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**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 whose market values accrue with age. The analysis is motivated by the high and increasing taxation rates in the wine industry across the globe. If society values both quality and quantity as goods, an optimal tax system would *never* reduce the quality marketed, though it necessarily reduces quantity. Any two-tax system that includes a *volumetric sales tax* and any one of three other types of tax – an *ad valorem sales tax*, an *ad valorem storage tax*, or a *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. Given this, the *only* explanation for taxation schemes that reduce both the quality and quality of goods like wine must be a Calvinistic social welfare function.

# 1. Introduction

Although often considered a relatively small specialty commodity, wine is in reality a substantial global industry. Anderson (2001) estimates that the total value of wine consumption in 1999 at US$100 billion. In 1998, nearly 7 billion gallons of wine were produced in over 60 countries from grapes grown on over 19 million acres of vineyards. However, wine consumption and production is subject to heavy taxation in virtually every country in the world. Economic distortions are therefore widespread, globally impacting consumption, production, and wine quality.

Wine taxes can be split into 3 broad categories. In order of decreasing importance, wine is subject to: Excise Taxes or wholesale taxes, value-added or sales taxes, and import duties/other taxes. Wittwer, Berger, and Anderson (2001) assert 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. Excise taxes are per unit volume taxes paid by the proprietors of bonded wine facilities on all wine for domestic sales. In the United States, these taxes are paid at both the federal and state levels.

Section 5401 of title 26 of the United States Tax Code requires US$1.07 per gallon of table wine to be paid to the federal government. All states require additional taxes, and many are volumetric sales taxes. The median state excise tax is US$.73 per gallon, but the charges range from a low of $.11 in Louisiana to a high of $2.25 in Florida. Many other countries employ excise taxes as well, including Canada, New Zealand, England, France, and Japan. On the other hand, some nations choose to impose percentage, or *ad*

*valorem*, taxes on wine premises. Notable examples include Mexico and Australia's 29% wine equalization tax (WET).[1] Some prominent wine producing and consuming countries have no excise or similar taxes on wineries or wholesalers, including Italy, Spain, Germany, and China. Nearly every major wine consuming country imposes a goods-and-services tax (GST) or a value-added tax (VAT). These taxes are assessed as a percentage of the purchase price of wine. In the United States, 44 states levy sales taxes on the purchase of alcoholic beverages. Many local governments in these states levy further retail sales taxes. Several states assess personal property taxes on business inventories.[2] Comparable global examples include Australia's 10% GST and New Zealand's 12.5% GST. European Union VAT's range from 15-25%, China imposes a 17% VAT, and the VAT in Argentina is 21%.

Many other taxes are levied on the consumption, production, trade, and sale of wine. However, while quite substantial in some markets, these taxes play a significantly smaller role in the distortions of the global market. For example, import tariffs can be ex-

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[1] Australia's WET is a special cast that is interesting in its own right. The basic point of the current situation for the WET is that any change in the value of wine stocks held by a vintner is treated as ordinary income. Stocks can be valued by any one of three methods, chosen by the producer –cost of production (excluding, in particular, storage costs), market value, or replacement value – with the stipulation that the ending valuation method in the previous period equals the beginning valuation method in the following period. Winemakers typically choose cost of production basis for valuation, so that aging wine does not increase the value of their stocks, and therefore, income until the wine is sold. With a bit of algebra, it can be shown that the WET has qualitatively the same effect as each of the four considered here on quantity, and precisely the same effect on quality/age as an *ad valorem sales tax.*

[2] California exempts the wine industry from property taxes on business inventories and also exempts almost all brands of wine from the bottle tax on glass containers. The former is an industry specific exemption from an *ad valorem storage tax*, while the latter is an industry specific exemption from a *volumetric sales tax*. We can interpret the results of this paper for California as a contrapositive analysis of these tax exemptions.

tremely high for exports to Asian nations (for example, 50% of total value for Chinese imports in 2000) but tend to be less than 5% of the total value of a premium quality wine for most developed nations (Berger and Anderson 1999). And importantly, trade levies are essentially non-existent within regions covered by trade agreements, like the EU and North America (NAFTA). Many other miscellaneous wine taxes exist globally, at all levels of government, and include levies such as special winery occupational taxes (US), licensing fees (US, Australia), and environmental fees (Canada).

Trends in wine taxation are also quite pronounced. Overall wine taxation has unambiguously risen in the past 2 decades and continues to do so. While tariffs are decreasing with trade liberalization and the WTO, the relatively larger excise taxes and goods and services taxes (or their respective global equivalents) are increasing. For example, between 1985 and 1998, the United States federal excise tax on table wine increased by 238%. During the same period, 16 states increased their excise taxes by an average of 69%.[3] More recently, the state of Illinois raised its tax rate more than 300%. The wholesale tax rate in Australia has more than doubled since the middle 1980's and the rate has increased in each of the past several years in New Zealand. In November of 2000, Japan proposed to double its excise tax rate. Volumetric excise taxes and *ad valorem* wholesale taxes, GSTs, and value-added taxes clearly play a large and increasing role in the wine industry.

