

Janda, Karel; Lajksnerova, Zuzana; Mikolasek, Jakub

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Institute of Economic Studies, Faculty of Social Sciences  
Charles University in Prague

# A General Equilibrium Model of Optimal Alcohol Taxation in the Czech Republic

Karel Janda  
Zuzana Lajksnerova  
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Institute of Economic Studies,  
Faculty of Social Sciences,  
Charles University in Prague

[UK FSV – IES]

Opletalova 26  
CZ-110 00, Prague  
E-mail : [ies@fsv.cuni.cz](mailto:ies@fsv.cuni.cz)  
<http://ies.fsv.cuni.cz>

Institut ekonomických studií  
Fakulta sociálních věd  
Univerzita Karlova v Praze

Opletalova 26  
110 00 Praha 1

E-mail : [ies@fsv.cuni.cz](mailto:ies@fsv.cuni.cz)  
<http://ies.fsv.cuni.cz>

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# A General Equilibrium Model of Optimal Alcohol Taxation in the Czech Republic

Karel Janda<sup>a,b</sup>

Zuzana Lajksnerova<sup>a</sup>

Jakub Mikolasek<sup>a</sup>

<sup>a</sup>Institute of Economic Studies, Faculty of Social Sciences, Charles University  
Opletalova 21, 110 00, Prague, Czech Republic

<sup>b</sup>Dept. of Banking and Insurance, Faculty of Finance and Accounting, University of  
Economics, Namesti Winstona Churchilla 4, 130 67 Prague, Czech Republic

Email (corresponding author): [Karel-Janda@seznam.cz](mailto:Karel-Janda@seznam.cz)

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## **Abstract:**

This paper provides a general equilibrium theoretical model of alcohol taxation and empirically estimates this model. For this purpose, we use a model determined by both externality corrections and fiscal considerations as the tax increase is assumed to immediately change other governmental policies such as labour taxation or medical expenditures. The results of our analysis show that under the most of parametric scenarios the current Czech tax rate on beer and wine is below its optimal level and that the fiscal component has a significant impact on the optimal level of tax.

**Keywords:** Alcohol, Beer, Wine, Czech Republic, Elasticity, Price, Social costs, Tax  
**JEL:** H21, Q02, Q18

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expressed here are those of the authors and not necessarily those of our institutions.  
All remaining errors are solely our responsibility.

# 1 Introduction

This paper provides a contribution towards improved understanding of alcohol economics in the Czech Republic. It focuses on estimation of optimal beer, wine and spirit taxes, using an analogy to a method developed by (Parry, et al., 2009). Our model is parametrized using values for the Czech Republic.

Our paper builds up upon a line of research by Janda and his co-authors (Janda, et al., 2010), (Janda, et al., 2010b), (Janda & Mikolášek, 2011), who dealt with Czech beer industry and provided suitable empirical estimations of elasticities of Czech alcohol demand. However, their analysis was focused on balancing Pigouvian tax and dead-weight loss of taxation. The major contribution of our current article is the incorporation of those previous research results in fully specified general equilibrium theoretical framework which enables in depth economic discussion of taxation of beer, wine and spirit.

Among recent Czech and Slovak economic literature dealing with alcohol which pays some attention mainly to wine demand and industry (Horska, et al., 2016); (Kucerova, 2014); (Syrovatka, et al., 2014); (Tomsik & Prokes, 2011), two papers are particularly related to our research in their coverage of Czech alcohol demand. (Slovackova, et al., 2016) provide the most recent time series econometric forecast of Czech alcohol consumption and (Jansky, 2016) investigates the Czech excise duties (taxes) on individual types of alcohol beverages, while building upon results of consumer demand system estimations on Czech or Slovak household budget data by (Jansky, 2014), (Dybczak, et al., 2014), (Cupak, et al., 2016), (Cupak, et al., 2015). While (Slovackova, et al., 2016) deal only with time series analysis of Czech alcohol consumption without considering taxation and other general equilibrium features of our model, they are relevant to our paper in their precise coverage (beer, wine, spirit in pure alcohol content) and in their description of Czech alcohol consumption empirical and institutional situation. As opposed to our general equilibrium approach, (Jansky, 2016) relies on a partial-equilibrium framework, but his results are complementary to ours as his outputs provide valuable input parameters for the future development of our model. While our paper focuses only on alcohol, Jansky (2016) covers alcohol just as a subset of the set of all goods subjected to Czech excise

duties. As opposed to our more complex representative consumer model, the much simpler model in (Jansky, 2016) focuses on taking own and cross-price elasticities of demand from (Jansky, 2014) and computing the changes in demand for fuel, alcohol and tobacco products when excise duties exogenously change. All this is done by (Jansky, 2016) for different income groups ordered by their total expenditures quintiles.

In the Czech wine oriented literature, (Kucerova, 2014) provides a description of the Czech wine market, including the data on production, consumption and prices while (Tomsik & Prokes, 2011) focus entirely on the description of the production side of Czech wine industry. On the consumption side, (Horska, et al., 2016) focus on investigation of preferences of consumers between different wines using electroencephalography neuro-science approach. Out of this wine oriented literature, (Syrovatka, et al., 2014) who provide econometric estimation of wine consumption in the Czech Republic are the closest to our article since they also consider cross-price elasticities of demand between wine, beer and spirit.

Existing international literature, e.g. (Manning, et al., 1989) and (Saffer & Chaloupka, 1994) usually focuses on measuring various externalities such as cost associated with drunk driving, increase in health care costs and the estimation of a corresponding Pigouvian tax. (Kenkel, 1996) concludes that alcohol taxation is not the only solution to problems connected with alcohol abuse and that stricter penalties for drunk driving together with higher public awareness of the health consequences of heavy drinking might significantly reduce social costs arising from alcohol consumption. Another study by (Lyon & Schwab, 1995) compares effect of alcohol taxation with respect to annual and lifetime revenues. Results of all these studies agree on the fact that past alcohol tax rates were too low.

(Pogue & Sgontz, 1989) as well as previous authors focus on measuring the optimal Pigouvian tax using a partial-equilibrium approach, balancing dead-weight losses of taxation due to distorted consumption choices by moderate drinkers against the benefits from reducing negative externalities arising from abusive drinking. For this purpose, the population is divided into several groups according to the level of their alcohol consumption/abuse. The result is either taxation near the present level or higher.

