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Specific or *ad valorem*? A theory of casino taxation

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This paper explores the effects of excise taxation in markets containing two consumer groups with distinct differences in demand elasticity. A model of second degree price discrimination is employed with an endogenously funded public good to represent a protected casino market with two distinct consumer groups, problem gamblers and recreational gamblers. The paper finds that, when quantity is used as the endogenous product variable, consumers tend to obtain a higher provision of the public good with specific taxes than with *ad valorem* taxes. The model also provides evidence that the casino gambling industry may not be a good candidate for a Pigovian tax due to the behaviour of a small group that produces negative externalities (problem gamblers) but that also tends to be more price-insensitive than the rest of the population.

Keywords: casino tax; tax theory; commodity; addiction; inelastic demand

Throughout the world, casino style gambling tends to be a heavily taxed industry (Eadington, 1996, 1998). However, the way gaming taxes are structured varies significantly from one jurisdiction to another, and even tends to differ substantially within the same country (Anderson, 2005). Although some variation is sensible, since each jurisdiction has a different market structure, the different tax policy decisions frequently seem to be made on an *ad hoc* basis, without full consideration to the efficiency of those decisions (Anderson, 2005). This study puts forth a theoretical analysis that seeks to provide more clarity on one aspect of casino tax design, choosing between specific or *ad valorem* taxes.

Casino market structure

A common delineation of casino patrons is between players characterized as pathological (or problem) gamblers and non-problem (or recreational) gamblers. These two groups in particular can also be classified as those which have a weak sensitivity to price (relatively inelastic problem gamblers) and a strong sensitivity to price (relatively elastic recreational gamblers).[1] Problem gamblers have been clinically described as characterized by a need to continue to increase the amount of money spent gambling to receive the same excitement, and a need to continue to gamble once they have lost (American Psychiatric Association, 2000). In its comprehensive review of the gaming industry, the Australian Productivity Commission (1999) modelled problem gamblers as having a more inelastic demand curve than non-problem gamblers, reflecting a lower sensitivity to price changes. A similar view on the reduced sensitivity of problem gamblers to price has been expressed by several authors, including Quiggin (2000), Clarke (2008), Paldam (2008) and Forrest (2008).

Since tax policy is often used as an instrument to regulate the gaming industry, examining how taxes affect each of these groups – either directly, or indirectly through an increase in gaming operators' costs – seems to be an important policy consideration. The potential for policy decisions that lead to the opposite of the intended outcomes is noted by Forrest (2010, p 15):

> 'Advocates of restrictive regulation have proposed that high prices should be retained in a gambling market in order not to encourage over-consumption by existing and potential problem gamblers. For this to be an effective policy, it would have to be the case that any fall in price would raise losses among dysfunctional players. Whether or not this or the contrary occurs depends on whether demand from this pool of players is 'elastic' or 'inelastic'. Inherent problems exist in designing an experiment to settle this issue and, to date, no relevant scientific evidence is available.'

From a fairness perspective, it may be sensible for casino taxes and fees to be as high as they are currently. Casinos have many infrastructure requirements, including the creation of an entire regulatory body to monitor the industry, ensure the fairness of the games, evaluate license holders, and so forth – and the majority of these services are directly provided by government entities. There are also many negative externalities caused by casino gambling (Eadington, 1996, 2003; Collins and Lapsley, 2003; Walker, 2007), therefore there may be a Pigovian justification for high effective tax rates (Pigou, 1920). In line with this 'fairness' perspective, this paper analyses a partial equilibrium framework, where all public goods must be endogenously funded.

The combination of high effective tax rates and industry price discrimination creates a compelling motive to examine the effect of excise taxes on overall efficiency and cross-subsidization between the consumer price groups. There is also an added interest in studying this model within the field of casino gambling. The analysis will help reveal the policies under which the public good is more highly funded by people whose behaviour can be described as addictive. Put simply, does tax revenue generated from gambling tend to come disproportionately from problem gamblers because of the choice of taxation method?

Excise tax theory

The literature examining the efficiency effects of *ad valorem* and specific taxation is quite developed. In the case of perfect competition, the two commodity taxes are widely cited as being equivalent, but perfect competition tends to be quite rare in the casino gaming industry.[2] The original findings on this topic can be found in Cournot (1960) and Suits and Musgrave (1953).