The tendency for a *volumetric sales tax* to increase the average quality of a con-

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[3] 16 states lowered their excise tax rates, but by an average rate of less than 3%. Steve Barnsby & Associates, Inc. Columbus, NC. 1998.

sumed good is often referred to as the Alchian-Allen effect. In *University Economics* (1964), Alchian and Allen argued that any sort of fixed per unit charge for a good with both high and low quality versions will increase the relative consumption of the high quality good relative to the low quality good. This result has actually been credited to the UCLA oral tradition prior to the publication of Alchian and Allen's textbook (Borcherding and Silberberg, 1978). Barzel (1976) explained this effect in terms of product attributes; an *ad valorem* tax is based on all product attributes, while a *volumetric* tax affects only certain product attributes.

Numerous analyses have expanded upon the Alchian-Allen effect and Barzel's approach (Gould and Segall, 1969; Borcherding and Silberberg, 1978; Umbeck, 1980; Leffler, 1982; Kaempfer and Brastow, 1985; Cowen and Tabarrok, 1995; James and Alston, 2002). None of these analyses have addressed the time dimension of the quality-tax relationship. Many products, such as wine, aged cheese, cultured pearls, and most crop and livestock production are characterized by multi-period production processes. For these products, the tax/quantity/quantity relationship have an additional consideration; taxes that are assessed each period have a different effect on production decisions than do taxes that are assessed once during the production process. When time is an important contributing component to quality, the Alchian-Allen effect is no longer so obvious.

We examine the effects of taxes on the quantity and quality decisions of a single, competitive producer. Quantity is chosen in the intitial production period and quality increases with time. The producer chooses the optimal quantity and quality to produce and

sell. Including time in the profit maximization decision allows us to consider a broader range of tax instruments than is commonly considered in the literature regarding product quality and taxes. The passage of time affects the value of the product, and the share of that value that is captured by the tax authority.

We evaluate four separate types of taxes: and *ad valorem sales tax* assessed as a percentage of price and collected on the date the wine is sold, a *volumetric sales tax* assessed at a fixed rate per unit sold and collected on the date of sale, an *ad valorem storage tax* assessed as a percentage of each period's market value of the wine and collected during storage and aging of the wine prior to its sale to consumers, and a *volumetric storage tax* assessed at a fixed rate per unit held in storage and collected while the wine is stored and aged. Although this list is not complete, with a careful application of a little of algebra, they appear to the authors to cover most, if not all, of the cases we have found to be in existence across the world.

Our findings can be summarized as follows. An increase in any marginal tax rate unequivocally decreases quantity produced. An increase in the *ad valorem sales tax* rate can either increase or decrease the quality of wine depending on the level of all tax rates and other economic values important to the market for the production and storage of wine. An increase in the *volumetric sales tax* rate unequivocally increases quality. An increase in either the *ad valorem* or *volumetric storage tax* rate unequivocally decreases quality. If society values both quality and quantity as goods, an optimal tax system would not reduce quality, though positive tax revenue necessarily implies a reduction in quantity. Any two-tax system that includes a *volumetric sales tax* and any one of three other

types of tax spans the quality/revenue feasible set and can support an optimal tax system. We derive the relationships between the three possible two-tax systems that give rise to *tax equivalence* aming them. 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. Given this, the only explanation we can find for tax schemes that reduce both the quality and quality of goods such as wine must be driven by a Calvinistic social welfare function.

The rest of the paper is organized in the following way. The next section briefly develops the basic economic model with no taxes to establish our base point for the analysis that follows. Section 3 introduced the four taxes into this model and derives some essential comparative statics and iso-revenue and iso-tax relationships that are used later in the paper. Section 4 establishes the relationships necessary and sufficient for tax equivalence among the two-tax systems that span the revenue/quality feasible set and proves our main result relating to tax revenue and quality in a society that values both quantity and quality as welfare increasing goods. The last section summarizes and concludes our story.