In contrast (Parry, et al., 2009) consider both Pigouvian and fiscal rationales. They

present an analytical framework for assessing the optimal levels and welfare effects of alcohol taxes and drunk driver penalties, accounting for both externalities and for the interaction of alcohol taxes with other taxes within the broader fiscal system. In their model, the optimal alcohol tax is decomposed into four different components - a Pigouvian tax, a revenue-recycling tax, a tax-interaction effect and productivity effect. This approach was introduced earlier in the article by (Sandmo, 1975) who stated that optimal tax on alcohol may differ considerably from Pigouvian tax on fiscal grounds. Empirical estimations show that fiscal considerations can significantly strengthen the case for higher alcohol taxes as the fiscal component of the optimal alcohol tax may be as large as (or even exceed) the externality-correcting component. Unlike in (Pogue & Sgontz, 1989) individual beverages have different optimal taxes because of beverage-specific fiscal components. The results of (Parry, et al., 2009) indicate that optimal levels of alcohol taxes in the USA are much higher than their observed level.

## 2 The Model

First, we present a model with a structure very similar to the one used in (Parry, et al., 2009). This static general - equilibrium model with a representative agent that assumes the agent's future costs of addiction are internalized and not undervalued and that efficiency determines optimality of policy. The fiscal system is highly simplified as government expenditures are financed only through labour taxes, excise taxes on alcohol and pecuniary penalties.<sup>1</sup>

### 2.1 Preferences

Let us assume that the agent, representing an aggregation over all households in the real economy, has a continuous, quasi-concave utility function:

$$U = U(A, D, \tau_D D, C, l, G^P, H) \tag{1}$$

---

<sup>1</sup> By doing so, we silently use a simplifying assumption that both alcoholic goods and non-alcoholic goods are taxed with the same VAT rate, which is not technically correct as some consumer goods (including non-alcoholic beverages) are subject to lower tier of tax. The lower-bracket goods, however, account for only a small fraction of total tax revenue. In order to account for the lower VAT brackets, we'd need to include alcoholic/non-alcoholic goods elasticity of substitution for each VAT bracket, which would make our model much more complex.



$$H = H(A, D, \bar{D}, M) \quad (2)$$

In (1) all variables are expressed on a per capita basis and the bar accent in (2) depicts a variable exogenous to our agent.  $U$  is a function increasing in all arguments except  $\tau_D D$  and  $H$ . Agent can arbitrarily choose the consumed level of alcohol  $A$  and non-alcoholic goods  $C$ , number of driving trips under the influence of alcohol  $D$  and leisure time  $l$ .  $\tau_D$  denotes non-pecuniary penalties (e. g. license suspensions, jail) per drunk-driver trip.  $G^P$  is government spending on public goods and  $H$  health risks, further explained in the next paragraph.

Health risks  $H$  comprise risks of becoming ill, injured, disabled or killed due to heavy-drinking or alcohol-involved traffic incident. These risks are defined in (2) by the continuous, quasi-concave function, increasing in agent's own alcohol consumption, drunk driving, drunk driving committed by others  $\bar{D}$  and decreasing in agent's consumption of medical services  $M$ , as this mitigates health risks and improves the chance of recovery.

## 2.2 Production

Let us assume there are no pure profits on the production side of the economy because alcohol, general goods, medical and automobile services are produced by competitive firms with constant returns to scale. Therefore, producer prices are fixed and firms pay a gross wage of  $w$  that is equal to the value of a marginal product of labour. Effective labour supply is defined as  $W = wL$  where  $L$  is labour supply (time at work). Changes in  $H$  are assumed to have a negative impact on  $W$  ( $\partial W / \partial H < 0$ ).

The government pays for fraction  $s$  of medical care costs, while the rest  $1-s$  is paid for by private insurance and car insurance companies that cover their costs through charging a variable payment amounting to the fraction  $\nu_M$  of medical expenses charged by insurance companies or  $\nu_D$  per drunk-driver trip charged by automobile/insurance companies ( $\nu_D < c_D$  where  $c_D$  is the expected cost of car repair) and also a lump-sum premium to households of  $K_M$  (respectively  $K_D$ ). Insurance companies' profits are zero in equilibrium because  $\nu_M$  and  $\nu_D$  adjust,  $K_M$  and  $K_D$  are given.

## 2.3 Government

The government faces the following budget constraint:

$$G^P + G^T + sM = t_L W + t_A A + (t_D - r)D \quad (3)$$

The left-hand side of the equation (3) describes three kinds of government spending

$G^P$  - spending on public goods,

$G^T$  - lump-sum transfer spending

$sM$  - government medical expenditures.

These expenses are financed by revenues, which are described on the right-hand side.

$t_L$  - proportional tax on labour income

$t_A$  - excise tax on alcohol

$t_D$  - expected fine per drunk-driver trip.

$r = r(v_D, t_D)$  denotes resource costs expended by the government in order to enforce drunk driver penalties and it is increasing in both  $v_D$  and  $t_D$ .

## 2.4 Agent Optimization.

Agents face the following budget and time constraints:

$$\begin{aligned} (1-t_L)W + G^T &= (p_A + t_A)A + C + K_M + v_M M + K_D + v_D D + t_D D \\ T(H) &= L + l \end{aligned} \quad (4)$$

In the first equation, net of tax labour income and the government transfer spending cover expenditures on alcohol ( $p_A$  is the producer price of alcohol), general consumption, lump-sum and variable costs paid to medical and auto insurance companies and drunk driver fines.  $T$  is available time divided between leisure and labour, a function decreasing in health risks  $H$ .

The consumer's maximization problem yields the first order conditions:

$$\begin{aligned}
\frac{U_A}{\lambda} &= p_A + t_A + mpc H_A & \frac{U_D}{\lambda} &= v_D + t_D + \tau_D + mpc H_D \\
-mpc H_M &= v_M & \frac{U_L}{\lambda} &= (1-t_L)w
\end{aligned} \tag{5}$$

In (5) we have normalized  $-\frac{U_{\tau_D D}}{\lambda} = 1$ ,  $\lambda$  is the marginal utility of income and  $mpc = -(U_H/\lambda + (1-t_L)(wT_H + W_H))$  denotes the marginal private cost of health risks, which consists of direct disutility from suffering  $-U_H/\lambda$ , the value of lost time from incapacitation or premature mortality  $-(1-t_L)wT_H$  and forgone private earnings from lower workplace productivity  $-(1-t_L)W_H$ .

It is seen from (5) that agents increase their alcohol consumption up to the point where the marginal benefit received from the last unit of drink is equal to the tax-inclusive alcohol price and the own-health cost. Similarly driving under the influence of alcohol is committed until the marginal benefit from drunk driving<sup>2</sup> equals the expected out-of-pocket expenses for auto crashes, monetized government penalties, and own health risks. Individuals also equate the marginal private benefit from medical care with the variable cost and the marginal benefit from leisure with the net wage.