Diamond and Mirrlees (1971a, 1971b) make a widely cited contribution, finding that it may be appropriate not to tax any intermediate good. However, this finding relies on a perfectly competitive market (their model also assumes that firms are characterized by constant returns to scale and zero externalities), which is not applicable in general to the gaming industry. Accordingly, there still may be efficiency gains by taxing casino providers, such as slot manufacturers. For an overview of key results in the commodity tax literature, Keen (1998) provides a very useful survey of the literature that arises under conventional market structures. Delipalla and Keen (2006) extends the results of optimal commodity taxation in a model of endogenous product quality. In a limited empirical analysis of gaming excise taxes, Paton *et al* (2001) find that *ad valorem* taxation of net revenue is an alternative that is at least as efficient as a commodity-based tax on gross stakes.

Overview

This paper explores a model of excise taxation to fund a public good in a market with second degree price discrimination. In particular, the paper attempts to provide an insight into who are the winners and losers when *ad valorem* versus specific taxes are imposed in a monopoly casino market. Following this introduction an outline of the structure of the model is provided, along with the key results. The next section discusses the findings, highlighting potential limitations and opportunities for future research. Full derivations of the results shown can be found in the appendices.

Model

The structure of this second degree price discrimination model is adapted from the 'two-type/nonlinear pricing' case by Tirole (1988).[3,4] The monopolist (casino) produces in a market serving two consumer groups; low-value consumers (recreational gamblers) and high-value consumers (problem gamblers). There are no substitutes for the good provided by the casino – although this can be considered a simplification for ease of calculation, if we set the value of utility from the numeraire good to be zero, we can achieve the same results.

Consumers

Suppose consumers preferences for casino gaming are defined by a utility curve such that they receive no utility if they do not buy any quantity (that is, they do not gamble), and receive net benefits of some utility function less the price paid if they do gamble; this could be defined by the following utility function:

$$U^i(y_j) = \begin{cases} \theta^i V(y_j) - q_j & \text{if consumer } i \text{ purchases bundle } j \\ 0 & \text{if they do not buy} \end{cases}$$

$i \in \{R,P\}$ and $j \in \{1,2\}$,

where y_j denotes the quantity purchased and q_j denotes the after tax price. The y_j value could be characterized as the identification of whether the gambler is playing a higher denomination slot machine versus a lower denomination slot machine, whether they play for a long period versus a short period, or the combination of these two variables. The player increases his coin-in (consumes a higher quantity) given higher values of y_j.

The typical assumption that utility is concave in y_j is made, such that there is diminishing marginal utility in consumption of gambling – for example, the first $100 of coin-in produces higher utility to the player than the last $100:

$$V_y > 0 \text{ and } V_{yy} < 0.$$

To illustrate the general effects of excise taxation, we restrict the theoretical market to contain two utility maximizing consumer group types, problem gamblers (P) and recreational gamblers (R). Each has a distinct taste parameter for casino gaming:

θ^P = Problem Gambler Value of Gaming,

θ^R = Recreational Gambler Value of Gaming

where we assume that:

$$0 < \theta^R < \theta^P.$$

This reflects the phenomenon that problem gamblers have a higher valuation of consumption – that is, they value gambling more. Consumers in each group are assumed to be homogeneous.

Firm

The market is served by a monopolist, which is aware of the existence of these two (problem gambler and non-problem gambler) groups, but is unable to distinguish directly between the two. Therefore, the monopolist must choose a pricing mechanism that maximizes profit, without directly restricting consumption to either consumer type. The bundles provided by the monopolist can be generally categorized as (y_1, p_1) intended for recreational gamblers in proportion β and (y_2, p_2) intended for problem gamblers in proportion $(1 - \beta)$, where the sum of these two proportions represents the population of potential gamblers, $\beta \in [0,1]$.[5] The pre-tax price of good y_j is noted by p_j. The cost of production of the good is a constant value equal to c. As in Tirole (1988), it is assumed that the monopolist serves both types of consumers – which will occur if the share of the lower valued recreational consumer group (β) is sufficiently large.

The profit maximizing monopolist therefore behaves in a way that solves the following equation:

$$Max\Pi = \beta(p_1 - cy_1) + (1 - \beta)(p_2 - cy_2)$$

$$\text{s.t.} \qquad (1)$$

(1) $U^R(y_1) \geq 0$, and

(2) $U^P(y_2) \geq U^P(y_1)$.

