, and most crop and livestock production are characterized by multi-period production processes. We examine the effects of taxes on the quantity and quality decisions of competitive producers. The representative producer chooses the optimal quantity and quality to produce and sell. Quantity is determined in the initial production period, and quality is determined by the number of periods the good is aged prior to sale. The passage of time affects the value of the product, and a share of that value that is captured by the tax authority.

We evaluate four taxes: an ad valorem sales tax assessed as a percentage of price and collected on the date of sale; volumetric sales tax, or excise tax, assessed at a fixed rate per unit and collected on the date of sale; an ad valorem storage tax, or ad valorem

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1 This result has been credited to the UCLA oral tradition prior to the publication of Alchian and Allen’s textbook (Borcherding and Silberberg, 1978).
accrual tax, assessed as a percentage of each period’s market value, and collected each period prior to sale; and a volumetric storage tax, or accrual excise tax, assessed at a fixed rate per unit collected each period prior to sale. All previous analyses of the Alchian-Allen effect have restricted attention to the ad valorem and volumetric sales taxes.

We find that an increase in any marginal tax rate unequivocally decreases the quantity produced. Consistent with Alchian-Allen, an increase in the volumetric sales tax rate unequivocally increases quality. However, because quality increases over time, an increase in the ad valorem sales tax rate can either increase or decrease quality, depending on the level of all tax rates and other parameters. Further, the Alchian-Allen dichotomy between ad valorem and volumetric taxes does not hold for storage taxes. An increase in either storage tax rate unequivocally decreases quality.

Given the effects of individual tax instruments, if society values both quality and quantity an optimal tax system would not reduce quality, although obtaining positive tax revenue necessarily implies a reduction in quantity. Specifically, any two-tax system that includes a volumetric sales tax and any one of the three other taxes spans the quality/revenue feasible set and can support an optimal tax system. Any tax system that reduces quality relative to the market equilibrium with no taxes could increase tax revenues and reduce the quality distortion without increasing the quantity distortion. This finding raises the question of why tax regimes would lower both the quality and quantity of a specific product where quality increases with time.

Wine is a particularly interesting aged product to examine, for three reasons. First, unlike many other aged products, a substantial share of the aging process occurs after sale. Most wine is sold by the producer within a few years of the initial grape har-
Wine and Taxes

Wohlgenant (1982) examines vintner aging decisions across vintages as an inventory problem. In contrast, several studies have examined the rate of return to holding wine over time, and established that there is a positive return to aging over at least a twenty-year time period for the subsets of wines they examine, although their conclusions regarding its rate of return relative to other assets differ (Krasker, 1979; Jaeger, 1981; Burton and Jacobsen, 2001). Byron and Ashenfelter (1995) examine determinants of wine prices, and also find that there is a positive return to aging. Because most wine is drunk soon after its purchase, tax distortions affecting the producer’s aging decision potentially may have a large effect on social welfare.

Second, taxes are an important share of the cost of wine in many countries. Wine taxes can be split into 3 broad categories. In order of decreasing importance, wine is subject to excise taxes, value-added and sales taxes, and import duties and other related taxes. Wittwer, Berger, and Anderson (2001) calculate that 16% of the average global cost of a bottle of wine is attributable to excise taxes or their equivalent, 6% to sales/VAT taxes or their equivalent, and 1% to import duties.

Wine tax systems vary widely across countries. For example, in the United States, at the federal level wine is subject to a volumetric sales tax (excise tax) and an ad valorem sales tax. Many states impose additional ad valorem sales taxes, and some tax business inventories, such as wine held by a winery. In Australia, wine is subject to an ad valorem sales tax and to an ad valorem storage tax, referred to as the Wine Equalization Tax (WET). In France, wine is subject to the Value Added Tax (VAT). Wine stocks are taxed with either an ad valorem storage tax, or a quasi-volumetric storage tax based on the wine’s initial declared value that does not adjust for appreciation in wine value over
time. Such variations across tax systems provides an empirical motivation for our analysis of quality-neutral tax systems and their equivalence across certain tax instruments. (See Goodhue, LaFrance and Simon, 2004, for a detailed discussion of wine taxes worldwide.)

Previous work has examined wine taxes. Tsolakis (1983), Buccola and Vander-Zanden (1997), and James and Alston (2002) have examined the empirical effects of wine-specific taxes but have not addressed the effects on aging and quality, or the difference between storage taxes and sales taxes. They also have not compared tax systems.