## 2.5 Marginal Welfare Effect from an Increase in Tax on Alcohol

Totally differentiating the indirect utility function (see Appendix for derivation and definition of elasticities), we obtain marginal welfare effect from an increase in  $t_A$ , accounting for any changes in  $t_L$ ,  $G^T$  and  $G^P$  to maintain government budget balance.

$$\begin{aligned}
& (E^A - t^A)\left(\frac{-\partial A}{\partial t_A}\right) + t_L\left(\frac{\partial W}{\partial t_A}\right) + MEG_{G^P}\left(\frac{\partial G^P}{\partial t_A}\right) \\
& E^A = (1-v_M)M_A + E^D D\eta_{DA}/A\eta_{AA} \\
& E^D = mpc H_D + c_D - v_D + (1-v_M)(M_D + M_{\bar{D}}) + r - t_D
\end{aligned} \tag{6}$$

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<sup>2</sup> This is not to say that drivers would generally enjoy driving more while drunk. Drunk driving enters the utility function because despite being drunk, some drivers apparently prefer driving over searching for other (safer) means of transport.

In these expressions:

$\eta_{AA} < 0$  - elasticity of alcohol consumption with respect to the price of alcohol

$\eta_{DA} < 0$  - elasticity of alcohol drunk driving with respect to the price of alcohol

$MEG_{G^P} = U_{G^P}/\lambda - 1$  denotes marginal efficiency gain/loss from spending on public goods and

$E^A$  stands for the marginal external cost of alcohol consumption. Finally,  $E^D$  denoting the external cost per drunk driver trip is independent of the non-pecuniary penalty  $\tau_D$ , which implies that the optimal level of alcohol taxes will be independent of the level of non-pecuniary penalties as well.

The change in effective labour supply in (6) is defined as

$$\frac{\partial W}{\partial t_A} = \frac{\partial W}{\partial H} \frac{\partial H}{\partial t_A} + \frac{w \partial L}{\partial t_A} + w \left( \frac{\partial L}{\partial t_L} \frac{\partial t_L}{\partial t_A} + \frac{\partial L}{\partial G^T} \frac{\partial G^T}{\partial t_A} \right) \quad (7)$$

The change in effective labour supply has three components - the increase in productivity due to the effect of lower alcohol consumption on reducing illness or road injuries, the labour supply effect of raising the price of alcohol relative to leisure and the effect of revenue recycling (leisure is a normal good, so if we use revenues to decrease  $t_L$ , labour supply increases and it decreases if we use it to increase  $G^T$ ).

## 2.6 Optimal Tax with Revenue Neutrality.

Through the optimization, it is assumed that the government's goal is to maximize the utility of an agent by finding the optimal level of  $t_a$ , given the level of  $G^T$  and  $G^P$ , and keeping the budget balanced when using all the revenues to reduce the labour tax  $t_l$ . From the first equation in (6) and (7) we calculate the optimal alcohol tax (see derivation in Appendix):

(8)

$$t_A^* = PV^A + RR^A - TI^A + PR^A$$

Where:

$$PV^A = E^A; \quad RR^A = MEG_{t_L} \left\{ \frac{p_A + t_A}{-\eta_{LL}} - t_A + g^A \right\}$$

$$TIA = \frac{(1 + MEG_{t_L})t_L(p_A + t_A)(\eta_{Al}^c + \eta_{LI})}{(1 - t_L)(-\eta_{AA})}; \quad PR^A = (1 + MEG_{t_L})t_L (-W_H H_A)$$

(9)

$$MEG_{t_L} = \frac{-t_L \frac{\partial L}{\partial t_L}}{L + t_L \frac{\partial L}{\partial t_L}} = \frac{\frac{t_L}{1 - t_L} \eta_{LL}}{1 - \frac{t_L}{1 - t_L} \eta_{LL}}$$

$$g^A = sM_A + \{s(M_D + M_{\bar{D}}) + (r - t_D)\} D\eta_{LL} / A\eta_{AA}$$

$\eta_{Al}$  - elasticity of demand for alcohol with respect to the price of leisure

$\eta_{LL}$  - labour supply elasticity.  $\eta_{LL} > 0$

$\eta_{LI}$  - income elasticity of labour supply.  $\eta_{LI} < 0$

$c$  denotes a compensated elasticity (all elasticities are defined in Appendix).

In equation (9),  $MEG_{t_L} > 0$  is the efficiency gain from using a unit of revenue to cut the labour tax. It can be seen from (8) that the optimal alcohol tax consists of four components - the marginal external cost of alcohol consumption  $E^A$  and three other components that arise from various fiscal interactions.

$PV^A$  (or  $E^A$ ) is the Pigouvian tax, the marginal external cost of alcohol (for the detailed formula, see (6)). These costs are divided into two parts. First is the fraction of medical costs due to the health risks from alcohol consumption paid by third parties (government and insurance companies). The second component accounts for drunk-driver trip costs.

The first extra component is the revenue - recycling tax ( $RR^A$ ), that captures changes in both tax revenues and alcohol-related public expenditure induced by alcohol tax. It is equal to  $MEG_{t_L}$  times marginal revenue to the government from raising the alcohol tax, including indirect savings in government medical and resource expenditures  $g^A$ . Regarding the role of price elasticity of alcohol demand: the lower it is, the greater the tax revenue from alcohol taxation, as well as the revenue - recycling component.

The second extra component  $TI^A$  is the tax-interaction effect which arises from the change in labour supply as the alcohol price rises relative to the price of leisure, multiplied by  $1 + MEG_{t_L}$  to account for the change in labour tax revenue. To maintain the government revenue balanced,  $t_L$  must be changed. When alcohol and leisure are complements ( $\eta_{Al}^C < 0$ ), the alcohol tax increases the labour supply and the tax-interaction effect is positive. It also includes the income effect from higher alcohol prices, which reduces labour supply because leisure is a normal good ( $\eta_{LI} < 0$ ). If alcohol and leisure were substitutes ( $\eta_{Al}^C > 0$ ), the alcohol tax would decrease both labour supply and labour tax revenue, which implies the negativity of the tax-interaction effect. In reality, the relationship between alcohol and leisure may not be straight forward. There is a simple rationale behind the assumption of complementarity – alcohol consumption by definition takes time, especially if consumed in a gastronomic facility. On the other hand, alcohol consumption, especially of a lower level, may readily be complementary to time spent working (and thus a substitute to leisure). Either as a short-term relief from work-induced stress, or as a result of socializing with colleagues. As mentioned by (Institute for Fiscal Studies (Great Britain), 2009), the former effect may be underreported since heavy drinkers generally tend to underreport their consumption in official surveys and it is therefore possible, that some countries could report alcohol and leisure as mild substitutes.

Finally, as the third component, there is the productivity effect ( $PR^A$ ), expressed in per unit reduction in alcohol consumption. Taxing alcohol reduces drinking and also drunk driving, resulting in better health of individuals and positive effect on effective labour supply. It equals the health-induced increase in productivity per unit reduction in alcohol  $-W_H H_A = (\partial W / \partial H)(dH/dA)$  times the labour tax  $t_L$ , times  $1 + MEG_{t_L}$  to account for the change in labour tax revenue.