Profit, defined as the sum of revenue less costs from problem gamblers plus the revenue less costs from recreational gamblers, is maximized subject to two constraints. Constraint (1) is an incentive compatibility constraint, which requires a non-negative return for recreational gamblers to purchase any gambling activity. That is, recreational gamblers must at least receive utility greater than or equal to the utility of zero that they could receive from not consuming any amount of gambling. Constraint (2) is an individual rationality constraint needed for problem gamblers to reveal themselves as the higher valued group. That is, they must yield higher utility from consuming the bundle (y_2, p_2) than they would from consuming (y_1, p_1), since they could receive a given positive return by purchasing the bundle intended for recreational gamblers.

Government

Much in the way that tax revenue from casinos are used to fund public works projects, or generally support government budget, a planner is introduced that can provide a public good (x), and tax purchases of casino activity (y). For simplicity, both consumer groups are assumed to value the public good equally; the value of the public good can therefore be expressed by:

$$\beta\overline{V}(x) + (1 - \beta)\overline{V}(x) = \overline{V}(x). \qquad (2)$$

Again, a typical assumption about the concavity of consumption is made that represents diminishing marginal utility:

$$\overline{V}_x(x) > 0 \text{ and } \overline{V}_{xx}(x) < 0.$$

Under the constraints of this model, the government seeks to raise revenue to fund provision of the public good by imposing an excise tax on casino revenue. The government sets either an *ad valorem* tax (t) on the value of consumption or a specific tax (T) on the incidence of consumption to raise this revenue. Consumer prices are therefore:

$q_j^s = p_j + T$ under specific taxation, and

$q_j^v = p_j(1 + t)$ under *ad valorem* taxation.

The planner seeks to maximize consumer welfare – defined as the sum of utility from problem gamblers consumption of gambling, recreational gamblers consumption of gambling, and both consumers utility from the public good.[6]

Under specific taxation, the government planner's optimization equation can be represented by the following function:

$$\underset{T}{Max}\ W(T) = \beta[\theta^R V(y_1) - (p_1+T)] + (1-\beta)[\theta^P V(y_2) - (p_2+T)] + \overline{V}(x)$$

$$\text{s.t. } x = \beta \bullet T + (1-\beta) \bullet T = T.$$

Under *ad valorem* taxation, the government planner's optimization equation can be represented by the following function:

$$\underset{t}{Max}\ W(t) = \beta[\theta^R V(y_1) - p_1(1+t)] + (1-\beta)[\theta^P V(y_2) - p_2(1+t)] + \overline{V}(x)$$

$$\text{s.t. } x = t \bullet [\beta p_1 + (1-\beta) p_2].$$

Results of Model

No Taxation

The baseline – zero taxation – result for the problem outlined above is identical to the two consumer, second degree price discrimination problem outlined by Tirole (1988). The planner has no means of affecting the market to increase consumer welfare. The monopolist's first order conditions are therefore:

$$y_1:\ \theta^R \frac{dV(y_1)}{dy} = c \Big/ \left(1 + \frac{(\theta^R - \theta^P)}{\theta^R} \bullet \frac{(1-\beta)}{\beta}\right) \tag{3}$$

$$y_2:\ \theta^P \frac{dV(y_2)}{dy} = c. \tag{4}$$

Worth noting is the result of Equation (4) where the welfare optimal condition for problem gamblers is reached. There, the marginal benefit of additional quantity equals its marginal cost. Also of interest is that there will be under provision of quantity to recreational gamblers since:

$$c \Big/ \left(1 + \frac{(\theta^R - \theta^P)}{\theta^R} \bullet \frac{(1-\beta)}{\beta}\right) > c.$$

That is, the marginal benefit of additional quantity,

$$\theta^R \frac{dV(y_1)}{dy},$$

is larger than the marginal cost, c. These would be equal under an efficient solution.

Specific taxation[7]

Since the monopolist's profit function under specific taxation is:

$$\underset{y_1,y_2}{Max}\Pi = \beta(\theta^R V(y_1) - T - cy_1) + (1-\beta)(\theta^P V(y_2) - (\theta^P - \theta^R)V(y_1) - T - cy_2).$$

The level of tax T does not enter the first order conditions, and (ignoring participation constraints) the monopolist will operate in an identical manner (in terms of providing pricing and quantity bundles) as it would in the zero taxation environment:

$$y_1\text{: } \theta^R \frac{dV(y_1)}{dy} = c \bigg/ \left(1 + \frac{(\theta^R - \theta^P)}{\theta^R} \cdot \frac{(1 - \beta)}{\beta}\right)$$

$$y_2\text{: } \theta^P \frac{dV(y_2)}{dy} = c.$$

The choice of tax level by the government planner does not affect any marginal decisions by the monopolist, therefore it continues to offer bundles (y_1, p_1) intended for recreational gamblers and (y_2, p_2) intended for problem gamblers that reaches the typical monopolist equilibrium. Again, the problem gamblers reach their efficient solution, but there is an under-provision of quantity to recreational gamblers.