## 2. The Basic Model

Consider the problem of the production, storage and aging, and ultimate sale of a single variety of wine by a single representative winery. Let $q$ denote the quantity of wine produced at the initial date in the production/aging/sales process, $t = 0$, $x(t)$ the quality of the wine when it is sold at date $t$, $p(x(t))$ the market price for wine as a function of its quality, $c(q)$ the variable cost of production, $p_s$ the marginal cost of storage per unit of wine per

period, and $r$ the real rate of time discount. The realized profit from producing $q$ units of wine at time 0, aging the wine until date $t$, and sale at the final storage date is

$$\pi = e^{-rt} p(x(t))q \; - \; c(q) \; - \; \left(1 - e^{-r\tau}\right) p_s q \big/ r .$$ (1)

Wine quality evolves as a result of a stochastic process,

$$dx = \alpha(x,t)dt + \beta(x,t)dz ,$$ (2)

where $dz = \sqrt{dt}\varepsilon$, with $\varepsilon$ *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 (for almost all realizations for $x$). 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 unpre-dictable and uncontrollable factors. We assume that the vintner realizes the initial quality $x_0$ at the grape harvest and wine production date and is able to continuously sample small quantities of wine from existing unsold stocks to learn the current quality at each date, $\tau \in [0,t]$. Consumers realize the quality of wine when it is purchased and con-sumed. We also assume the market price is an increasing and concave function of quality, $p'(x) > 0$ and $p''(x) < 0 \; \forall \; x$, and that the vintner is risk neutral.

Maximizing $E_0(\pi)$ with respect to $q$ implies

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

where $E_0(\cdot)$ denotes the conditional expectation operator, given information available to the vintner at time $t = 0$, when the grapes are harvested and the current vintage of wine is

produced. Rearranging terms, we obtain

$$E_0(p)e^{-rt} = c'(q) + (1 - e^{-rt})p_s/r,\tag{4}$$

which staes that the optimal level of wine production is where the expected marginal dis-counted present value of quantity equals the sum of the marginal cost of production plus the discounted present value of the marginal cost of aging for the entire storage period prior to sale of the vintage.

The optimal sales date satisfies the stopping rule,

$$\frac{1}{dt}E_t(dp) = rp + p_s,\tag{5}$$

which by Ito's lemma can be rewritten in the form,

$$\alpha(x,t)p'(x) + \frac{1}{2}\beta(x,t)^2 p''(x) = rp + p_s.\tag{6}$$

In other words, the optimal age of sale is when the conditionally expected marginal value of quality equals the marginal opportunity cost of foregone revenues from foregoing sale another period plus the marginal cost of storage per unit of time. The first term on the left-hand-side is the conditional mean effect on marginal quality due to additional aging, which tells us how the marginal value of age $t$ wine with current quality $x(t)$ increases on average with $dt$ additional aging. The second left-hand-side term is the conditional vari-ance effect on marginal quality due to additional aging. Since we assume that the market price is concave in quality, there are diminishing marginal returns to aging and there is an induced risk effect due to the variability of future qualities given current quality.

Let $t^*$ denote the *ex ante* expected optimal age of wine. That is, $t^*$ is implicitly

defined by

$$\frac{1}{dt} E_0 \big[ dp\big(x(t^*)\big) \big] = r E_0 \big[ p\big(x(t^*)\big) \big] + p_s . \tag{7}$$

We refer to $t^*$ as the *first-best* optimal age. Similarly, let $q^*$ denote the choice with with no taxes, and refer to $q^*$ as the *first-best* optimal quantity.

### 3. Wine Taxes, Quantity, Quality, and Revenue

As discussed in the introduction, we consider four separate types of taxes. First is an *ad valorem sales tax* assessed as a fixed percentage of the market price and collected when the vintner sells the wine. The discounted present value of the tax paid in this case is $e^{-rt}p(t)q\tau_p^r$, where $\tau_p^r \in [0,1]$ is the ad valorem sales tax rate. Second is a *volumetric sales tax* assessed as a fixed monetary amount per unit volume and collected at sale. The discounted present value of tax paid in this case is $e^{-rt}q\tau_q^r$, where $\tau_q^r \geq 0$ is the volumetric valorem sales tax rate. Third is an *ad valorem storage tax* assessed as a fixed percentage of the *ex ante* expected value of the market price of wine, $E_0\big[p\big(x(\theta)\big)\big]$, $\theta \in [0,t]$, and collected continuously throughout the storage period. The discounted present value of the total tax paid in this case is $\int_0^t e^{-r\theta}\tau_p^s E_0\big[p\big(x(\theta)\big)\big]qd\theta$, where $\tau_p^s \in [0,1]$ is the ad valorem storage tax rate. And fourth is a *volumetric storage tax* assessed as a fixed monetary amount per unit volume and collected continuously throughout the storage period. The discounted present value of the total tax paid in this last case is $\big(1-e^{-rt}\big)\tau_q^s q / r$, where $\tau_q^s \geq 0$ is the volumetric storage tax rate.