## 2.7 Taxation of Individual Beverages

Now, let us assume that:

$$A = A_{BE} + A_{WI} + A_{SP} \quad (10)$$

$$E^{Ai} = E^A ; H^{Ai} = H^A$$

where alcohol consumption  $A$  is a sum of individual beverages consumed: beer ( $BE$ ), wine ( $WI$ ) and spirits ( $SP$ ). The second equation indicates that marginal external costs  $E^{Ai}$  and productivity effects  $H^{Ai}$  per unit of alcohol are the same across these beverages.

We calculate optimal taxes on these individual beverages as:

$$\hat{t}_i = t_i^* - \sum_{k \neq i} (t_k^* - \hat{t}_k) \left( \frac{\eta_{ki} A_k}{\eta_{ii} A_i} \right) \quad (11)$$

where  $i, k = BE, WI, SP$  and  $\eta_{ii}, \eta_{ki}$  denote own and cross-price beverage elasticities.  $t_i^*$  is the optimal tax in the absence of cross-price effects among beverages and it is analogous to that in (8). Therefore the more elastic and complementary to leisure a beverage is, the higher an optimal tax on that beverage is likely to be.

## 2.8 Other Considerations

Although the above model could be already considered quite complex, it does not and perhaps even could not capture all the effects that could potentially interact in the system. Let us mention at least one of these omissions that could be considered in the same time important as well as controversial. The fact that drinking could cause higher death rates (either by sudden deaths under influence of alcohol by one of the actors, or after a long-term alcohol-related health condition), also means that such deaths generally occur at lower age than if the individual were to abstain. This implies that there could be potential government savings (on retirement pensions and/or costs of future medical treatment unrelated to alcohol) in case a person died earlier because of his/her drinking habits. In fact, a study dealing with similar matter for the Czech Republic in detail (Hait, 2012) concludes that because of these effects, smoking really seems to be even beneficial for the Czech state budget (at the expense of the individuals affected). As analysing this problem would bring another level of complexity to the model, but result in only redistribution of the costs and benefits between individuals and the state budget, we treat this omission as justifiable.

### 3 Parametrization of Model

Let us now describe the parameter values of our model. If not stated otherwise, all values were estimated for a 2012 baseline. For important parameters that are calculated or estimated with some degree of uncertainty, we usually consider three different values to obtain the mid, low (conservative) and high (non-conservative) estimates. We allow a  $\pm 30\%$  variation to find the lower and upper limit.

#### 3.1 Alcohol Market and Labour Tax

To calculate the total consumption of pure alcohol (or ethanol) in the Czech Republic, we first need to find out how many litres of pure alcohol were contained in the amount of beer, wine and spirits consumed (computed in Table 1).

Table 1: Per Capita Amount of Pure Alcohol Consumed

Beverage	Per-capita consumption	Alcohol content	Per-capita consumption of pure alcohol	Share on Total pure alcohol consumed
Beer	148.6 l/year	4.5%	6.687 l/year	57.0%
Wine	19.8 l/year	12.0%	2.376 l/year	20.2%
Spirits	6.7 l/year	40.0%	2.680 l/year	22.8%

Source: Own calculation based on Czech Statistical Office data

Initial alcohol consumption  $A$  is thus 11.743 l of pure ethanol per capita per year, which means 123,365,441 l of pure alcohol in total at the 2012 population level of the Czech Republic of 10 505 445 inhabitants (CSO, 2012)<sup>3</sup>.

The average price of one litre of beer, wine and spirits, taken from Czech Household Budget Survey data from 2012 reached 24.30 CZK, 66.18 CZK and 246.21 CZK respectively,

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<sup>3</sup> The figures by Czech Statistical Office (C) are constructed using a balance method (taking import and export of alcohol into account), but are likely to fail in capturing the tourism effect. The incoming tourism in 2012 accounted for 8.9 million visitors (excluding overnight stays and transfers) whereas number of foreign visits by the Czechs is estimated to only 5.4 million. Taking into account that alcohol is generally cheaper in the Czech Republic than in most of the tourists' countries of origin as well as in travel destinations visited by Czechs, it is legitimate to assume that foreign tourists inside Czech Republic consume more alcohol (in total terms) than Czechs consume abroad. The per capita figures by CSO could be therefore overestimated.



where the average price of beer was calculated by multiplying the average price of bottled beer 20.24 CZK and the average price of draft beer 40.22 CZK by the rate of their occurrence (52.2% and 47.8%). The price of wine was similarly counted with both red and white wine and the price of spirits with two Czech popular ones – rum and vodka .

For the purpose of our analysis we are not interested in the price of a litre of the particular drink, but rather the price of such an amount of the beverage that contains one litre of pure ethanol (22.22 l of 4.5% beer, 8.33 l of 12% wine and 2.50 l of 40% spirit). These imply prices  $p_a$  of 539.95 CZK for beer, 551.28 CZK for wine and 615.53 CZK for spirits.

The current alcohol tax rate  $t_a$  is calculated as a sum of excise tax and VAT, which is the same for all the three beverage types - 21%, the basic rate (VAT for 1 litre of pure alcohol in beer, wine and spirits is therefore 113.39 CZK, 115.77 CZK and 129.26 CZK). On the other hand, excise tax differs for every one of them. For spirits it is 285 CZK/l, while for still wines, excise tax does not apply at all. Calculation of excise tax on beer is a bit more complicated – it depends both on the size of a brewery and the content of original wort extract (details can be found in Table 2).

Table 2: Excise Tax on Beer

<b>Brewery size (hl of beer produced)</b>	<b>Tax rate for 1% of original wort extract in 1 litre</b>
< 10 000	16.0 CZK
000 - 50 000	19.2 CZK
000 - 100 000	22.4 CZK
000 - 150 000	25.6 CZK
000 - 200 000	28.8 CZK
> 200 000	32.0 CZK

Calculating with the standardized rate of 0.31 CZK/l (over 90% of beer is being produced in the breweries with production over 200,000 hl) and the average 11 degrees Plato beer, we get beer excise tax of 3.41CZK/l of beer or 75.02 CZK/amount of beer containing 1 litre of pure alcohol.

Altogether, the current alcohol tax rate  $t_a$  per litre of pure alcohol is estimated to be 188.41 CZK for beer, 115.77 CZK for wine and 414.26 CZK for spirits.

In 2011, the implicit tax rate on labour was 39% in the Czech Republic (Eurostat, 2013).

Given the fact that in 2012 real GDP was approximately the same and the government did not implement any new policies concerning income tax,  $t_L = 0.39$  remains valid even for 2012 and is therefore applied throughout this paper.

### 3.2 Drunk Driving

In 2012, the Police of the Czech Republic recorded a total of 4,974 traffic accidents caused by drunk driving. In these accidents, 45 persons were killed and 2,770 injured. Alcohol in blood of drivers was also detected during 11,037 roadside checks. Altogether there were 16,011 cases of drunk driver trips registered in 2012. Nevertheless, this value represents only a small fraction of the actual number.