Third, wine and alcohol in general are generally taxed at a higher rate than most goods and services are. High taxes on alcohol are justified by the argument that there are large negative externalities due to alcohol consumption, and taxes force users to internalize these costs.² Beyond these costs, there is the question of the extent to which alcohol and wine taxes are not only correcting for negative externalities but are true “sin taxes” in the sense that alcohol consumption in wine or any other form is considered a demerit good, and taxes are a means of deterrence. Roughly 40 to 45 percent of American adults consume no alcohol at all (Moulton, Spawton and Bourqui, 2001). In some cases, their decision is influenced by the belief that alcohol consumption is morally wrong. This suggests that there may be a moral component to wine taxation. Society as a whole, or certain, potentially influential, groups, may prefer an inefficient tax system in order to reduce wine consumption below the levels where taxes induce drinkers to internalize exter-

² However, see Heien and Pittman (1989) for a critique of the methodology of studies of the public costs of alcohol abuse. They observe that in these studies private costs internalized by alcohol consumers are included in the calculations of costs borne by society at large.
2. The Basic Model

Consider the problem of the production, aging, and ultimate sale of wine from a single crushing by a single representative winery. The quantity of wine produced, \( q \), is determined at the initial date, \( t = 0 \). The quality of the wine when it is sold at date \( t \), \( x(t) \), is a stochastic function of the initial quality and the number of periods it is aged:

\[
dx = \alpha(x,t)dt + \beta(x,t)dz,
\]

where \( dz = \sqrt{dt} \epsilon \), with \( \epsilon \) i.i.d. \( n(0,1) \), \( \alpha(x,t) > 0 \), \( \forall t \geq 0 \), \( \lim_{t \to \infty} \alpha(x,t) = 0 \), \( \beta(x,t) > 0 \) \( \forall t \geq 0 \), and \( \lim_{t \to \infty} \beta(x,t) = 0 \) with probability one.\(^3\) The initial condition for the stochastic process for wine quality, \( x(0) = x_0 \), is the result of a random outcome determined by temperature, rainfall, pest infestations, and other unpredictable and uncontrollable factors. We assume that the vintner observes the initial quality \( x_0 \) at crushing, and is able to continuously sample arbitrarily small quantities of wine from existing unsold stocks to learn the current quality at each date, \( \tau \in [0,t] \).

The market price \( p(x(t)) \) is an increasing and concave function of quality, so that \( p'(x) > 0 \) and \( p''(x) < 0 \) \( \forall x \). We assume that price is a perfect signal of quality.\(^4\) We denote the variable cost of initial production as \( c(q) \), the marginal cost of storage per unit

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\(^3\) We include stochastic production and quality development for descriptive reality and to allow for variations in the prices received and qualities realized of the good under study. While neither property plays an active role in the present paper, both are the objects of ongoing research. In particular, we are currently studying the effects of the choice of taxation regimes on the variability of tax revenue generated, as well as mean tax revenues.

\(^4\) We assume that price is a perfect signal of quality.
of wine per period as \( p_s \), and the real discount rate as \( r \). The realized profit from producing \( q \) units of wine at time 0 and aging the wine until its sale at date \( t \) is

\[
\pi = e^{-rt} p(x(t))q - c(q) - \left( 1 - e^{-rt} \right) p_s q / r.
\] (2)

We assume that the vintner is risk neutral. Maximizing \( E_0(\pi) \) with respect to \( q \) implies

\[
E_0 \left( \frac{\partial \pi}{\partial q} \right) = E_0 (p) e^{-rt} - c'(q) - \frac{1}{r} (1 - e^{-rt}) p_s = 0,
\] (3)

where \( E_0(\cdot) \) denotes the conditional expectation operator, given the information available to the vintner at \( t = 0 \). Equation (3) can be rewritten as

\[
E_0 (p) e^{-rt} = c'(q) + (1 - e^{-rt}) p_s / r.
\] (3')

Equation (3') shows that the optimal quantity of wine \( q^* \) is determined by where the expected marginal discounted present value of quantity equals the sum of the marginal cost of production and the discounted present value of the marginal cost of aging for all storage periods prior to its sale at \( t \). We refer to \( q^* \) as the first-best optimal quantity.

