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Abstract: We consider the impact of taxes on the quantity and quality produced of goods, such as wine, for which market value accrues with age by a competitive producer. Any pair of taxes 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 full range of feasible tax revenues with positive tax rates. For any tax system that reduces quality relative to the firm's no-tax equilibrium, there is another tax system that increases tax revenues, eliminates the quality distortion, and does not increase the quantity distortion. Many wine industry observers believe that most, if not all, existing tax systems tend to result in the suboptimal provision of quality. Our results suggest that the wide variety of wine tax systems is not prima facie evidence that these systems, or most of them, are inefficient. Provided the system includes a volumetric sales tax it may be efficient, regardless of which of the other instruments, or how many of them, are used. Assertions regarding inefficiency must be evaluated on an empirical case-by-case basis. Our analysis provides a theoretical framework for such research.

Keywords: aging, Alchian-Allen effect, tax policy, wine

Running Head: Returns to Aging

JEL: D2, H2, Q1

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WINE TAXES, PRODUCTION, AGING AND QUALITY

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).[1] 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 – 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.

In this paper, we develop a dynamic model of the producer's profit-maximizing choices in the presence of a tax system. 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 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. Previous analyses of the Alchian-Allen effect have restricted attention to the ad valorem and volumetric sales taxes.

We derive the effects of each tax instrument on the quantity and quality supplied, and obtain equivalency results regarding various two-tax systems. We find that an increase in any marginal tax rate unequivocally decreases quantity produced. Consistent with Alchian-Allen, an increase in a volumetric sales tax rate increases quality at the time of sale. However, because quality increases over time, an increase in the ad valorem sales tax rate can either increase or decrease quality at the time of sale, 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

[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).

storage tax rate unequivocally decreases quality at the time of sale.

Any two-tax system that includes a volumetric sales tax and any one of the three other taxes spans the quality/revenue feasible set. The supply side distortions of any tax system that results in a lower quality relative to the no-tax equilibrium can be mitigated by an alternative tax system that increases tax revenues, eliminates the quality distortion, and does not increase the quantity distortion.

A volumetric sales tax is distinguished from the other taxes considered here only because it permits the construction of a full range of two-tax schemes with *positive* taxes. If subsidies were permitted, then *any* tax system with two instruments could deliver the optimal quality level. Since direct subsidies of wine production on a per-unit basis are not typically observed in practice, such schemes would be of little practical interest. The exception to this rule is the European Union. While most of its subsidies are not on a per-unit of wine basis, under the 2000 CAP reforms there is limited aid to private storage of wine (Corsi, Pomarici, and Sardone, 2004).

Wine is a particularly interesting aged product to examine, for three reasons. First, 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. Berger, and Anderson (1999) 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, wine is subject to a volumetric sales tax (excise tax) and an ad valorem sales tax at the federal level. 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, which 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.

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 externalities.

Our analysis provides a starting point for examining the validity of a true sin tax component in wine taxes. If a given tax system is efficient, then there is no sin tax component. On the other hand, if a given tax system is inefficient, then the possibility of a sin tax component cannot be rejected in our framework. In that event, one or more of our simplifying assumptions should be relaxed in order to ascertain whether the tax system continues to be inefficient, and, hence whether the possibility of a sin tax component continues to exist.

Previous work has examined wine taxes. Tsolakis (1983), Buccola and VanderZanden (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. Wohlgenant (1982) examines vintner aging decisions across vintages as an inventory problem, but does not consider taxes.

2. The Basic Model

We assume a perfectly competitive market, so that the market price of wine at the date of sale is a perfect signal of quality.[3] We also invoke the small country assumption, and focus on the effects of taxes through wine prices and costs on a representative winery. Both the tax authority and the representative winery have rational expectations. The quantity of wine produced is determined at the initial date, $t = 0$, while quality is a function of the wine's initial quality and the number of periods it is aged.

Consider the problem of the production, aging, and ultimate sale of wine from a single crushing by a representative winery. The winery maximizes profits by choosing

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[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.