According to data of the Czech Ministry of Transport, drivers with a blood alcohol level higher than allowed amount<sup>4</sup> account for approximately 2% of total kilometres travelled within the countries of the EU. Assuming 10 000 kilometres travelled per year per driver, average trip length of 20 kilometres and the proportion of drivers in the population of 64.62% gives initial drunk driver trips  $D$  equal to 67,886,186 with the proportion of registered drunk driving lower than 0.024%. Expected fine per drunk-driver trip  $t_D = 5.9$  CZK is calculated as the maximum penalty rate that can be charged in the Czech Republic for driving under the influence of alcohol (25 000 CZK) multiplied by share of registered drunk driving on total estimated drunk driving.

### 3.3 External Costs

In order to separate the Pigouvian part of our model properly, we need to split the cost into part internalized by the drinker and part that represents damage caused to the others. Unfortunately, Czech police statistics do not provide the split between internal and external consequences of car incidents. In order to approximate this, we refer to (Levitt & Porter, 2001) estimate that only 16.8% of injuries in alcohol-involved crashes are external. Applying the same ratio to alcohol-related incidents registered in 2012 in the Czech Republic results in eight fatalities and 471 injuries being external. For fatalities, the marginal private cost  $mpc$

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<sup>4</sup> The allowed amount varies across EU countries. For the Czech Republic, it is zero.

corresponds to estimates of the value of life. Czech Supreme Court assumes a value of life of 10,051,200 CZK, thus 80,409,760 CZK is the estimated value of eight lives.

Estimating compensation for non-fatal injuries is a more complicated task. Under the Czech law, every injury or social impairment caused by a traffic accident has a different value in points, which then define the compensation. Value of one point is 120 CZK. Averaging all these compensation gives a mean value of 72,000 CZK (that means 33,912,000 CZK for 471 injuries), which we set as the marginal private cost  $mpc$  of non-fatal external injuries. Aggregating over the value of fatal and non-fatal injuries and dividing by alcohol consumption gives a value for  $mpcH_{\bar{D}}D/A = 0.927$  CZK per litre of alcohol.

Based on data from the Ministry of Finance, we estimate the total costs of car repair to be 500 mil. CZK. In the Czech Republic, car accident costs are almost entirely covered by mandatory car insurance. Average individual financial participation reaches only 9% of the damage in an accident. Dividing by alcohol consumption results in  $(c_D - \eta_D)D/A = 3.68$  CZK.

For the calculation of government resource costs from implementing drunk driver penalties (including law, police and jailing costs), adjusted European average data from (Anderson & Baumberg, 2006) have been used. Values for the Czech Republic were obtained by multiplying European data by ratio of Czech inhabitants in the EU (2.09%), ratio between average Czech and EU alcohol consumption (116%) the 2006 mid-year exchange rate EUR/CZK (27.495, source: Czech National Bank) and a conversion factor - ratio of CZ/EU productivity of labour (49.6%, source: Eurostat) for the productivity parameters and purchasing price parity ratio (79.3%, source: Eurostat). Estimated legal costs of alcohol-related crime are 5,900 million CZK. Alcohol-related car incidents are closely linked to alcohol-related costs of crime. Again using (Anderson & Baumberg, 2006), we assume that alcohol-related car incidents accounted for 88% of the previously mentioned amount, thus 5,192 million CZK and  $r/A = 42.09$  CZK.

Using again the European data, we could estimate medical expenditures connected to treatment of alcohol related health problems to be CZK 6.7 billion. This estimate includes costs of treatment of diseases caused by alcohol consumption, own drunk driving and drunk driving of others. Unlike the U.S. healthcare system, Czechs have most of the medical services paid by the government through their taxes. Variable payment  $v_M$  (which consists mainly of cost of

medicaments) must therefore be lower than in (Parry, et al., 2009) and we assume it to be 0.1.

All the above mentioned values give together  $E^A = 106.93$  CZK per litre of pure alcohol. This value is the same for all the three beverages.

### 3.4 Elasticities and Marginal Efficiency Gain

Elasticities used to derive the optimal tax level are presented in Table 3.

Table 3: Applied Elasticities

Parameter		Low	Mid	High
Drinking with respect to leisure (compensated)	$\eta_{Al}^C$	0.10	-0.05	-0.20
Labour supply with respect to income	$\eta_{LI}$	-0.10	-0.10	-0.10
Labour supply with respect to wage rate	$\eta_{LL}$	0.15	0.15	0.15
Drinking with respect to alcohol price - beer	$\eta_{bb}$	-0.972	-0.972	-0.972
Drinking with respect to alcohol price - wine	$\eta_{ww}$	-1.088	-1.088	-1.088
Drinking with respect to alcohol price - spirits	$\eta_{ss}$	-1.210	-1.210	-1.210

Elasticity of drinking with respect to leisure  $\eta_{Al}^C$  was drawn from (Parry, et al., 2009) who indicate an interval between 0.1 and -0.2 and -0.05 is used as mid value. In this case, using three different values is really appropriate because of limited evidence on this parameter, which is more suggestive than definitive.

Own-price alcohol elasticities have been estimated in numerous studies - among others, let us name (Hogarty & Elzinga, 1972), (Gallet, 2007), (Fogarty, 2010) and from the most recent ones (Nelson, 2014), (Srivastava, et al., 2014) and (Meng, et al., 2014). Significantly fewer authors have also focused on cross-price elasticities of alcohol beverages. In this paper, we will use elasticities calculated by (Janda, et al., 2010), based on the data from Czech Household Budget Survey, presented in Table 4, which seems to be the most suitable for our purposes. It also focuses both on own and cross-price elasticities. Therefore, we assume own-price elasticity  $\eta_{AA}$  of beer, wine and spirits to be -0.9715, -1.0880 and -1.2104 respectively.

We assume  $\eta_{DA} = \eta_{AA}$  based on estimated responses of drunk driving and highway

fatalities to alcohol prices.

Table 4: Alcohol Price Elasticities

	<b>Beer</b>	<b>Wine</b>	<b>Spirits</b>
<b>Beer</b>	<b>-0.9715</b>	-0.0681	0.0933
<b>Wine</b>	-0.1143	<b>-1.0880</b>	0.0491
<b>Spirits</b>	0.2047	0.2302	<b>-1.2104</b>

Source: (Janda, et al., 2010)

There is a vast amount of literature estimating labour supply elasticity. The majority of them agree on the fact that it is inelastic. For the purpose of this paper, we use the value of  $\eta_{LL} = 0.15$  analogous to (Parry, et al., 2009), which is averaged over all male and female workers and hours worked. The latter produces an outcome of  $MEG_{tL}$  of approximately 0.106.