Let \( t^* \) denote the ex ante expected optimal age of wine. That is, \( t^* \) is implicitly defined by

\[
\frac{1}{dt} E_0 \left[ dp(x(t^*)) \right] = r E_0 \left[ p(x(t^*)) \right] + p_s.
\] (4)

We refer to \( t^* \) as the first-best optimal age. By Itô’s lemma, (4) can be rewritten as

\[
\alpha(x,t)p'(x) + \frac{1}{2}\beta(x,t)^2 p^*(x) = rp + p_s.
\] (4')

---

\(^4\) We therefore are abstracting from the potential asymmetric information issues that may arise between the producer and consumers.
The optimal age at sale is when the conditionally expected marginal value of quality equals the marginal opportunity cost of foregone revenues from waiting another period to sell the wine, plus the marginal cost of storage per unit of time. The conditionally expected marginal value of quality includes two terms. The first term on the left-hand-side is the conditional mean increase in marginal quality due to additional aging, or the average effect of $dt$ additional aging on the marginal value of age $t$ wine with current quality $x(t)$. Because the market price is concave in quality, there are diminishing marginal returns to aging. The second left-hand-side term is the conditional variance effect on marginal quality due to additional aging. This induced risk effect is due to the variability of quality in future periods given current quality, which results from the stochastic quality determination process.

3. Wine Taxes, Quantity, Quality, and Revenue

We now introduce taxes into the producer’s profit maximization problem. We consider four taxes: an ad valorem sales tax, a volumetric sales tax, an ad valorem storage tax, and a volumetric storage tax. In all four cases, we require full commitment of the taxing authority to the given tax regime. In other words, once the tax system has been designed and chosen, it remains in place unchanged throughout the producer’s planning horizon. In addition, we focus on the comparative analyses of long-run responses to the different taxation schemes considered. An ad valorem sales tax is assessed as a fixed percentage of the market price, and collected when the vintner sells the wine. The discounted present value of the realized tax paid is $e^{-rt} p(t) q \tau^r_p$, where $\tau^r_p \in [0,1]$ is the ad valorem sales tax rate. A volumetric sales tax is assessed as a fixed monetary amount per unit volume and
collected at sale. The discounted present value of the realized tax paid in this case is 
\[ e^{-rt}q \tau^r_q, \] where \( \tau^r_q \geq 0 \) is the volumetric valorem sales tax rate. An *ad valorem storage tax* is assessed as a fixed percentage of the *ex ante* expected value of the market price of wine, \( E_0[p(x(\theta))] \), \( \theta \in [0,t] \), and is collected continuously throughout the storage period. The discounted present value of the total tax paid in this case is 
\[ \int_0^t e^{-r\theta}E_0[p(x(\theta))]q d\theta, \] where \( \tau^s_p \in [0,1] \) is the ad valorem storage tax rate. A *volumetric storage tax* is assessed as a fixed monetary amount per unit volume and is collected continuously throughout the storage period. The discounted present value of the total tax paid is \( \left(1 - e^{-rt}\right)\tau^s_q q/r \), where \( \tau^s_q \geq 0 \) is the volumetric storage tax rate.

After incorporating all four tax instruments, the vintner’s realized profit is
\[
\pi(t) = e^{-rt} \left[p(x(t))(1 - \tau^r_p - \tau^r_q)q - \int_0^t e^{-r\theta}E_0[p(x(\theta))]\tau^s_p q d\thetaight] - \left(1 - e^{-rt}\right)\left(p_s + \tau^s_q\right)q/r - c(q).
\] (5)

For future use, given the tax regime \( \tau = [\tau^r_p \quad \tau^r_q \quad \tau^s_p \quad \tau^s_q] \) we define the *ex ante* expected value of the total effective tax rate per unit of wine as
\[
\upsilon(\tau) = e^{-rt} \left\{ \tau^r_p E_0 [x(t(\tau))] + \tau^r_q \right\} + \int_0^t e^{-r\theta} \left[ \tau^s_p E_0 [p(x(\theta))] + \tau^s_q \right] d\theta,
\] (6)

and the *ex ante* expected value of total tax revenue as \( R(\tau) = \upsilon(\tau)q(\tau) \), where \( q(\tau) \) is the optimal choice for quantity and \( t(\tau) \) is the optimal *ex ante* choice for the age of wine.