The final result of this tax structure is that the planner will use the specific tax to capture the entire monopoly surplus and use this revenue to fund the public good. Effectively, the economic rents from the provision of gambling in a market characterized by a single firm have been entirely transferred to the government planner, who then redistributes the rents in the form of a public good. The planner's first order condition is constant:

$$\frac{d\bar{V}}{dT} = 1. \qquad (5)$$

Ad valorem *taxation*

Under *ad valorem* taxation, the tax rate enters the marginal decisions made by the monopolist, leading to different outcomes for all stakeholders. The monopolist's profit function can be represented by the following optimization equation in the presence of an *ad valorem* tax:

$$\underset{y_1,y_2}{Max}\Pi = \beta\left(\frac{\theta^R V(y_1)}{1 + t} - cy_1\right) + (1 - \beta)\left(\frac{\theta^P V(y_2) - (\theta^P - \theta^R)V(y_1)}{1 + t} - cy_2\right).$$

The solution of the above equation yields the following first order conditions:

$$y_1\text{:}\ \theta^R \frac{dV(y_1)}{dy} = c\bullet(1+t) \Big/ \left(1 - \frac{\theta^P}{\theta^R} \bullet (1-\beta)\right) \tag{6}$$

$$y_2\text{:}\ \theta^P \frac{dV(y_2)}{dy} = c\bullet(1+t). \tag{7}$$

In Equation (7) the marginal benefit of additional quantity for problem gamblers equals the after tax marginal cost, as opposed to strictly the marginal cost under the no taxation or specific taxation environments. The *ad valorem* tax distorts consumption by problem gamblers below the efficient level. As seen in Equation (6), the change in marginal quantity is less clear for recreational gamblers. The $(1 + t)$ term affects recreational gamblers in the same way as it affects problem gamblers, but the net change in consumption differs appreciably from the no taxation or specific taxation result, due to the denominator on the right hand side of Equation (6). Comparing this term to the right hand side denominator from Equation (3), we have:

$$1 - \frac{\theta^P}{\theta^R} \bullet (1-\beta) \neq 1 + \frac{(\theta^R - \theta^P)}{\theta^R} \bullet \frac{(1-\beta)}{\beta}.$$

This inequality can be simplified to show that if

$$\beta > \frac{\theta^P - \theta^R}{\theta^P},$$

then the effect of $(1 + t)$ will be magnified to create an even larger distortion from the no tax/specific tax result, and if

$$\beta < \frac{\theta^P - \theta^R}{\theta^P},$$

then the impact of $(1 + t)$ will be abated, reducing the level of distortion. Note that if

$$\beta > \frac{\theta^P - \theta^R}{\theta^P},$$

then recreational gamblers consumption levels will be distorted even more than problem gamblers consumption levels have been distorted, which is important if taxes are being used by policy makers to discourage problem gambling; this result would imply that recreational gamblers' consumption would be more affected by the tax than problem gamblers' consumption, and public revenue generated from the tax would tend to come in greater proportion from problem gamblers, as compared to a specific tax.

The planner's first order condition with respect to the *ad valorem* tax is:

$$\frac{d\bar{V}}{dt} = 1 - \left(\frac{dV}{dy} \cdot \frac{\partial y}{\partial t}\right) \cdot \left(\frac{\beta\theta^R + (1 - \beta)\theta^P}{\beta p_1 + (1 - \beta)p_2}\right). \tag{8}$$

This equation implies that

$$\frac{d\bar{V}}{dt} > 1.$$

Since we know that

$$\frac{d\bar{V}}{dT} = 1$$

from Equation 5 we can combine these results to show that:

$$\frac{d\bar{V}}{dt} > \frac{d\bar{V}}{dT}.$$

That is, there is a higher provision of the public good (to both consumers) when a specific taxation mechanism is used instead of *ad valorem* taxation mechanism.