Finally, for labour supply elasticity with respect to income  $\eta_{LI}$  we use the value of  $\eta_{LI} = -0.1$  that is also applied in both (Saar, 2011) and (Parry, et al., 2009).

### 3.5 Productivity Effect

According to the estimates by (Anderson & Baumberg, 2006) from Institute of Alcohol Studies, we could estimate total workplace productivity costs due to the lower state of health of alcohol abusers and those that arise from increased absence at work while influenced by alcohol consumption to be 4.7 billion CZK. For the revenue-neutral alcohol tax this implies a productivity cost  $W_H / A$  of 26.7 CZK - 49.50 CZK per litre of pure alcohol with a mean value of 38.1 CZK.

## 4 Results - Optimal Taxation for the Czech Republic

Results of the simulation are presented in Table 5, Table 6 and Table 7.

Table 5: Optimal Tax on Beer (CZK per litre of pure alcohol)

<b>Components of alcohol tax</b>	<b>Low</b>	<b>Mid</b>	<b>High</b>
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Pigouvian	106.93	106.93	106.93
Revenue-recycling	59.54	59.54	59.54
Tax-interaction	0	106.03	159.05
Productivity	11.52	16.44	21.36
<b>Total</b>	<b>177.99</b>	<b>288.94</b>	<b>346.88</b>
Current		188.41	

As shown, the optimal tax rate for beer ranges from 177.99 CZK to 348.66 CZK per litre of pure alcohol with a mid estimate of 288.94 CZK. The low, mid and high estimate of optimal tax (a sum of VAT and excise tax) on 0.5 l of beer is therefore 4 CZK, 6.5 CZK and 7.8 CZK. While the low estimate is slightly below the current tax rate of 4.2 CZK per 0.5 l of beer, both mid and high estimate exceed the current tax level.

High estimate represents almost 200% of the low estimate, which seems to be a reasonable difference. Individual estimates differ in Tax-interaction effect and Productivity effect. The variability is caused mainly by differences in elasticities of drinking with respect to leisure (from 0.1 to -0.2) applied to derive low, mid and high estimates.

The most volatile component of the optimal tax is the Tax-interaction effect. On the one hand, it completely disappears under the low-case assumptions, because under the given parameter values the substitution effect between alcohol and leisure, which decreases the labour supply, is offset by the income effect from the higher alcohol price that in turn increases labour supply. On the other hand, it represents almost the same proportion of the optimal tax as the entire Pigouvian tax at the mid estimate. Finally, Tax-interaction effect under the high estimate is so high that it represents over 45% of the total optimal tax rate.

Similarly to the results from the USA presented in (Parry, et al., 2009), the fiscal component (which we define by the Revenue-recycling component net of the Tax-interaction effect) of the total tax rate under mid and high estimate exceeds the Pigouvian tax. This fact highlights the need for both fiscal and externality consideration. Productivity effects play only a marginal role in the level of beer tax.

Table 6: Optimal Tax on Wine (CZK per litre of pure alcohol)

<b>Components of alcohol tax</b>	<b>Low</b>	<b>Mid</b>	<b>High</b>
Pigouvian	106.93	106.93	106.93

Revenue-recycling	52.75	52.75	52.75
Tax-interaction	0	86.71	130.07
Productivity	11.52	16.44	21.36
<b>Total</b>	<b>171.20</b>	<b>262.83</b>	<b>311.11</b>
Current		115.77	

In order to obtain the optimal beer tax, we had to calculate the optimal tax on wine and spirits as well. Alike the current tax, the calculated optimal wine taxation is the lowest from all the three beverages. The optimal tax on wine was estimated to be 171.20 CZK - 311.11 CZK per litre of pure alcohol with the mid value of 262.83 CZK. After the recalculation we get 20.54 CZK - 37.35 CZK per litre of wine, thus way above the current level of 13.88 CZK.

Table 7: Optimal Tax on Spirits (CZK per litre of pure alcohol)

<b>Components of alcohol tax</b>	<b>Low</b>	<b>Mid</b>	<b>High</b>
Pigouvian	106.93	106.93	106.93
Revenue-recycling	46.30	46.30	46.30
Tax-interaction	0	120.33	180.49
Productivity	11.52	16.44	21.36
<b>Total</b>	<b>164.75</b>	<b>290.00</b>	<b>355.08</b>
Current		414.26	

The current Czech level of tax on spirits is significantly higher than those on wine and beer because of a number of fiscal, social or public policy reasons. While the general EU principle of free movement of goods supports the same taxation of alcoholic beverages so that lower or higher taxation of particular beverages would not violate fair competition, the EU Council Directive 92/83/EEC (1992), which is in force since 1992 up to now (as of February 2018), explicitly allows different level of excise duties among beer, wine, and spirits. The original European Commission intention dating back to 1989 was to have the same excise duties for all alcoholic beverages based on pure alcohol content, however member countries with low taxation of wine or with high taxation of beer did not agreed with this (Siroky, 2016). Different taxation of beer, wine and spirits is driven mainly by efforts of particular countries or groups of countries to have lower taxation on their “national” alcoholic beverages (for example wine for southern countries, whisky for Ireland or United Kingdom, beer for Central European countries).

This in turn allows wine production/distribution lobbies in countries like Czech Republic to keep low taxation of wine even in countries with different “national” beverages.

The results of our analysis show that although the optimal level of tax rate on spirits is still the highest from all the beverages presented, it is way below its current level for all low, mid and high estimates. The value of mid estimated tax on 1 litre of 40% spirit of 116 CZK represents only about 70% of the current tax.

As some of the exogenous variables play a significant role in our model, it is worth assessing what impact a change in the most important ones could have on the overall result of optimal tax calculation in our model. The impact of an absolute increase in the key factors by 1pp is summarized in Table 8.

Table 8: Sensitivity analysis

Increase (in absolute terms) in:	notation	Change in optimal tax value		
		Beer	Wine	Spirit
Corresponding beverage’s own-price elasticity by -1pp	$\eta_{ii}$	-0.582%	-0.487%	-0.493%
Labour Tax by 1pp	$t_L$	1.568%	1.410%	1.773%
Elasticity of demand for alcohol respect leisure by -1pp	$\eta_{LL}$	1.835%	1.649%	2.075%
Income elasticity of labour supply by -1pp	$\eta_{LI}$	3.670%	3.299%	4.149%

To compare our results with existing literature, an obvious choice is the study by Janda et al. (2010b) who analyse the development of Czech brewing industry and optimal alcohol taxation. Using methodology of (Anderson & Baumberg, 2006) and statistical data about Czech alcohol consumption, an analogy of a model developed by (Pogue & Sgontz, 1989) is used to estimate the optimal tax on alcohol, balancing social costs and benefits connected with the beer production and consumption. In order to maximize the welfare of society, alcohol consumers are divided into two groups - abusers and non-abusers, differing in volume and elasticity of alcohol demand.