### 3.1 Quality Choice with Taxes

In this section, we consider the effects of changes in the tax regime on the quality of wine.
produced. The stochastic dynamic programming stopping rule for the age that maximizes the expected per-unit value of the wine with respect to its date of sale is

\[
\frac{1}{dt} E_t(dp) (1 - \tau'_p) = r [p (1 - \tau'_p) - \tau'_q] + p_s + E_0(p) \tau'_s + \tau'_q. \tag{7}
\]

Dividing through by \((1 - \tau'_p)\) and rearranging terms, we obtain

\[
\frac{1}{dt} E_t(dp) = rp + p_s + \left( \frac{-r \tau'_q + \tau'_q p_s + E_0(p) \tau'_s + \tau'_q}{1 - \tau'_p} \right). \tag{8}
\]

Equation (8) illustrates several important properties of these taxes. First, within our framework, the basic Alchian-Allen effect holds for a one-time volumetric tax: an increase in the tax increases the profit-maximizing age at sale. Formally,

\[
\frac{\partial t}{\partial \tau'_q} = \frac{-r}{(1 - \tau'_p) \Delta_t} > 0. \tag{9}
\]

Second, the volumetric retail tax has the same qualitative effect on age/quality at sales as lower storage costs do. Third, the Alchian-Allen dichotomy does not hold for volumetric and ad valorem storage taxes. Both taxes unambiguously decrease the profit-maximizing age. Formally,

\[
\frac{\partial t}{\partial \tau'_q} = \frac{1}{(1 - \tau'_p) \Delta_t} < 0, \tag{10}
\]

\[
\frac{\partial t}{\partial \tau'_q} = \frac{E_0(p)}{(1 - \tau'_p) \Delta_t} < 0, \tag{11}
\]

Fourth, both storage taxes have the same qualitative effect on age/quality at sales as increased storage costs do. Fifth, the impact of ad valorem retail taxes on age is indeterminate. Formally,
\[
\frac{\partial t}{\partial \tau_p^r} = \frac{-r\tau_q^r + p_s + E_0(p)\tau_p^s + \tau_q^s}{(1 - \tau_p^r)^2 \Delta_t} \geq 0 \iff r\tau_q^r \geq p_s + E_0(p)\tau_p^s + \tau_q^s,
\]

where \( \Delta_t = \frac{\partial}{\partial t} [E_t(d\pi)/dt] < 0 \) by the second-order condition for a unique optimum.

Sixth, due to the linear nature of the numerator on the far right-hand-side of (8) in each of the tax rates, a given tax revenue objective can be achieved with different combinations of tax instruments. Finally, provided the second order condition for a unique optimal solution is met, the optimal choice for quality/age of wine exceeds, equals, or is less than the first-best age if and only if \(-r\tau_q^r + \tau_p^r p_s + E_0(p)\tau_p^s + \tau_q^s \leq 0\). This result is illustrated in Figure 1. The figure plots the lefthand side of (8), \( \frac{1}{dt} E_0(dp) \), against the righthand side in age-price space. The first-best age and price are determined by the intersection of \( \frac{1}{dt} E_0(dp) \) and \( rp + p_s \). The intersections of the other two curves with the \( \frac{1}{dt} E_0(dp) \) curve are examples of tax packages that distort age above and below its first-best level.

When the effect of the volumetric sales tax is dominated by the joint effect of the other three taxes, then the profit-maximizing wine age exceeds the first-best age. When the effect of the volumetric sales tax dominates the joint effect of the other three taxes, then the profit-maximizing wine age is less than the first-best age.
3.2 Quantity Choice with Taxes

Next, we consider the impacts of changes in the tax system on the vintner’s quantity choice. The choice of quantity that maximizes ex ante expected profits satisfies the first-order condition,

\[ 0 = \frac{\partial}{\partial q} E_0(\pi) = e^{-rt} \left[ E_0(p)(1 - \tau^r_p) - \tau^r_q \right] - \int_0^t e^{-r\theta} [p_s + E_0(p)\tau^s_p + \tau^s_q] d\theta c'(q) . \tag{13} \]

The second-order condition for \( q \) is simply \( c''(q) \geq 0 \). To evaluate the comparative statics for \( q \) with respect to each of the taxes, we first need to evaluate the ex ante cross-price effect of age on quantity, \( \frac{\partial^2 E_0(\pi)}{\partial q \partial t} \). Differentiating the first-order condition for \( q \) with respect to \( t \), we obtain

\[ \frac{\partial^2 E_0(\pi)}{\partial q \partial t} = e^{-rt} \left\{ \frac{\partial}{\partial t} E_0(p)(1 - \tau^r_p) - r \left[ E_0(p)(1 - \tau^r_p) - \tau^r_q \right] - p_s - E_0(p)\tau^s_p - \tau^s_q \right\} . \tag{14} \]