Results

In the confines of this model, a few noteworthy results arise. The first is that both consumers generally prefer specific taxation while the monopolist prefers *ad valorem* taxation. Under specific taxation, the planner is essentially employing a lump-sum tax on the producer that will be equal to his entire monopoly profits. With this mechanism, consumers obtain a higher provision of the public good than under *ad valorem* taxes, and the equivalent level of consumption as under no taxation. Effectively, government planners are capturing all of the economic rents from the casino gambling market, and redistributing these rents in the form of a public good for all consumers.

These findings provide some support for altering the method in which excise (or retail) taxes are levied on the gaming industry. Currently, the most popular taxes (in terms of generating the most public revenue) are *ad valorem* taxes on gross gaming revenue (Anderson, 2005). The above finding suggests that maximization of consumer welfare may be better served by expanding the use of specific taxes, such as admission fees or fixed transaction fees on wagers. Currently, these tend to be used only in limited capacity.[8]

A second point of interest occurs when *ad valorem* taxes are employed. As seen in Equation (7), the marginal benefit of higher consumption now equals the after tax marginal cost (as opposed to strictly the marginal cost under a no taxation environment), creating distortions to the efficient consumption level of problem gamblers. Distortions are also expected to occur to recreational gamblers, as the marginal benefit of higher consumption equals the after tax marginal cost, and another term shown in Equation (6). By comparing Equation (6) with Equation (3), we can interpret which consumer group has had their consumption distorted more by the *ad valorem* tax. The reduction in marginal quantity is either greater for recreational gamblers if

$$\beta > \frac{\theta^P - \theta^R}{\theta^P},$$

or less severe if the inequality is reversed. This implies that the larger the market for recreational gamblers, the more recreational gamblers will have their (no taxation) consumption levels distorted from the imposition of an *ad valorem* tax. That is, recreational gamblers consumption levels will be reduced (at a higher rate relative to problem gamblers), leaving a higher share of problem gamblers in the market to fund the tax.

Another implication of the inequality is that if problem gamblers have only moderately higher values of gambling, then the population proportion effects described above may not be offset. For example, if problem gamblers value of gambling (θ^P) is twice as large as recreational gamblers value of gambling (θ^R), then recreational gamblers consisting of over half the population ($\beta > 0.5$) would lead to them having their consumption distorted more than problem gamblers.

Empirically, the proportion of problem gamblers in the general population has been cited as being fairly small, roughly 1–6% in national studies (Williams *et al*, 2012). At even a 10% problem gambling prevalence rate, problem gamblers value of gambling would have to be ten times as large as recreational gamblers value of gambling in order to lead to equal distortions in consumption. Combining the theoretical findings from this study with those simple empirical results suggests that recreational gamblers, who face no health issues from addiction and create minimal negative externalities, are the same gamblers whose consumption is being reduced most from the distortive *ad valorem* tax. An increased reliance on *ad valorem* taxes to generate revenue from the gaming industry will tend to lead disproportionately to more public revenue from problem gamblers, since those gamblers continue to consume higher relative levels of casino gambling, in spite of the imposition of the tax.

This is an unfortunate side-effect if policy makers are attempting to force problem gamblers to internalize the externalities caused by their consumption – healthy gamblers who are not expected to create externalities are having their consumption reduced due to the blunt imposition of the tax on all consumer types. The casino gambling industry may therefore not be a good candidate for a Pigovian tax since negative externalities occur from only a small group (of problem gamblers) in the population and this group is generally found to be much more price insensitive than the rest of the population.

Conclusion

Both the demand for casino gaming and the theory of excise taxation have been studied thoroughly, but very little has been done to study the interaction between these two topics. In particular, there are few studies that focus on the theoretical issues relevant to casino taxation and fewer still that model these formally. High levels of taxation in the casino industry imply that the welfare effects from an efficient tax schedule will be quite substantial, and is most certainly worth further research. The US commercial casino industry alone contributed US$7.59 billion in tax revenue to state and local governments in the USA during 2010 (American Gaming Association, 2011). The framework for studying the gaming industry is also quite unique, as it is characterized by two very different consumers. One is consuming a standard good with no externalities as a by-product of consumption, while the other (much smaller) consumer is characterized by addiction/inelasticity, and produces negative externalities. This study revealed that such subtleties of the industry can lead to important policy differences, even for straightforward topics such as the choice between an *ad valorem* or specific commodity tax.