[3] We therefore are abstracting from the potential asymmetric information issues that may arise between the producer and consumers.

the quantity of wine produced, *q*, and by choosing the quality of the wine through choosing its sale date *t*.

We denote the cost of production as *c*(*q*), the marginal cost of storage per unit 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

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

Maximizing π with respect to *q* implies

$$\frac{\partial \pi}{\partial q} = p(t)e^{-rt} - c'(q) - \frac{1 - e^{-rt}}{r} p_s = 0 \tag{2}$$

Equation (2) can be rewritten as

$$p(t)e^{-rt} = c'(q^*) + \left(\frac{1 - e^{-rt}}{r} \right) p_s \; . \tag{2'}$$

Equation (2') shows that the optimal quantity of wine *q** is determined by where the 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 firm's *first-best* quantity.

The firm chooses the age at which it sells the vintage according to the following profit-maximization condition:

$$p'(t) = rp(t) + p_s \; . \tag{3}$$

That is, the firm sells the wine at time *t* when the marginal increase in value from holding the wine for an additional period is equal to the marginal cost of holding it: the opportunity cost of the money obtained from selling the wine at time *t* plus the marginal cost of storing the wine a little longer. Hereafter, we call this date of sale the firm's *first-best* age of wine, *t**. We assume that *t** is a unique global maximizer.

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

We now introduce taxes into the producer's profit maximization problem, focusing on the comparative analyses of long-run responses to the different taxation schemes considered. 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 assume that once the tax system has been designed and chosen, it remains in place unchanged throughout the producer's planning horizon. *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 tax paid at time t is $e^{-rt}\tau_p^r p(t)q$, where $\tau_p^r \in [0,1]$ 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. In this case, the discounted present value of the tax paid at time t is $e^{-rt}\tau_q^r q$, where $\tau_q^r \geq 0$ is the volumetric valorem sales tax rate. An *ad valorem storage tax* is assessed as a fixed percentage of the market price of wine, *p(t),* and is collected continuously throughout the storage period.[4] The discounted present value of the total tax paid in this case is $\int_0^t e^{-rx}\tau_p^s p(x)qdx$, where $\tau_p^s \in [0,1]$ 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 $(1-e^{-rt})\tau_q^s q/r$, where $\tau_q^s \geq 0$ is the volumetric storage tax rate.

After incorporating all four tax instruments, the vintner's profit is

$$\pi(t) = e^{-rt}\left[p(t)(1-\tau_p^r) - \tau_q^r\right]q \; - \; \int_0^t e^{-rx}\tau_p^s p(x)qdx \\ -\left(\frac{1-e^{-rt}}{r}\right)(p_s + \tau_q^s)q \; - \; c(q). \tag{4}$$

For future use, given the tax regime $\boldsymbol{\tau} = [\tau_p^r \quad \tau_q^r \quad \tau_p^s \quad \tau_q^s]'$ we define the *effective tax rate per unit of wine* as

$$v(\boldsymbol{\tau}) = e^{-rt(\boldsymbol{\tau})}\left[\tau_p^r p(t(\boldsymbol{\tau})) + \tau_q^r\right] + \int_0^{t(\boldsymbol{\tau})} e^{-rx}\left[\tau_p^r p(x) + \tau_q^r\right]dx, \tag{5}$$

and the value of total tax revenue as $R(\boldsymbol{\tau}) = v(\boldsymbol{\tau})q(\boldsymbol{\tau})$, where $q(\boldsymbol{\tau})$ is the optimal choice for quantity and $t(\boldsymbol{\tau})$ is the optimal 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 firm's optimal stopping rule for the age that maximizes the expected per-unit value of the wine with respect to its date of sale is

$$(1-\tau_p^r)p'(t) = r\left[(1-\tau_p^r)p(t) - \tau_q^r\right] + p_s + \tau_p^s p(t) + \tau_q^s. \tag{6}$$

[4] We thus abstract away from tax collection costs and other complications associated with cases where the tax authority must continuously appraise the value of wine that has not yet been sold in order to collect ad valorem taxes.