From equations (3') and (4') above, we see that

\[ \frac{\partial}{\partial t} E_0(p) = E_0 \left[ \alpha(x(t),t)p'(x(t)) + \frac{1}{2} \beta(x(t),t)^2 p''(x(t),t) \right] = E_0 \left[ \frac{1}{dt} E_t(dp) \right] . \tag{15} \]

Therefore, the first-order condition for the age/quality choice implies

\[ \left[ \frac{\partial}{\partial t} E_0(p) \right] (1 - \tau^r_p) - r \left[ E_0(p)(1 - \tau^r_p) - \tau^r_q \right] - p_s - E_0(p)\tau^s_p - \tau^s_q = 0 . \tag{16} \]

In other words, \( \frac{\partial^2 E_0(\pi)}{\partial q \partial t} = 0 \). Intuitively, because the producer’s decisions governing the two variables are completely independent, the ex ante choice of quantity has no impact on the optimal ex post choice of age/quality. It follows that when the unconditional expectation of the objective function is evaluated, the unconditional expected value of the ex post choice for age will have no impact on the optimal ex ante choice of quan-
tity. This independence greatly simplifies the derivation of the following comparative statics results examining the effect of different tax instruments on the profit-maximizing choice of quantity. An increase in any of the four types of taxes unambiguously decreases the quantity produced. Formally,

$$\frac{\partial q}{\partial \tau_p} = -e^{-\eta} E_0(p) c''(q) < 0, \quad (17)$$

$$\frac{\partial q}{\partial \tau_q} = -\frac{1}{c''(q)} < 0, \quad (18)$$

$$\frac{\partial q}{\partial \tau_s} = -\frac{\int_0^t e^{-\eta \theta} E_0(p(\tau)) d\theta}{c''(q)} < 0, \quad (19)$$

and

$$\frac{\partial q}{\partial \tau_q} = -\frac{(1 - e^{-\eta})}{rc''(q)} < 0. \quad (20)$$

### 3.3 Age/Quality Neutral Tax Systems

The effects of individual tax instruments on the producer’s age/quality and quantity decisions has interesting implications for the design of multi-instrument tax schemes. All four taxes reduce the profit-maximizing quantity. Equivalently, the first-order condition for quantity implies that for a fixed age/quality outcome, any change in the taxation scheme that increases the \textit{ex ante} mean total tax rate per unit, \( v(\tau) \), decreases quantity, \( q(\tau) \):

$$\left. \frac{\partial q(\tau)}{\partial \tau} \right|_{\nu(\tau)} = -\frac{1}{c''(q(\tau))} \times \left. \frac{\partial v(\tau)}{\partial \tau} \right|_{\tau(\tau)} \quad (21)$$

The varying effects of individual tax instruments on the profit-maximizing choice of quality allows us to create a class of tax schemes that result in the first-best quality level. The first-order condition for the \textit{ex ante} age/quality choice implies that there will
be no age/quality distortion if and only if the tax system satisfies the condition

\[ r \tau'_q = p_s \tau'_p + E_0 \left( p(t(\tau)) \right) \tau^s_p + \tau^s_q. \]  

(22)

Hence, an increase in the volumetric retail tax can be used to offset any increase in any of the other three taxes, so that the first-best age can be achieved. Equivalently, if any of the other three types of taxes are imposed, a positive volumetric retail tax is necessary in order for there to be no age distortion. Therefore, for any given tax revenue target, a two-tax system including the positive volumetric retail tax can be constructed to eliminate an age/quality distortion, but no tax system (absent negative tax rates, or subsidies) will eliminate the quantity distortion.

There are three possible two-tax systems that do not distort the \textit{ex ante} mean wine age/quality:

1. \textit{retail taxes} satisfying \( \tau'_q = p_s \tau'_p / r \), so that \( \tau_1 = \left[ \begin{array}{ccc} \tau'_p & (p_s/r) \tau'_p & 0 & 0 \end{array} \right] \) and

\[ v_1 \equiv v(\tau_1) \equiv \frac{1}{r} e^{-r(t(\tau_1))} \left[ rE_0 \left( p(t(\tau_1)) \right) + p_s \right] \tau'_p; \]

