Optimal taxation of substitute goods - the case of e-cigarettes

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Abstract

E-cigarettes have become a substitute for tobacco cigarettes. This brings about the question of how to best levy excise duties on them. By assuming partial equilibrium conditions and tobacco excise rates as exogenous, we derive a set of expressions for the ad-valorem excise rates which maximise tax revenues or social welfare. Using own price and cross-price demand elasticities for vape and tobacco; public data on the costs of tobacco externalities; and recent estimations of the relative harmfulness of vape, the expression are applied to EU countries and US states. Using Monte Carlo uncertainty analysis, some tentative recommendations are made for vape market shares at which imposition of excise duties would increase social welfare. The developed framework can be applied to other cases as well, e.g. taxes on sugary beverages.

Keywords: Tax policy, Excise, Externalities, E-cigarettes

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Introduction

Since their introduction in 2007, e-cigarettes have established themselves as a substitute for tobacco cigarettes. The total market for e-cigarettes, or vaping, was estimated at $8 billion in 2016, of which about $6 billion in the European Union and the United States. Although the harmfulness of e-cigarettes is still debated, the scientific consensus currently is that they are substantially less harmful than other tobacco products. Because of the fiscal and health implications of e-cigarettes, it is not surprising that many governments are considering how to regulate this market and which excise regime is optimal. In most countries e-cigarettes only attract the general VAT or sales tax but some countries (e.g. Italy, Romania and Finland) and states (e.g. California, Minnesota and North Carolina) have actually implemented excise taxes on e-cigarettes.

In this paper we put forth a partial equilibrium framework to determine what an optimal excise regime for e-cigarettes may look like under different government objectives. The basic premise is to treat tobacco and electronic cigarettes as partial substitutes and to incorporate their respective externalities. The framework is applied to the EU and United States.

Literature Review

This article contributes to the economic literature on optimal taxation. It also contributes to the health policy literature that is concerned with the use and regulation of tobacco products. Taxation of tobacco and other inelastic or luxury goods is typically justified by economists for two reasons. First, it is considered an efficient tax. Ramsey (1927) showed that in absence of other taxes, goods should be taxed inversely proportional to their price elasticity of demand, which is typically low for tobacco (Chaloupka & Warner, 2000). Second, tobacco taxes compensate for the cost of negative externalities, i.e. Pigouvian corrective taxes. Notwithstanding some theoretical objections, the Pigouvian principle has been validated in the context of a more comprehensive system of indirect taxation (Sandmo, 1975). An important practical problem of Pigouvian taxes is that one cannot always quantify the cost of externalities at either the individual or group levels accurately enough for the purposes of calculating an optimal tax. Baumol (1972) argued that it nevertheless can be perfectly reasonable for a social planner to set minimum standards of acceptability and to determine a tax based on them. Individual tobacco consumption patterns affect externalities but cigarettes can only be taxed uniformly. A defensible cigarette tax could then be one that is equal to the average cost of externalities per unit of consumption. Although quantification of these externalities is often highly uncertain, one can arrive at some reasonable estimates, as will be shown later.

Methodology

In this section we develop a partial equilibrium framework to determine what an optimal excise regime for e-cigarettes might look like under different government objectives. The basic premise is to treat tobacco and electronic cigarettes as partial substitutes and to include their respective costs of externalities, accepting that there are still substantial uncertainties regarding those costs. The framework is then applied to the EU and the USA.

A Model of E-Cigarette Taxation

We take a single cigarette as the basic unit of consumption. For now, suppose that an equivalent vape consumption can be defined (we will come back to this later). Each cigarette or vape equivalent has a market price, which depends on the product-specific ad-valorem excise rate (if present) and on the general VAT or sales tax. Assume also that a per-unit cost of externalities can be defined (we will come back to this later as well). It then follows that the total excise and tax revenues as well as the cost of externalities depend on the mentioned unit prices and costs and on the volume of tobacco and vape products consumed. When tobacco and vape products are imperfect substitutes, their respective consumption depends not only on their own price elasticity of demand but also on the cross price elasticity of the substitute. Any change in product-specific excise of either tobacco or vape thus affects the consumption of both.