Thus, the vintner's realized profit with all four types of taxes is

$$\pi(t) = e^{-rt}\left[ p(x(t))(1-\tau_p^r) - \tau_q^r \right] q - \int_0^t e^{-r\theta} E_0(p(x(\theta))\tau_p^s q d\theta$$

$$-\left(1-e^{-rt}\right)(p_s + \tau_q^s)q/r - c(q) \tag{8}$$

We also can define the *ex ante* expected value of the total effective tax rate per unit of wine by

$$\upsilon(\tau) = e^{-rt}\left\{ \tau_p^r E_0 p\left[ x\left(t(\tau)\right)\right] + \tau_q^r \right\} + \int_0^{t(\tau)} e^{-r\theta}\left[ \tau_p^r E_0 p\left( x(\theta)\right) + \tau_q^r \right] d\theta, \tag{9}$$

and the *ex ante* expected value for total tax revenue by $R(\tau) = \upsilon(\tau)q(\tau)$, where $t(\tau)$ and $q(\tau)$ are the optimal *ex ante* expected choices for the age and quantity of wine, respectively, given the tax regime $\tau = [\tau_p^r \quad \tau_q^r \quad \tau_p^s \quad \tau_q^s]'$.

**3.1 Quality Choice with Taxes**

We now consider the revenue effects of changes in the tax regime on the quantity and quality of wine produced. Due to the recursive nature of the stochastic decision problem faced by the vintner, it turns out to be simpler to do this in reverse order. Thus, the stopping rule for the age that maximizes the expected value of the wine is

$$\frac{1}{dt}E_t\left(dp\right)(1-\tau_p^r) = r\left[ p(1-\tau_p^r) - \tau_q^r \right] + p_s + E_0(p)\tau_p^s + \tau_q^s. \tag{10}$$

Dividing through by $(1-\tau_p^r)$ and rearranging terms slightly, we have

$$\frac{1}{dt}E_t\left(dp\right) = rp + p_s + \left( \frac{-r\tau_q^r + \tau_p^r p_s + E_0(p)\tau_p^s + \tau_q^s}{1-\tau_p^r} \right). \tag{11}$$

This form for the stopping rule illustrates several important properties of these taxes on

quality. First, the impact of volumetric retail taxes on age and quality is qualitatively the same way as lower storage costs. Second, volumetric and ad valorem storage taxes act the same as increased storage costs. Third, the impact of ad valorem retail taxes on age is not obvious without further analysis. Fourth, due to the linear nature of the numerator on the far right-hand-side of (11) in each of the tax rates, it is transparent that there is a re-dundancy among the different types of taxes. Finally, so long as the second order condition for a unique optimal solution is met, the optimal choice for quality/age of wine ex-ceeds, equals, or is less than the *first best* age if and only if

$-r\tau_q^r + \tau_p^r p_s + E_0(p)\tau_p^s + \tau_q^s \underset{>}{\overset{\leq}{=}} 0$. This result is clearly illustrated by the shifts in the right-hand-side of equation (11)in figure 1.

[**Insert Figure 1 here**]

The formal comparative statics results for age with respect to each of the taxes are

$$\frac{\partial t}{\partial \tau_q^r} = \frac{-r}{(1-\tau_p^r)\Delta_t} > 0, \tag{12}$$

$$\frac{\partial t}{\partial \tau_q^s} = \frac{1}{(1-\tau_p^r)\Delta_t} < 0, \tag{13}$$

$$\frac{\partial t}{\partial \tau_p^s} = \frac{E_0(p)}{(1-\tau_p^r)\Delta_t} < 0, \tag{14}$$

$$\frac{\partial t}{\partial \tau_p^r} = \frac{[-r\tau_q^r + p_s + E_0(p)\tau_p^s + \tau_q^s]}{(1-\tau_p^r)^2\Delta_t} \underset{<}{\overset{\geq}{=}} 0 \iff r\tau_q^r \underset{<}{\overset{\geq}{=}} p_s + E_0(p)\tau_p^s + \tau_q^s, \tag{15}$$

where $\Delta_t = \frac{\partial}{\partial t}\left[\frac{1}{dt}E_t(d\pi)\right] < 0$ by the second-order condition for a unique optimum.

### 3.2 Quantity Choice with Taxes

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

$$0 = \frac{\partial}{\partial q} E_0(\pi) = e^{-rt} \left[ E_0(p)(1-\tau_p^r) - \tau_q^r \right] - \int_0^t e^{-r\theta} [p_s + E_0(p)\tau_p^s + \tau_q^s] d\theta - c'(q). \quad (16)$$

The second-order condition for $q$ is simply $c''(q) > 0$. 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 quanity, $\partial^2 E_0(\pi)/\partial q \partial t$. Differentiating the first-order condition for $q$ with respect to $t$, we obtain

$$\frac{\partial^2 E_0(\pi)}{\partial q \partial t} = e^{-rt} \left\{ \frac{\partial}{\partial t} E_0(p)(1-\tau_p^r) - r\left[ E_0(p)(1-\tau_p^r) - \tau_q^r \right] - p_s - E_0(p)\tau_p^s - \tau_q^s \right\}. \quad (17)$$

From equations (2) and (3) above, we see that

$$\frac{\partial}{\partial t} E_0(p) = E_0 \left[ \alpha(x(t),t)p'(x(t)) + \frac{1}{2}\beta(x(t),t)^2 p''(x(t),t) \right] = E_0 \left[ \frac{1}{dt} E_t(dp) \right], \quad (18)$$

which also can be seen by interchanging the integration and differentiation operators.