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

$$p'(t) = rp(t) + p_s + \left(\frac{\tau_p^r p_s - r\tau_q^r + p(t)\tau_p^s + \tau_q^s}{1-\tau_p^r} \right). \tag{7}$$

In the presence of taxes, the firm chooses t such that the marginal value of quality equals the marginal opportunity cost of waiting another period to sell then wine plus the cost of storage, plus the net effect of taxes on the returns to waiting. Equation (7) illustrates several important properties of these taxes. First, in this framework, the basic Alchian-Allen effect holds for a volumetric retail tax: an increase in this tax increases the profit-maximizing age at sale. Formally,

$$\frac{\partial t}{\partial \tau_q^r} = \frac{-r}{(1-\tau_p^r)\Delta_t} > 0\,, \tag{8}$$

where $\Delta_t = \partial^2 \pi / \partial t^2 < 0$ by the second-order condition for a unique maximum.[5] Second, the volumetric retail tax has the same qualitative effect on age/quality at sales as a decrease in storage costs does. Third, the Alchian-Allen dichotomy does not hold for a volumetric or an ad valorem storage tax. Both taxes unambiguously decrease the profit-maximizing age. Formally,

$$\frac{\partial t}{\partial \tau_q^s} = \frac{1}{(1-\tau_p^r)\Delta_t} < 0\,, \tag{9}$$

$$\frac{\partial t}{\partial \tau_p^s} = \frac{p}{(1-\tau_p^r)\Delta_t} < 0\,, \tag{10}$$

Fourth, an increase in either storage tax has the same qualitative effect on age/quality at sales as an increase in storage costs. Fifth, the impact of ad valorem retail taxes on age is indeterminate, rather than always negative, as in the single-period case. Formally,

$$\frac{\partial t}{\partial \tau_p^r} = \frac{(-r\tau_q^r + p_s + \tau_p^s p + \tau_q^s)}{(1-\tau_p^r)^2 \Delta_t} \gtreqless 0 \;\Leftrightarrow\; r\tau_q^r \gtreqless p_s + \tau_p^s p + \tau_q^s\,. \tag{11}$$

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[5] This is equivalent to $(1-\tau_p^r)p''(t) < [r(1-\tau_p^r) + \tau_p^s]p'(t)$. A sufficient condition for this to be satisfied for any tax system is that there exists a t_0 satisfying $0 < t_0 < \infty$ and $p''(t) < 0 \;\forall\; t > t_0$.

Sixth, since the numerator of the parenthesized expression in (7) is linear in the tax rates, any given tax revenue objective can be achieved with different combinations of tax instruments. Finally, provided the second order condition for a unique maximum is met, the optimal choice for quality/age of wine exceeds, equals, or is less than the *first-best* age if and only if

$$-r\tau_q^r + \tau_p^r p_s + \tau_p^s p + \tau_q^s \lesseqgtr 0\,. \tag{12}$$

This result is illustrated in Figure 1. The figure plots $p'(t)$ against the right-hand side of (7) in age-price space. The *first-best* age and price are obtained when $p'(t) = rp(t) + p_s$, and the net effect of the taxes on the *first-best* age of wine is zero. This outcome is where the curve labeled $p'(t)$ intersects the line labeled $rp(t) + p_s$. The intersections of the other two curves with the $p'(t)$ curve illustrate 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. With an arbitrary tax system, the profit-maximizing quantity satisfies the first-order condition,

$$\frac{\partial \pi}{\partial q} = e^{-rt}\left[(1-\tau_p^r)p(t) - \tau_q^r\right] - \int_0^t e^{-rx}\left[p_s + \tau_p^s p(x) + \tau_q^s\right]dx - c'(q) = 0\,. \tag{13}$$