Janda et al. (2010b) use quite diverse sets of parameters, varying in level of external abuse costs (with and without intangible costs) and assumptions about the number of abusers attributed to each alcoholic beverage as well as their elasticities of demand. Their four models’ results are summarized in Table 9.



Table 9: Optimal Tax Comparison - Model by Janda et al. (2010)

	<b>Tax per litre of ethanol(CZK)</b>	<b>Tax per litre of the beverage(CZK)</b>
beer	85 - 415	3.58 - 17.45
wine	56 - 416	5.67 - 42.43
spirits	43 - 284	17.14 - 113.67

Source: Janda et al. (2010b)- Socially Optimal Taxation of Alcohol: The Case of Czech Beer

The range of the optimal taxes calculated by Janda et al. (2010b) is generally wider than the one in this paper, which is likely to be the result of quite borderline assumptions of some of their model cases. The fact that all their mean and especially the lower-bound estimates are much lower, can be attributed to them considering only externality rationales, whereas our study also accounts for other aspects such as the labour, tax-interaction and productivity effects, which go generally in favour of higher tax. This is especially true for spirits. Whereas (Janda et al., 2010b) propose that optimal tax on spirits is the lowest of all three beverages (which is in contradiction to existing excise tax rates), our results suggest that spirits should be taxed the most among the three beverages. This difference in results could be attributed to the fact that our model does not rely solely on price-elasticity (which is assumed to be the highest for spirits), but also takes into account other effects. The tax interaction effect for example (which is not a part of the model by Janda et al. (2010b)) seems to be relatively strong for spirits. Both our models, however, agree in the general finding that the optimal beer and wine taxes in the Czech Republic seem to be higher than their existing levels.

## 5 Conclusions

Regardless of possible benefits of alcohol production and consumption, it has a significant negative external effect. The scale of costs is very broad, including medical expenditures, productivity loss, drunken driving accidents and police and law costs. Alcohol taxes seem to be a suitable means of addressing these externalities. Using a static

general-equilibrium model with a representative agent we found that in order to find the optimal level of beer taxation, which balances social costs and benefits, government should set the tax rates between 4 CZK and 7.8 CZK per 0.5 l of beer. Our analysis suggests that under most of the combinations of parameters taxes on beer in the Czech Republic are lower than their optimal levels. On the other hand, optimal tax was shown to be slightly under its current level when low values were applied to parameters with a high degree of uncertainty. This implies the need for more empirical research on some model parameters. Besides externality correction, these optimal levels are also determined by fiscal considerations as increase of taxation is assumed to immediately change other governmental policies such as labour taxation or medical expenditures. By decomposing the estimated optimal tax into four components, we conclude that the fiscal component significantly affects the optimal tax rate as it may be as large as or even greater than the externality-correcting component. Apart from taxes on beer, our analysis also estimates tax on wine of 20.5 CZK/l - 37.4 CZK/l and tax on spirits of 65.9 CZK/l - 142 CZK/l, which shows that optimal tax rates on different alcoholic beverages should vary according to their characteristics.

In the future, this study could be extended in many different ways. As said above, more empirical research on some model parameters (e.g. leisure cross-price elasticities) is needed for a more accurate estimation of the optimal tax levels. Similarly to (Parry, et al., 2009), we could estimate the optimal tax levels decreasing public spending and increasing drunk driving penalties, as alcohol taxes are typically justified as means of raising government revenues. Intangible costs of alcohol consumption such as pain or psychological harm to families of alcohol abusers were not considered in our analysis - another expansion could therefore include these in our model. Finally, a similar type of analysis might be used to estimate the optimal taxes on other goods with negative external effects such as tobacco and cannabis.

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## 6 Appendix

### List of variables

Variable	Description	Equation	
$A_i$	Alcohol consumption (i ranges through individual types – beer/wine/spirit)	(1)	
$c_D$	Expected cost of car repair per a drunk drive	(3)	
$C$	Non-alcoholic goods consumption	(1)	
$D$	Number of driving trips under influence of alcohol by the agent	(1)	
$\bar{D}$	Number of driving trips under influence of alcohol by others	(2)	
$g^A$	indirect savings in government medical and resource expenditures	(9)	
$G^P$	Government spending on public goods	(1)	
$G^t$	Government tax revenue	(3)	
$H$	Health risk function	(2)	
$l$	Leisure time consumption	(4)	
$L$	Labour supply (number of hours worked)	(4)	
$E^A$	marginal external cost of alcohol consumption	(8)	
$E^D$	external cost per drunk driver trip	(6)	
$K_D$	Lump sum coinsurance paid by the agent as a part of car repair costs	(3)	
$K_M$	Lump sum coinsurance paid by the agent as a part of medical costs	(3)	
$mpc$	Marginal private cost of health risks	(5)	
$M$	Agent's costs of medical treatment	(2)	
$\bar{M}$	Others' costs of medical treatment	(8)	
$MEG_{G^P}$	marginal efficiency gain/loss from spending on public goods	(6)	
$MEG_{t_L}$	marginal efficiency gain cutting labour tax	(8)	
$PR^A$	Productivity effect of alcohol tax given reduction in alcohol consumption	(8)	
$PV^A$	Pigouvian tax, equal to marginal external cost of alcohol consumption	(8)	
$p_A$	producer price of alcohol	(4)	
$r$	Cost for enforcing drunk-driving penalties paid by the government	(3)	
$RR^A$	revenue - recycling tax	(8)	
$s$	Share of medical costs financed from public budget	(3)	
$t_A$	Tax on alcohol (in form of an excise tax)	(3)	
$t_D$	expected fine per drunk-driver trip	(3)	
$t_L$	Effective tax on labour	(3)	
$T_H$	Available time (that could be distributed between work and leisure), as a function of H	(4)	
$TI^A$	tax-interaction effect from change in labour supply due to the alcohol price rise	(8)	
$U$	Utility function aggregated over all households	(3)	
$w$	Wage	(3)	
$W_H$	Effective labour, as a function of H	(7)	
$\eta_{AA}$	elasticity of alcohol consumption with respect to the price of alcohol	(6)	
$\eta_{DA}$	elasticity of drunk driving with respect to the price of alcohol	(6)	
$\eta_{AL}$	elasticity of demand for alcohol respect leisure	(9)	
$\eta_{ii}; \eta_{ki}$	Own-price; cross-price elasticity of demand for individual beverage types	(9)	
$\eta_{LL}$	Elasticity of labour supply	(9)	
$\eta_{Ll}$	Income elasticity of labour supply	(9)	
$\eta^c$	Compensated elasticity (in general)	(9)	
$\lambda$	Marginal utility of income	(5)	
$\tau_D$	Non-pecuniary penalties (e. g. license suspensions, jail) per drunk driver trip	(1)	
$u_D$	Variable payment charged by insurance companies as a fraction of medical expenses	(3)	
$u_M$	Variable payment charged by car-insurance companies per a drunk driver trip	(3)	