Limitations and future research

This study provided some guidance on only one aspect of the issues facing gaming policy makers, and is far from a complete perspective on the issues raised. Significantly more thought is needed to explore how different taxes affect this very unique industry. This model relied on comparative statics, but a more general equilibrium framework may reveal other findings. For example, applications of the double-dividend results by Tullock (1967) and Sandmo (1975) may be appropriate, as increasing gaming taxes beyond those necessary to internalize any negative externalities could theoretically reduce more distortive taxes elsewhere in the economy. Non-excise taxes may also be more appropriate mechanisms worth exploring as means for generating public revenues (such as licence auctions). Furthermore, the findings in this study rely heavily on a single period model of consumer utility. Using a forward looking model of addiction where consumption decisions are maximized over multiple time periods, such as that prescribed by Becker and Murphy's model of rational addiction (1988), may yield different outcomes.

Endnote

1. Although high elasticity consumers and low elasticity consumers cannot be perfectly divided into these respective recreational and problem gambler categories, these groups appear to display sufficient differences in their demand to create these groupings for theoretical discussion. Alternative modeling of gamblers into (relatively) inelastic and elastic groups may be appropriate, such as between high rollers and non-high rollers.
2. The closest jurisdiction whose market resembles perfect competition in casino gaming is Nevada, which does not restrict the quantity of casino licences issued.
3. This article continues to use quantity as an endogenous good, but similar arguments could be made with quality that would have relevance to the casino gaming industry.
4. For generalization of second degree price discrimination past the two-type case, see Maskin and Riley (1984)
5. Bundles need not differ.

6. Although this specification departs from some commodity taxation literature in that monopolist profits do not appear in the welfare maximization equation, this specification likely better reflects the positivist reasons for decision making in terms of casino adoption. There is much evidence that gaming policy has been shaped by the desire to raise (and perhaps maximize) public revenues (Eadington, 1996, 1998; Chapman *et al*, 1997; Adam Rose and Associates, 1998; Smith, 1998; Paldam, 2008).
7. See Appendix A for full derivation of results.
8. This finding could also be extended to other markets with dichotomically divided consumer groups, such as business and leisure tourists in the wider tourism industry.

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Appendix A – specific taxation

Monopolist problem

The profit maximizing monopolist seeks to solve:

$$Max\Pi = \beta(p_1 - cy_1) + (1 - \beta)(p_2 - cy_2)$$

s.t. (9)

(1) $U^R(y_1) \geq 0$, and

(2) $U^P(y_2) \geq U^P(y_1)$.

The constraints can be rewritten as:

$$(1)\ \theta^R V(y_1) - (p_1 + T) \geq 0 \quad \text{or} \quad p_1 \leq \theta^R V(y_1) - T \tag{10}$$

$$(2)\ \theta^P V(y_2) - (p_2 + T) \geq \theta^P V(y_1) - (p_1 + T) \text{ or } p_2 \leq \theta^P V(y_2) - \theta^P V(y_1) + p_1$$

At the optimum the inequalities becomes equalities. Substituting Equation (10–1) into (10–2) we have:

$$p_2 = \theta^P V(y_2) - (\theta^P - \theta^R) \bullet V(y_1) - T.$$

The monopolist problem can therefore be simplified:

$$\underset{y_1,y_2}{Max}\Pi = \beta(\theta^R V(y_1) - T - cy_1) + (1-\beta)(\theta^P V(y_2) - (\theta^P - \theta^R) \bullet V(y_1) - T - cy_2).$$

First order conditions:

$$y_1:\ \theta^R \frac{dV(y_1)}{dy} = c \bigg/ \left(1 + \frac{(\theta^R - \theta^P)}{\theta^R} \bullet \frac{(1-\beta)}{\beta}\right)$$

$$y_2:\ \theta^P \frac{dV(y_2)}{dy} = c.$$

Government problem

The government seeks to maximize welfare defined as the sum of consumer surpluses and value from a public good, $\bar{V}(x)$.

$$\underset{T}{Max}\ W(T) = \beta[\theta^R V(y_1) - (p_1+T)] + (1-\beta)[\theta^P V(y_2) - (p_2+T)] + \bar{V}(x)$$

$$\text{s.t. } x = \beta \bullet T + (1-\beta) \bullet T = T. \quad (11)$$

First order condition:

$$\frac{dW}{dT} = \beta\left(\theta^R \bullet \frac{dV}{dy_1} \bullet \frac{\partial y_1}{\partial t} - 1\right) + (1-\beta)\left(\theta^P \bullet \frac{dV}{dy_2} \bullet \frac{\partial y_2}{\partial T} - 1\right) + \frac{d\bar{V}}{dT} = 0. \quad (12)$$