The second-order sufficient condition for a unique 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 cross partial derivative, $\partial^2\pi/\partial q\partial t$. Differentiating the first-order condition for q with respect to t, we obtain

$$\frac{\partial^2 \pi}{\partial q \partial t} = e^{-rt}\left\{(1-\tau_p^r)p'(t) - r\left[(1-\tau_p^r)p(t) - \tau_q^r\right] - \left[p_s + \tau_p^s p(t) + \tau_q^s\right]\right\}. \tag{14}$$

From equations (3′) and (7) above, we see that

$$(1-\tau_p^r)p'(t) - r\left[(1-\tau_p^r)p(t) - \tau_q^r\right] - \left[p_s + \tau_p^s p(t) + \tau_q^s\right] = 0\,. \tag{15}$$

The economic intuition for this separation property is straightforward. Once the producer has chosen how much wine to produce, each bottle of wine is simply an investment instrument. While the internal rate of return, $p'(t)$, exceeds the marginal holding cost $rp(t)+p_s$, it is worthwhile to hold the bottle to capture the excess returns from further aging. This asset management decision is independent of the total quantity of wine that was produced at time t = 0. Hence, the firm's profit function is separable between quantity and age. This property greatly simplifies the comparative statics for the effects of different tax instruments on the quantity produced. Indeed, an increase in any of the wine taxes unambiguously decreases the quantity produced. Formally,

$$\frac{\partial q}{\partial \tau_p^r} = \frac{-e^{-rt}p(t)}{c''(q)} < 0\,, \tag{16}$$

$$\frac{\partial q}{\partial \tau_q^r} = \frac{-1}{c''(q)} < 0\,, \tag{17}$$

$$\frac{\partial q}{\partial \tau_p^s} = \frac{-\int_0^t e^{-rx}p(x)dx}{c''(q)} < 0\,, \tag{18}$$

and

$$\frac{\partial q}{\partial \tau_q^s} = \frac{-(1-e^{-rt})}{rc''(q)} < 0\,. \tag{19}$$

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 quantity supplied. Equivalently, the firm's first-order condition for quantity implies that for a fixed age/quality outcome, any change in the tax system that increases the per unit tax rate, $v(\boldsymbol{\tau})$, decreases quantity, $q(\boldsymbol{\tau})$.[6]

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[6] Formally, let $\boldsymbol{V}(\tau)$ denote the set of all non-vanishing vectors $\boldsymbol{v}$ such that the directional derivative of t with respect to $\boldsymbol{\tau}$ in the direction $\boldsymbol{v}$ is zero. Then $\forall\ \boldsymbol{v} \in \boldsymbol{V}(\boldsymbol{\tau})$,

$$\frac{\partial q(\boldsymbol{\tau})}{\partial \boldsymbol{v}} = -\frac{1}{c''(q(\boldsymbol{\tau}))} \times \frac{\partial v(\boldsymbol{\tau})}{\partial \boldsymbol{v}}\,.$$

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 age/quality choice implies that there will be no age/quality distortion if and only if the tax system satisfies the condition

$$r\tau_q^r = p_s\tau_p^r + \tau_p^s p\left(t(\boldsymbol{\tau})\right) + \tau_q^s . \tag{20}$$

There are three possible two-tax systems with positive tax rates that do not distort the *first best* wine age:

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

$$v_1 \equiv v(\boldsymbol{\tau}_1) \equiv e^{-rt^*}\left(rp(t^*) + p_s\right)\tau_p^r \big/ r ;$$

(2) *volumetric taxes* satisfying $\tau_q^r = \tau_q^s / r$, so that $\boldsymbol{\tau}_2 = \tau_q^s\left[0 \quad 1/r \quad 0 \quad 1\right]^{\mathsf{T}}$ 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 $\tau_q^r = p(t^*)\tau_p^s / r$, so that $\boldsymbol{\tau}_3 = \tau_p^s\left[0 \quad p(t^*)/r \quad 1 \quad 0\right]^{\mathsf{T}}$ and