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

$$\left[ \frac{\partial}{\partial t} E_0(p) \right](1-\tau_p^r) - r\left[ E_0(p)(1-\tau_p^r) - \tau_q^r \right] - \left[ p_s + E_0(p)\tau_p^s + \tau_q^s \right] = 0. \quad (19)$$

In other words, $\partial^2 E_0(\pi)/\partial q \partial t = 0$. This makes good intuitive sense. Since 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 un-conditional expected value of the *ex post* choice for age will have no impact on the opti-mal *ex ante* choice of quantity. This greatly simplifies the derivation of the following

*ex ante* choice of quantity. This greatly simplifies the derivation of the following comparative statics results for quantity,

$$\frac{\partial q}{\partial \tau_p^r} = \frac{-e^{-rt}E_0(p)}{c''(q)} < 0, \tag{20}$$

$$\frac{\partial q}{\partial \tau_q^r} = \frac{-1}{c''(q)} < 0, \tag{21}$$

$$\frac{\partial q}{\partial \tau_p^s} = \frac{-\int_0^t e^{-r\theta}E_0\left(p(x(\theta))\right)d\theta}{c''(q)} < 0, \tag{22}$$

and
$$\frac{\partial q}{\partial \tau_q^s} = \frac{-\left(1-e^{-rt}\right)}{rc''(q)} < 0. \tag{23}$$

In other words, an increase in any of the four types of taxes leads to a decrease in the quantity of wine produced.

### 3.3 Age/Quality Neutral Tax Systems

It follows from the first-order condition for quantity that, for a fixed age/quality outcome, any change in the taxation scheme that increases the *ex ante* mean per unit tax rate, $v(\tau)$, decreases quantity, $q(\tau)$, since we then have

$$\left.\frac{\partial q(\tau)}{\partial \tau}\right|_{t(\tau)} = -\frac{1}{c''(q(\tau))} \times \left.\frac{\partial v(\tau)}{\partial \tau}\right|_{t(\tau)}. \tag{24}$$

It also follows from the first-order condition for the *ex ante* age/quality choice that there will be no age/quality distortion if and only if the tax system satisfies the condition

$$r\tau_q^r = p_s\tau_p^r + E_0\left(p\left(t\left(\tau\right)\right)\right)\tau_p^s + \tau_q^s. \tag{25}$$

In other words, as long as the volumetric retail tax increases in a corresponding manner,

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each of the other three taxes can be increased without distorting the age/quality decision. Furthermore, if any of the other three types of taxes are imposed, a positive volumetric retail tax is necessary for there to be no age distortion. On the other hand, all four types of taxes distort quantity in the same direction. Hence, for any given tax revenue target, a two-tax system is necessary and sufficient to eliminate an age/quality distortion, but no tax system (absent negative tax rates, or subsidies) will eliminate the quantity distortion.

It therefore is of some interest to consider two-tax systems that do not distort the *ex ante* mean wine age/quality. Three cases are possible:

(1) *retail taxes* satisfying $\tau_q^r = p_s \tau_p^r / r$, so that $\boldsymbol{\tau}_1 = \left[\tau_p^r \quad (p_s/r)\tau_p^r \quad 0 \quad 0\right]'$ and

$$v_1 \equiv v(\boldsymbol{\tau}_1) \equiv \frac{1}{r} e^{-rt(\boldsymbol{\tau}_1)} \left[rE_0\left(p\left(t\left(\boldsymbol{\tau}_1\right)\right)\right) + p_s\right]\tau_p^r;$$

(2) *volumetric taxes* satisfying $\tau_q^r = \tau_q^s / r$, so that $\boldsymbol{\tau}_2 = \left[0 \quad \tau_q^s/r \quad 0 \quad \tau_q^s\right]'$ and

$$v_2 \equiv v(\boldsymbol{\tau}_2) \equiv \tau_q^s / r; \text{ and}$$

(3) *volumetric retail tax* and *ad valorem storage tax* satisfying $\tau_q^r = E_0\left(p\left(t\left(\boldsymbol{\tau}\right)\right)\right)\tau_p^s / r$,

so that $\boldsymbol{\tau}_3 = \left[0 \quad E_0\left(p\left(t\left(\boldsymbol{\tau}\right)\right)\right)\tau_p^s/r \quad \tau_p^s \quad 0\right]'$ and

$$v_3 \equiv v(\boldsymbol{\tau}_3) \equiv \left[e^{-rt(\boldsymbol{\tau}_3)} E_0\left(p\left(t*\right)\right)/r + \int_0^{t(\boldsymbol{\tau}_3)} e^{-r\theta} E_0\left(p(\theta)\right)d\theta\right]\tau_p^s.$$