This can be rearranged to produce Equation (13):

$$\frac{d\bar{V}}{dT} = 1, \text{ since } \frac{\partial y_i}{\partial T} = 0,\ i \in \{1,2\}. \quad (13)$$

Appendix B – *ad valorem* taxation

Monopolist problem

As in the case of specific taxation, the profit maximizing monopolist seeks to solve:

$$Max \Pi = \beta(p_1 - cy_1) + (1-\beta)(p_2 - cy_2)$$

$$\text{s.t.} \quad (14)$$

(1) $U^R(y_1) \geq 0$, and

(2) $U^P(y_2) \geq U^P(y_1)$.

The constraints can be rewritten as:

$$(1)\ \theta^R V(y_1) - (p_1 + t) \geq 0 \quad \text{or} \quad p_1 \leq \theta^R V(y_1)/1 + t \tag{15}$$

$$(2)\ \theta^P V(y_2) - p_2\,(1 + t) \geq \theta^P V(y_1) - p_1\,(1 + t)$$

$$\text{or } p_2 \leq \frac{\theta^P V(y_2) - \theta^P V(y_1)}{1 + t} + p_1.$$

At the optimum the inequalities becomes equalities. Substituting Equation (14) into (15) we have:

$$p_2 = \frac{\theta^P V(y_2) - (\theta^P - \theta^R)\bullet V(y_1)}{1 + t}.$$

The monopolist problem can therefore be simplified:

$$\underset{y_1, y_2}{Max}\Pi = \beta\left(\frac{\theta^R V(y_1)}{1 + t} - cy_1\right) + (1 - \beta)\left(\frac{\theta^P V(y_2) - (\theta^P - \theta^R)V(y_1)}{1 + t} - cy_2\right).$$

First order conditions:

$$y_1\text{: } \theta^R \frac{dV(y_1)}{dy} = c\bullet(1+t) \Big/ \left(1 - \frac{\theta^P}{\theta^R} \bullet (1 - \beta)\right)$$

$$y_2\text{: } \theta^P \frac{dV(y_2)}{dy} = c\bullet(1+t).$$

Government problem

The government seeks to maximize welfare defined as the sum of consumer surpluses and value from a public good, $\bar{V}(x)$.

$$\underset{t}{Max}\, W(t) = \beta[\theta^R V(y_1) - p_1(1+t)] + (1-\beta)[\theta^P V(y_2) - p_2(1+t)] + \bar{V}(x)$$

$$\text{s.t. } x = t\bullet[\beta p_1 + (1 - \beta)p_2]. \tag{16}$$

First order condition

$$\frac{dW}{dt} = \beta\left(\theta^R\bullet \frac{dV}{dy_1} \bullet \frac{\partial y_1}{\partial t} - p_1\right) + (1-\beta)\left(\theta^P\bullet \frac{dV}{dy_2} \bullet \frac{\partial y_2}{\partial T} - p_2\right) + \frac{d\bar{V}}{dT}$$

$$\bullet[\beta p_1 + (1 - \beta)p_2] = 0. \tag{17}$$

Rearrange:

$$\frac{d\bar{V}}{dt} = \frac{\beta(p_2 - p_1) - p_2 + \beta V'(\theta^R - \theta^P) + \theta^P V'}{\beta(p_2 - p_1) - p_2} \tag{18}$$

$$\frac{d\bar{V}}{dt} = 1 + \frac{\beta V'(\theta^R - \theta^P) + \theta^P V'}{\beta(p_2 - p_1) - p_2}.$$

$$\frac{d\bar{V}}{dt} = 1 - \left(\frac{dV}{dy_1} \cdot \frac{\partial y}{\partial t}\right) \cdot \left(\frac{\beta\theta^R + (1 - \beta)\theta^P}{\beta p_1 + (1 - \beta)p_2}\right) > 1. \tag{19}$$

Since from Equation (5):

$$\frac{d\bar{V}}{dT} = 1, \text{ then}$$

$$\frac{d\bar{V}}{dt} > \frac{d\bar{V}}{dT}.$$