2. \textit{volumetric taxes} satisfying \( \tau'_q = \tau^s_q / r \), so that \( \tau_2 = \left[ \begin{array}{ccc} 0 & \tau^s_q / r & 0 & \tau^s_q \end{array} \right] \) and

\[ v_2 \equiv v(\tau_2) \equiv \tau^s_q / r; \] and

3. \textit{volumetric retail tax} and \textit{ad valorem storage tax} satisfying \( \tau'_q = E_0 \left( p(t(\tau)) \right) \tau^s_p / r \), so that \( \tau_3 = \left[ \begin{array}{ccc} 0 & E_0 \left( p(t(\tau)) \right) \tau^s_p / r & \tau^s_p & 0 \end{array} \right] \) and

\[ v_3 \equiv v(\tau_3) \equiv \left[ e^{-rt(\tau_3)} E_0 \left( p(t^*) \right) / r + \int_0^{t(\tau_3)} e^{-r\theta} E_0 \left( p(\theta) \right) d\theta \right] \tau^s_p. \]

In each case, the \textit{ex ante} condition for the age/quality choice by the producer reduces to
the original condition for the first-best age/quality, $t^*$. Examining the total effective \textit{ex ante} mean tax rate $v$, in each case the total effective \textit{ex ante} mean tax rate is linearly increasing in the other tax rate used to balance the volumetric retail tax to maintain age/quality neutrality. Therefore, an increase in each of these taxes increases $v$ and decreases $q$.

Now consider the relationship between tax rates and tax revenues for tax schemes that maintain age/quality neutrality. It follows from the definition of the \textit{ex ante} mean tax revenue, $R(\tau) = v(\tau)q(\tau)$, that

$$\frac{\partial R(\tau)}{\partial \tau} = \frac{\partial v(\tau)}{\partial \tau} q(\tau) + v(\tau) \frac{\partial q(\tau)}{\partial \tau} .$$

(23)

Thus, for any given age/quality outcome,

$$\frac{\partial R(\tau)}{\partial \tau} \bigg|_{u(\tau)} = q(\tau) \frac{\partial v(\tau)}{\partial \tau} \bigg|_{u(\tau)} - v(\tau) \frac{\partial q(\tau)}{\partial \tau} \bigg|_{u(\tau)}$$

$$= \left( \frac{c''(q(\tau))q(\tau) - v(\tau)}{c''(q(\tau))} \right) \frac{\partial v(\tau)}{\partial \tau} \bigg|_{u(\tau)} .$$

(24)

Hence, maintaining age/quality neutrality while increasing the tax rates in each two-tax system results in an increase, no change, or a decrease in \textit{ex ante} expected total tax revenue if and only if $c''(q(\tau))q(\tau) - v(\tau) \geq 0$. Because we assume that $c''(q) > 0$, it follows that for all cost functions satisfying $\lim_{q \to 0} c''(q)q = 0$, the left-hand-side of this condition is strictly positive at $\tau = 0$ and $q = q^*$, but eventually vanishes and then becomes negative as the average effective tax rate increases and quantity decreases.
3.4 Tax Equivalence of the Two-Tax Age-Neutral Systems

We establish tax equivalence among the three two-tax age-neutral systems by finding relationships that equate the mean ex ante tax rates. With no age/quality distortion, this relationship ensures that the quantity distortion and the mean ex ante tax revenue generated will be the same for each two-tax system. Using the expressions for $v_1$, $v_2$ and $v_3$ obtained in the previous subsection, it follows that $v_1 = v_2 = v_3$ if and only if

$$
\tau_q^s = e^{-rt^*} \left[ rE_0 \left( p(t^*) \right) + p_s \right] \tau_p^r
$$

$$
= \left[ e^{-rt^*} E_0 \left( p(t^*) \right) + r \int_0^{t^*} e^{-r\theta} E_0 \left( p(\theta) \right) d\theta \right] \tau_p^r,
$$

(25)

where, given the two-tax specifications, $\tau_p^r > 0$ only in the first, $\tau_q^s > 0$ only in the second, and $\tau_p^s > 0$ only in the third age neutral two-tax system, respectively.

These two sets of conditions are intuitively appealing. For the first equality, because retail taxes are paid once after $t^*$ time periods have elapsed, and because there is no age distortion $E_0 \left[ dp(t^*) \right]/dt = rE_0 \left[ p(t^*) \right] + p_s$. Hence, the net effect of balancing a volumetric retail tax against an ad valorem retail tax to achieve age neutrality is a tax system that is equivalent to paying the tax $e^{-rt^*} \left( E_0 \left[ dp(t^*) \right]/dt \right) \tau_p^r$ on each unit of wine in perpetuity. On the other hand, the volumetric storage tax is paid every period between production and sale, and is based on quantity rather than value.