In each case it is easy to check that the *ex ante* condition for the age/quality choice by the producer reduces to the original condition for the first-best age/quality, $t*$. Second, it is clear in each case from the right-hand-side expression for $v_i$, $i = 1,2,3$, that the total effective *ex ante* mean tax rate is linearly increasing in the tax rate used to balance the volu-

metric retail tax to maintain age/quality neutrality. Therefore, an increase in each of these taxes increases $v$ and decreases $q$.

Next, recalling the definition of the *ex ante* mean tax revenue, $R(\tau) = v(\tau)q(\tau)$, it follows that

$$\frac{\partial R(\tau)}{\partial \tau} = \frac{\partial v(\tau)}{\partial \tau}q(\tau) + v(\tau)\frac{\partial q(\tau)}{\partial \tau},\qquad(26)$$

which implies that for any given age/quality outcome,

$$\frac{\partial R(\tau)}{\partial \tau}\bigg|_{t(\tau)} = q(\tau) \times \frac{\partial v(\tau)}{\partial \tau}\bigg|_{t(\tau)} - \frac{v(\tau)}{c''(q(\tau))} \times \frac{\partial v(\tau)}{\partial \tau}\bigg|_{t(\tau)}$$

$$= \left(\frac{c''(q(\tau))q(\tau) - v(\tau)}{c''(q(\tau))}\right) \times \frac{\partial v(\tau)}{\partial \tau}\bigg|_{t(\tau)}.\qquad(27)$$

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 *ex ante* expected total tax revenue if and only if $c''\big(q(\tau)\big)q(\tau) - v(\tau) \gtreqless 0$. Since 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 $\tau = \mathbf{0}$ and $q = q^*$, but eventually vanishes and then changes sign to become negative as the average effective tax rate increases and quantity decreases.

## 3.4 Tax Equivalence of the Two-Tax Age-Neutral Systems

We can 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, it follows that the quantity distortion and the mean *ex ante* tax revenue generated will be the

same for each two-tax system under this condition. Using the right-hand-side expression

for the $v_i$ above, it follows that $v_1 = v_2 = v_3$ if and only if

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

$$= \left[e^{-rt^*}E_0\left(p(t^*)\right)+r\int_0^{t^*}e^{-r\theta}E_0\left(p(\theta)\right)d\theta\right]\tau_p^s, \tag{28}$$

keeping in mind that $\tau_p^r > 0$ 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. In the first case, since *re-*

*tail taxes* are paid at one in time after $t^*$ time periods have elapsed following production,

and since because there is no age distortion $\frac{1}{dt}E_0\left(dp(t^*)\right)=rE_0\left(p(t^*)\right)+p_s$. 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 $e^{-rt^*}\frac{1}{dt}E_0\left(dp(t^*)\right)\tau_p^r$ on

each unit of wine *in perpetuity*. On the other hand, the *volumetric storage tax* is paid

every period between production and sales 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 $\tau_q^s$ on each unit of wine *in per-*

*petuity*. The first line therefore equates the periodic perpetual annuity payments for these

two otherwise quite different taxation schemes. An analogous equating of incentives ap-

plies 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. The upshot is that, if we normalizing on the ad valorem retail sales tax, then for any $\tau_p^r > 0$ we have complete *tax equivalence* among the age-neutral two-tax systems defined by

$$\tau_1 = [\tau_p^r \quad p_s\tau_p^r/r \quad 0 \quad 0]',$$

(29)

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

(30)

$$\tau_3 = \left[0 \quad \frac{E_0(p)e^{-rt*}\left[rE_0(p)+p_s\right]\tau_p^r}{r\left[e^{-rt*}E_0(p)+\int_0^{t*}e^{-r\theta}E_0(p)d\theta\right]} \quad \frac{e^{-rt*}\left[rE_0(p)+p_s\right]\tau_p^r}{e^{-rt*}E_0(p)+\int_0^{t*}e^{-r\theta}E_0(p)d\theta} \quad 0\right]'.$$

(31)

## 4. Optimal Tax Systems

From the ex ante first order condition for quality, assuming that the second order condition is met, recall that $t(\tau) \underset{<}{\overset{>}{=}} t*$ if and only if $-r\tau_q^r + \tau_p^r p_s + E_0(p)\tau_p^s + \tau_q^s \underset{>}{\overset{\leq}{=}} 0$. Differentiating the ex ante expected tax rate with respect to $t$ gives, after a little algebra,

$$\frac{\partial v}{\partial t} = e^{-rt}\left(\frac{-r\tau_q^r + p_s + \tau_q^s + E_0\left(p(t)\right)\tau_p^s}{1-\tau_p^r}\right).$$

(32)

This shows us 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 greated than the *first best* age of wine. Since there is no in-

teraction 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 in this section.