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

Examining the effective tax rate *v*, we see that in each case it 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 tax revenue, $R(\boldsymbol{\tau}) = v(\boldsymbol{\tau})q(\boldsymbol{\tau})$, that

$$\frac{\partial R(\boldsymbol{\tau})}{\partial \boldsymbol{\tau}} = \frac{\partial v(\boldsymbol{\tau})}{\partial \boldsymbol{\tau}} q(\boldsymbol{\tau}) + v(\boldsymbol{\tau})\frac{\partial q(\boldsymbol{\tau})}{\partial \boldsymbol{\tau}} . \tag{21}$$

Thus, for all $\boldsymbol{v} \in \boldsymbol{V}(\tau)$,

$$\frac{\partial R(\boldsymbol{\tau})}{\partial \boldsymbol{v}} = q(\boldsymbol{\tau}) \times \frac{\partial v(\boldsymbol{\tau})}{\partial \boldsymbol{v}} - \frac{v(\boldsymbol{\tau})}{c''(q(\boldsymbol{\tau}))} \times \frac{\partial v(\boldsymbol{\tau})}{\partial \boldsymbol{v}}$$

$$= \left(\frac{c''(q(\boldsymbol{\tau}))q(\boldsymbol{\tau}) - v(\boldsymbol{\tau})}{c''(q(\boldsymbol{\tau}))} \right) \times \frac{\partial v(\boldsymbol{\tau})}{\partial \mathbf{v}} . \tag{22}$$

Hence, maintaining age neutrality while increasing the tax rates in each two-tax system results in an increase, no change, or a decrease in tax revenue if and only if $c''\big(q(\boldsymbol{\tau})\big)q(\boldsymbol{\tau}) - v(\boldsymbol{\tau}) \gtreqless 0$. Since $c''(q) > 0$ by assumption, for all cost functions that satisfy $\lim_{q \to 0} c''(q)q = 0$, the left-hand-side of this condition is strictly positive at $\boldsymbol{\tau} = \mathbf{0}$ and $q = q^*$, eventually vanishes as v increases, and then becomes negative as v increases further 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 each pair of effective per unit tax rates. With no age/quality distortion, this relationship ensures that for any pair of tax equivalent systems, the quantity distortion and the tax revenue generated will be the same across tax schemes. Using the expressions for v_1, v_2 and v_3 in the previous subsection, it is simple to show that the per unit taxes are equal, $v_1 = v_2 = v_3$, if and only if the periodic payments from an associated perpetual annuity for each of τ_q^s, τ_p^r, and τ_p^s are equal:

$$\tau_q^s = \tau_p^r e^{-rt^*}\left[rp(t^*) + p_s\right] = \tau_p^s \left[e^{-rt^*} p(t^*) + r\int_0^{t^*} e^{-rx} p(x)dx \right], \tag{23}$$

where, given the restriction to two taxes at any one time, $\tau_q^s > 0$ only in the first case, $\tau_p^r > 0$ only in the second case, and $\tau_p^s > 0$ only in the third age neutral two-tax case, respectively.

These conditions are intuitively appealing. Consider the first expression. 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 τ_q^s on each unit of wine in perpetuity.

Now consider the second expression. Because *retail taxes* are paid once after t^* time periods have elapsed, and because there is no age distortion, $p'(t^*) = rp(t^*) + p_s$. 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 $\tau_p^r e^{-rt^*} p'(t^*)$ on each bottle of wine in perpetuity.

Finally, consider the third expression. The first term reflects that the *volumetric retail* tax is delayed for t^* periods, and is only paid once. The second identifies the instantaneous per period effects of the *ad valorem storage* tax.