The net effect here of balancing a volumetric retail tax against a volumetric storage tax is a tax scheme that is equivalent to paying the storage tax $\tau_q^r$ on each unit of wine in perpetuity. The first line therefore equates the periodic perpetual annuity pay-
ments for these two otherwise quite different taxation schemes.

An analogous equating of incentives applies to the second condition. The first term in brackets on the second line identifies the present value incentive effects of the *ad valorem storage tax* on the *volumetric retail tax* component of the third tax system. Payment of this component of the second tax system is delayed $t^*$ periods and is made only once. The second term identifies the instantaneous per period incentive effects of the *ad valorem storage tax* component. As in the previous case, the second line therefore equates the perpetual periodic annuity payments for the second and third age neutral two-tax schemes. Thus, if we normalize on the ad valorem retail sales tax, then for any $\tau_p^r > 0$ we have complete tax equivalence among the three age-neutral two-tax systems that are defined by

$$\tau_1 = \left[ \tau_p^r \quad p_s \tau_p^r / r \quad 0 \quad 0 \right], \quad (26)$$

$$\tau_2 = \left[ 0 \quad e^{-rt^s}\left[rE_0(p) + p_s\right] \tau_p^r / r \quad 0 \quad e^{-rt^s}\left[rE_0(p) + p_s\right] \tau_p^r \right], \quad (27)$$

$$\tau_3 = \left[ 0 \quad E_0(p) e^{-rt^s}\left[rE_0(p) + p_s\right] \tau_p^r \quad e^{-rt^s}\left[rE_0(p) + p_s\right] \tau_p^r \quad \frac{e^{-rt^s}\left[rE_0(p) + p_s\right] \tau_p^r}{e^{-rt^s}E_0(p) + \int_0^{t^s} e^{-r\theta} E_0(p) d\theta} \quad 0 \right]. \quad (28)$$

### 4. Optimal Tax Systems

From the ex ante first order condition for quality (7), assuming that the second order condition is met, recall that $t(\tau) \geq t^*$ if and only if $-r\tau_q^r + \tau_p^r p_s E_0(p) \tau_p^r + \tau_q^r \leq 0$. Differentiating the ex ante expected tax rate with respect to $t$ results in
\[
\frac{\partial v}{\partial t} = e^{-rt} \left( \frac{-r\tau_q^r + p_s + \tau_q^s + E_0[p(t)]\tau_p^s}{1 - \tau_p^r} \right).
\]

Equation (29) establishes that the ex ante expected value of the average per unit tax rate increases, remains unchanged, or decreases with quality/age as the age of wine at the date that it is sold is less than, equal to, or greater than the first best age of wine. Since there is no interaction between the optimal choice of quantity and quality, this implies that ex ante expected tax revenues achieve a relative maximum with respect to age/quality at the first best age level. In this sense, the age neutral tax systems analyzed in the previous section play a pivotal role in our analysis of optimal tax systems.

Any change in the tax regime that keeps ex ante mean revenue constant, satisfies

\[
0 = dR = \frac{\partial R}{\partial \tau} d\tau = v \frac{\partial q}{\partial \tau} d\tau + q \frac{\partial v}{\partial q} \frac{\partial q}{\partial \tau} d\tau + q \frac{\partial v}{\partial t} \frac{\partial t}{\partial \tau} d\tau = (v - c^*(q)q) dq + q \frac{\partial v}{\partial t} dt.
\]

Therefore, the trade-off between quality and quantity along an iso-revenue locus has slope

\[
\left. \frac{dt}{dq} \right|_R = \frac{c''(q)q - v}{e^{-rt} \left[ -r\tau_q^r + \tau_p^r p_s + E_0[p(t)]\tau_p^s + \tau_q^s \right]}.
\]

Assuming that \( c''(q) > 0 \) \( \forall q \geq 0 \) and \( \lim_{q \to 0} c''(q)q = 0 \), the numerator of (31) is positive for small effective tax rates. As the tax rate increases, quantity decreases, and the numerator
of (31) becomes smaller, and eventually becomes negative.\textsuperscript{5} On the other hand, the denominator is positive if $t < t^*$, zero if $t = t^*$, and negative if $t > t^*$. These two properties imply that the ex ante expected revenue function for any tax system has the same general shape and level curves as Figure 2, which depicts the case of an ad valorem sales tax and volumetric sales tax two-tax system.