Deriving equation (7):

Using (1) and (4), agents solve the following optimization problem:

$$V(t_A, t_L, I, G^P, \bar{D}) = \text{Max}U(A, D, C, T(H) - L(H, \tau_D D, G^P) + \lambda \{ (1 - t_L)W + G^T - K_M - K_D - (p_A + t_A)A - (v_D + t_D)D - v_M M - p_C C \} \quad (12)$$

From partially differentiating (12):

$$\frac{\partial V}{\partial t_A} = -\lambda A; \quad \frac{\partial V}{\partial t_L} = -\lambda w L; \quad \frac{\partial V}{\partial G^P} = U_{G^P}; \quad \frac{\partial V}{\partial D} = -\lambda H_{\bar{D}} mpc; \quad \frac{\partial V}{\partial I} = \lambda \quad (13)$$

Totally differentiating (12) with respect to  $t_A$  using (13), gives:

$$\frac{1}{\lambda} \frac{\partial V}{\partial t_A} = -A - W \frac{dt_L}{dt_A} + \frac{dI}{dt_A} + \frac{U_{G^P}}{\lambda} \frac{dG^P}{dt_A} - H_{\bar{D}} mpc \frac{dD}{dt_A} \quad (14)$$

Totally differentiating the government budget constraint (14) with respect to  $t_A$ , allowing  $t_L$ ,  $G^T$  and  $G^P$  to vary, gives:

$$\frac{dG^T}{dt_A} - W \frac{dt_L}{dt_A} = t_L \frac{dW}{dt_A} + A + t_A \frac{dA}{dt_A} - s \frac{dM}{dt_A} + (t_D - r) \frac{dD}{dt_A} - \frac{dG^P}{dt_A} \quad (15)$$

Substituting  $K_M = (1 - s - v_M)M$  and  $K_D = (c_D - v_D)D$  (from the zero profit condition for medical and auto insurance companies) into  $I = G^T - K_M - K_D$  and totally differentiating with respect to  $t_A$  gives

$$\frac{dI}{dt_A} = \frac{dG^T}{dt_A} - (1 - s - v_M) \frac{dM}{dt_A} - (c_D - v_D) \frac{dD}{dt_A} \quad (16)$$

Substituting (16) and (17) in (15) and grouping terms gives:

$$\begin{aligned} \frac{1}{\lambda} \frac{\partial V}{\partial t_A} = & -(1 - v_M) \frac{dM}{dt_A} - (H_{\bar{D}} mpc + c_D - v_D - t_D + r) \frac{dD}{dt_A} \\ & + t_A \frac{dA}{dt_A} + t_L \frac{dW}{dt_A} + \left( \frac{U_{G^P}}{\lambda} - 1 \right) \frac{dG^P}{dt_A} \end{aligned} \quad (17)$$

Let us assume that medical services can be expressed as a simple function of alcohol consumption, own drunk driving and the drunk driving of others (as these variables drive medical care demand through their impact on health):  $M = M(A, D, \bar{D})$ .

Differentiating the expression with respect to  $t_A$  gives:

$$\frac{dM}{dt_A} = M_A \frac{dA}{dt_A} + M_D \frac{dD}{dt_A} + M_{\bar{D}} \frac{d\bar{D}}{dt_A} \quad (18)$$

In addition we define elasticities as:

$$\eta_{AA} = \frac{dA}{dt_A} \frac{p_A + t_A}{A}; \quad \eta_{dA} = \frac{dD}{dt_A} \frac{p_A + t_A}{D} \quad (19)$$

Substituting (18) and (19) in (17) gives, after some manipulation, equation (6).

*Deriving equation (9):*

From totally differentiating the government budget constraint (3) with respect to  $t_A$ , allowing  $t_L$  to vary with  $G^T$  and  $G^P$  fixed using (7) gives :

$$= - \frac{A + t_A \frac{dA}{dt_A} + (t_D - r) \frac{dD}{dt_A} - s \frac{dM}{dt_A} + t_L \left\{ w \frac{\partial L}{\partial t_A} + \frac{\partial W}{\partial H} \frac{dH}{dt_A} \right\}}{w \left\{ L + t_L \frac{\partial L}{\partial t_L} \right\}} \quad (20)$$



From (20) and the first equation in (9):

$$t_L w \frac{\partial L}{\partial t_L} \frac{dt_L}{dt_A} = MEG t_L \left\{ A + t_A \frac{dA}{dt_A} + (t_d - r) \frac{dD}{dt_A} - s \frac{dM}{dt_A} + t_L \left( w \frac{\partial L}{\partial t_A} + \frac{\partial W}{\partial H} \frac{dH}{dt_A} \right) \right\} \quad (21)$$

Substituting (7) and (21) into (6), with  $dG^T/dt_A = dG^P/dt_A = 0$  gives:

$$\begin{aligned} & (E^A - t^A) \left( \frac{-dA}{dt_A} \right) + MEG t_L \left\{ A + t_A \frac{dA}{dt_A} + (t_D - r) \frac{dD}{dt_A} \right\} \\ & + (1 + MEG t_L) t_L \frac{w \partial L}{\partial t_A} + (1 + MEG t_L) t_L \frac{\partial W}{\partial H} \frac{dH}{dt_A} \end{aligned} \quad (22)$$

From the Slutsky equation:

$$\frac{\partial L}{\partial t_A} = \frac{\partial L^C}{\partial t_A} - \frac{\partial L}{\partial I} A; \quad \frac{\partial L}{\partial t_L} = \frac{-\partial L^C}{\partial \tilde{w}} w - \frac{\partial L}{\partial I} wL \quad (23)$$

where superscript  $c$  denotes a compensated coefficient and  $\partial L/\partial I$  is the income effect on labour supply.

From the Slutsky symmetry property:

$$\frac{\partial L^C}{\partial t_A} = - \frac{\partial A^C}{\partial \tilde{w}} \quad (24)$$

where  $\tilde{w} = (1 - t_L)w$  denotes the net of tax wage.

In addition we define elasticities:

$$\eta_{LL} = \frac{\partial L^C}{\partial \tilde{w}} \frac{\tilde{w}}{L}; \quad \eta_{AL}^C = \frac{\partial A^C}{\partial \tilde{w}} \frac{\tilde{w}}{A}; \quad \eta_{LL} = \frac{\partial L}{\partial I} \frac{\tilde{w} I}{L} \quad (25)$$

Equating (22) to zero, and substituting (23) and (24) gives (8), where  $g^A$  is defined in (9) and elasticities in (25).

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Univerzita Karlova v Praze, Fakulta sociálních věd

Institut ekonomických studií [UK FSV – IES] Praha 1, Opletalova 26

E-mail : [ies@fsv.cuni.cz](mailto:ies@fsv.cuni.cz)

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