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

$$0 = dR = \frac{\partial R}{\partial \tau'} d\tau$$

$$= v \frac{\partial q}{\partial \tau'} d\tau + q \frac{\partial v}{\partial q} \frac{\partial q}{\partial \tau'} d\tau + q \frac{\partial v}{\partial t} \frac{\partial t}{\partial \tau'} d\tau$$

$$= (v - c''(q)q) dq + q \frac{\partial v}{\partial t} dt . \tag{33}$$

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

$$\frac{dt}{dq}\bigg|_R = \frac{[c''(q)q - v](1 - \tau_p^r)}{e^{-rt}\left[-r\tau_q^r + \tau_p^r p_s + E_0(p)\tau_p^s + \tau_q^s\right]} . \tag{34}$$

It is reasonable to assume that $c''(q) > 0 \ \forall \ q \geq 0$ and $\lim_{q \to 0} c''(q)q = 0$. Then the numerator of (34) is positive for small effective tax rates, but eventually vanishes and changes sign to become negative as the tax rate increases and quantity decreases.[4] On the other hand,

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[4] 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 $v = \delta p$. Then the numerator of (34) is positive, zero or negative as the price elasticity of quantity supplied, $\varepsilon_p^q = p/(c''(q)q)$, 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 (34) is strictly positive, at least for the typical current tax system imposed on the wine market.

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 that illustrated in figure 2 for the case of a two retail tax system.

**[Insert Figure 2 Here]**

In other words, when quantity and quality are both below their first best levels, but in the neighborhood of the no-tax equilibrium, the iso-revenue curves must have a positive slope. As quantity and quality both fall with an increase in the effective tax rate, *v*, the slope of the iso-revenue curve becomes vertical and eventually has a negative slope. Then, as we progress along the iso-revenue curve by increasing quality but continuing to decrease quantity, we eventually reach the age-neutral point and a horizontal iso-revenue locus in the quality/quantity plane as depicted in the figure. Continuing along this locus with increasing quality and quantity, and finally with increasing quantity and decreasing quality, we eventually complete the entire oval or egg-shaped iso-revenue locus.

The upshot is that the first best is a relative maximum of tax revenues with respect to quality for all quantity choices, every positive tax revenue can be supported by a two-tax system that accommodates the first best quality outcome, and 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. Therefore, 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 must be Calvinistic in nature for the tax structure to be socially optimal – both the quantity of wine consumed and high 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

In this paper, we have analyzed the impact of taxes on the quantity and quality produced of goods whose market values accrue with age. The model and our analysis are motivated by the high and increasing taxation rates in the wine industry across the globe. We have shown that a two-tax system that includes a *volumetric sales tax* and any one of three other tax types – an *ad valorem sales tax*, an *ad valorem storage tax*, or a *volumetric storage tax* – spans the quality/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 values both quality and quantity as goods, then an optimal tax system would *never* reduce the quality marketed, though it necessarily reduces quantity. Given this, the only explanation remaining for taxation schemes that reduce both the quality and quality of goods like wine must be Calvinistic social preferences.