In other words, when quantity and quality are below the first best levels, but in a neighborhood of the no-tax equilibrium, the iso-revenue curves are positively sloped. As quantity and quality both fall along an isorevenue curve with an increase in the effective tax rate, $\nu$, the slope of the iso-revenue curve ultimately becomes vertical and then becomes negatively sloped. As we progress along the same iso-revenue curve, increasing quality but continuing to decrease quantity, we return to the age-neutral point and a horizontal point on the iso-revenue curve. Continuing further along this same iso-revenue curve by increasing both quality and quantity we reach another vertical point where quality is greater than the first best choice but quantity is lower. Finally by increasing quantity and decreasing quality from this point onward to the original position at the first-best levels of both quantity and quality, we complete an oval or egg-shaped iso-revenue locus.

Finally, Figure 3 illustrates that nong negativity of the tax rates is not a binding constraint on these propositions. A simple comparative statics analysis readily verifies

\textsuperscript{5} Define $\delta$ as the proportion of the total value of wine sold that is taken by all governments in the form of taxes, so that $\nu = \delta p$. Then the numerator of (31) is positive, zero or negative as the price elasticity of quantity supplied, $e^p_q = p/(c'(q)q)$, is less than, equal to, or greater than $1/\delta$. Wine taxes currently account for roughly 25% of the total value of the wine sold worldwide, so that $1/\delta \approx 4$. On the other hand, the information contained in James and Alston (2002) implies that the supply elasticity of wine is something less than 2. Taken together, these two conditions imply that the numerator of (31) is strictly positive, at least for the typical current tax system imposed on the wine market.
that the full range of positive tax revenues that can be generated with any two-tax system that includes a volumetric retail sales tax can be supported by positive tax rates and at least as high quality wine as the first best no-tax level.

Based on this analysis, we conclude the following: first, the first best with respect to quality is a relative maximum of tax revenues for all quantity choices; second, every positive tax revenue can be supported by a two-tax system that accommodates the first best quality outcome; and third, if the tax system results in a quality outcome that is less than the first-best, then more tax revenue can be raised with a smaller quantity distortion and the complete elimination of the quality/age distortion. These three findings imply that if the social preference function values both quality and quantity as goods, then an optimal revenue generating taxation scheme requires $t > t^*$ and $q < q^*$, at least for tax systems with quality/quantity outcomes in the neighborhood of the first-best point $(q^*, t^*)$. On the other hand, tax systems that result in decreases in both quantity and quality from the first best point can only be socially optimal if they reflect social preferences regarding wine consumption: both the quantity of wine consumed and the quality wines must be socially undesirable. Moreover, the government has to be willing to forego some feasible tax revenue in order to achieve such an outcome.

5. Conclusions

We have analyzed the impact of taxes on the quantity and quality produced of goods whose market values accrue with age, such as wine. We have shown that a two-tax system that includes a volumetric sales tax and any one of three other taxes—an ad valorem sales tax, an ad valorem storage tax, or a volumetric storage tax—spans the qual-
ity/revenue feasible set and can support an optimal tax structure. We also derived tax equivalence for the three possible two-tax systems. The first best quality turns out to be a local tax revenue maximizing choice for any feasible tax system. Moreover, any tax system that reduces quality relative to the market equilibrium with no taxes could increase tax revenues and reduce the quality distortion without increasing the quantity distortion. Therefore, if society positively values both wine quality and wine quantity, then an optimal tax system would never reduce the quality marketed, though it necessarily reduces quantity. This finding suggests that social preferences regarding alcohol may be driving the use of taxation schemes that reduce both the quantity and quality of wine.
References


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Figure 1. Quality Choice With and Without Taxes.

\[
\frac{1}{dt} E_0(dp)
\]

\[
rt_q^r < p_s \tau_p^r + E_0(p)\tau_p^s + \tau_q^s
\]

\[
r^r t_q > p_s \tau_p^r + E_0(p)\tau_p^s + \tau_q^s
\]
Figure 2. Ad Valorem and Volumetric Retail Taxes: Tax Revenue Response

Surface Plot

Contour Plot
Figure 3. Feasible Tax Outcomes with Positive Tax Rates.

Ad Valorem and Volumetric Retail Taxes

Figure showing a graph with axes labeled 'quantity' and 'quality', with various lines indicating different tax outcomes, including Tax Revenue, Zero Ad Valorem Tax, Zero Volumetric Tax, Increasing Ad Valorem Tax, and Increasing Volumetric Tax.