Thus, we have complete tax equivalence among three age-neutral two-tax systems. If we normalize on the ad valorem retail sales tax, then for any $\tau_p^r > 0$ the tax-equivalent systems are defined by

$$\boldsymbol{\tau}_1 = \tau_p^r \times [1 \quad p_s / r \quad 0 \quad 0]^{\mathsf{T}}, \tag{24}$$

$$\boldsymbol{\tau}_2 = \tau_p^r e^{-rt*}[rp(t*) + p_s] \times \left[0 \quad 1/r \quad 0 \quad 1\right]^{\mathsf{T}}, \tag{25}$$

$$\boldsymbol{\tau}_3 = \left(\frac{\tau_p^r e^{-rt*}[rp(t*) + p_s]}{e^{-rt*} p(t*) + \int_0^{t*} e^{-rx} p(x) dx} \right) \times \left[0 \quad p(t*)/r \quad 1 \quad 0\right]^{\mathsf{T}}. \tag{26}$$

4. Optimal Revenue Generating Tax Systems

From the first order condition for quality, if the second order condition is met, then $t(\boldsymbol{\tau}) \gtreqless t*$ if and only if $-\tau_q^r r + \tau_p^r p_s + \tau_p^s p\left(t(\boldsymbol{\tau})\right) + \tau_q^s \lesseqgtr 0$. Differentiating the effective tax rate with respect to *t* results in

$$\frac{\partial v}{\partial t} = e^{-rt} \left(\frac{-\tau_q^r r + p_s + \tau_q^s + \tau_p^s p(t)}{1 - \tau_p^r} \right). \tag{27}$$

This shows that the effective tax rate increases, remains unchanged, or decreases with age/quality 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 quantity and quality, 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 *tax* revenue constant satisfies

$$\begin{aligned} 0 = dR &= \frac{\partial R}{\partial \boldsymbol{\tau}'} d\boldsymbol{\tau} \\ &= v \frac{\partial q}{\partial \boldsymbol{\tau}'} d\boldsymbol{\tau} + q \frac{\partial v}{\partial q} \frac{\partial q}{\partial \boldsymbol{\tau}'} d\boldsymbol{\tau} + q \frac{\partial v}{\partial t} \frac{\partial t}{\partial \boldsymbol{\tau}'} d\boldsymbol{\tau} \\ &= \left(v - c''(q) q\right) dq + q \frac{\partial v}{\partial t} dt. \end{aligned} \tag{28}$$

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

$$\left.\frac{dt}{dq}\right|_R = \frac{\left[c''(q)q - v\right](1-\tau_p^r)}{e^{-rt}\left[-\tau_q^r r + \tau_p^r p_s + \tau_p^s p(t) + \tau_q^s\right]}. \tag{29}$$

Recalling that $c''(q) > 0 \ \forall \ q \geq 0$ and assuming that $\lim_{q\to 0} c''(q)q = 0$, the numerator of (29) is positive for small effective tax rates. As the tax rate increases, quantity decreases, and the numerator of (29) becomes smaller, and eventually becomes negative.[7] 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 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.

Examining Figure 2, note that 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 iso-revenue curve with an increase in the effective tax rate, *v*, the slope of the iso-revenue curve ultimately becomes infinite and then negative. 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 zero-slope point on the iso-revenue curve. Continuing further along this same iso-revenue curve by increasing both quality and quantity we reach another point with an infinite slope 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.

Figure 3 illustrates that non-negative tax rates is not a binding constraint on the above propositions. A formal comparative statics analysis readily verifies that a full range of feasible positive tax revenues can be generated with any two-tax system that includes a volumetric retail sales tax. These revenues also can be supported by positive tax rates and at least as high quality wine as the firm's first best no-tax quality level.

Based on this analysis, we conclude the following: first, the firm's first best with respect to quality is a relative maximum of tax revenues for all quantity choices; second,

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[7] Define δ 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 (31) is positive, zero or negative as the price elasticity of quantity supplied, $\varepsilon_p^q = p/\left(c''(q)q\right)$, 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 $1/\delta \approx 4$. 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.

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 firms first-best (no tax) quality choice, then more tax revenue can be raised with a smaller quantity distortion and the complete elimination of the quality/age distortion.

5. Conclusions

We have analyzed the supply side effects of taxes on the quantity and quality 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 quality/revenue feasible set. We also derived tax equivalence for the three possible two-tax systems. The producer's first best quality also is 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.

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