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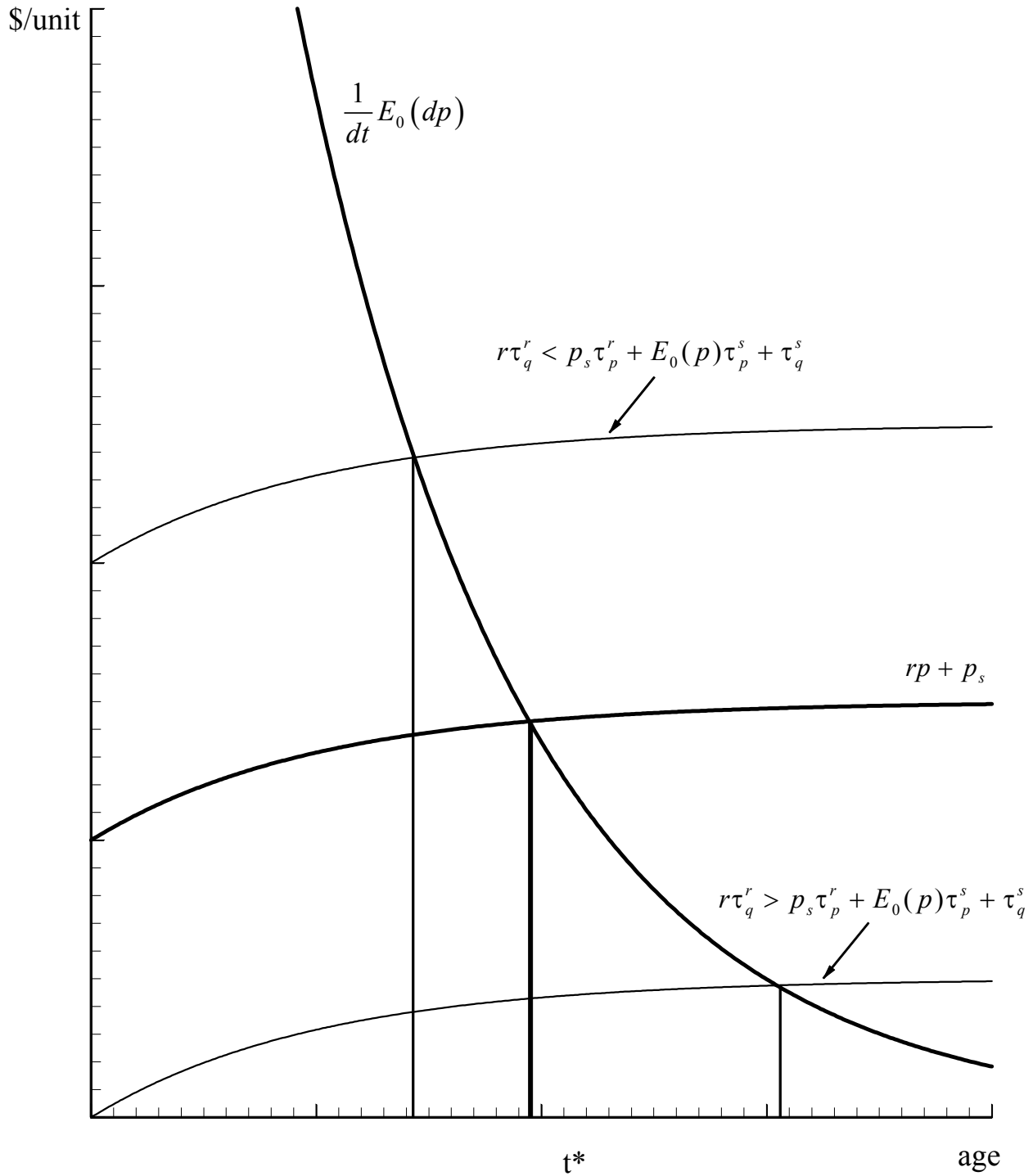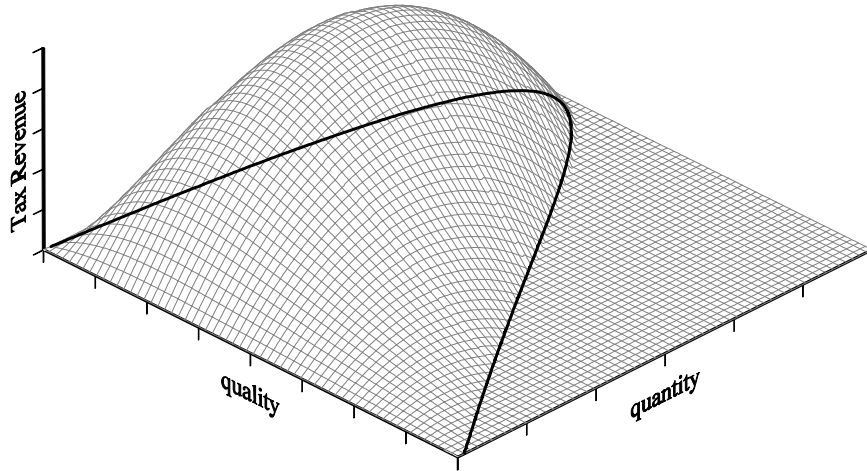# Figure 1. Quality Choice With and Without Taxes.



$/unit

$$\frac{1}{dt}E_0(dp)$$

$$r\tau_q^r < p_s\tau_p^r + E_0(p)\tau_p^s + \tau_q^s$$

$$rp + p_s$$

$$r\tau_q^r > p_s\tau_p^r + E_0(p)\tau_p^s + \tau_q^s$$

t*

age

**Figure 2. An *Ad Valorem* and *Volumetric* Retaim Tax System.**

**Ex Ante Tax Revenue**



**Ex Ante Iso-Revenue Contours**