As mentioned in the introduction, governments can have different objectives when levying excise duties. We here consider two of them: (i) maximisation of fiscal revenues (i.e. pure Ramsey taxation); and (ii) maximisation of social welfare, which we here define as fiscal revenues minus the cost of externalities (i.e. combined Ramsey and Pigouvian taxation). The above logic can be expressed mathematically as is done in the Table 5 in the Appendix. The bottom four rows of the table indicate respectively the change of (i) consumption volume; (ii) fiscal revenues; (iii) costs of externalities; and (iv) social welfare, all in response to a change of the fiscal regime (excise and/or VAT or sales tax). By assuming tobacco taxes as exogenous and not subject to change (i.e. $\Delta T_t = 0$), one obtains the most general expression for the vape excise rate change (Δe_v) needed to maximise social welfare:

$$\max_{\Delta e_v} \left\{ V_v.P_v \left[\Delta T_v + \left(T_v + \Delta T_v - \frac{\alpha.c_t}{P_v} \right) \phi_{v,v}.\frac{\Delta T_v}{1+T_v} \right] + V_t.P_t \left(T_t - \frac{c_t}{P_t} \right) \phi_{t,v}.\frac{\Delta T_v}{1+T_v} \right\} \tag{1}$$

One can optimise the required change of vape excise by considering the vape and tobacco categories together or by regarding the former as separate from smoking, i.e. taking $V_t = 0$. And one can set $c_t = 0$ to discard externalities and obtain the excise rate which solely maximises fiscal revenues. The solutions to the four different possibilities are summarised in Table 1.

Table 1: **Four different optimal excise duties for vaping derived from Eq. 1**

	Maximize Fiscal Revenues ($c_t = 0$)	Maximize Social Welfare ($c_t \neq 0$)
Vape only ($V_t = 0$)	$\Delta e_v^{MaxVapeF} = \frac{1}{2}\left(\frac{1}{(1+\tau)} - (1+e_v).\left[\frac{1}{\phi_{v,v}} + 1 \right] \right)$	$\Delta e_v^{MaxVapeW} = \Delta e_v^{MaxVapeF} + \underbrace{\frac{1}{2}\frac{\alpha.c_t}{(1+\tau).P_v}}_{\Delta e_v^{VapeExtAdj}}$
Vape & Tobacco ($V_t \neq 0$)	$\Delta e_v^{MaxF} = \Delta e_v^{MaxVapeF} + \underbrace{-\frac{1}{2}(1+e_v).\frac{\phi_{t,v}}{\phi_{v,v}}.\frac{S_t}{S_v}.\left(1 - \frac{1}{(1+\tau).(1+e_t)} \right)}_{\Delta e_v^{TobFisAdj}}$	$\Delta e_v^{MaxW} = \Delta e_v^{MaxVapeF} + \Delta e_v^{VapeExtAdj} + \Delta e_v^{TobFisAdj} + \underbrace{\frac{1}{2}(1+e_v).\frac{\phi_{t,v}}{\phi_{v,v}}.\frac{S_t}{S_v}.\frac{c_t}{(1+\tau).(1+e_t).P_t}}_{\Delta e_v^{TobExtAdj}}$

The table shows that the four optimal excise rates can be expressed as the sum of the excise rate that maximises the fiscal revenues (Ramsey tax) from solely the vape category ($\Delta e_v^{MaxVapeF}$) and one or more of three adjustment terms that express the compensating tobacco excise revenue (Ramsey correction) and the Pigouvian corrections for the cost of vape externalities and the prevented costs of tobacco externalities. In case of a zero VAT or sales tax and no existing excise duty on vape (i.e. $\tau = e_v = 0$) the excise duty that optimises fiscal revenues from vape products is inversely proportional to the price elasticity of vape demand. This is consistent with Ramsey's finding on efficient taxation of goods. One can see that $\Delta e_v^{MaxVapeW} \geq \Delta e_v^{MaxVapeF}$ because the costs of vape-related externalities justify a higher excise duty. Similarly, a higher vape tax excise rate is also justified because users that switch from vape products back to tobacco will generate tobacco excise revenues. Hence $\Delta e_v^{MaxF} \geq \Delta e_v^{MaxVapeF}$ (note that $\Delta e_v^{TobFisAdj} \geq 0$ due to the negative own price elasticity of vape). Finally, $\Delta e_v^{MaxW} \leq \Delta e_v^{MaxVapeW}$ and $\Delta e_v^{MaxW} \leq \Delta e_v^{MaxF}$ because the costs of tobacco related externalities become smaller when more smokers switch to vaping, thereby justifying a lower vape excise duty.

When the unit costs of tobacco externalities are equal to the unit tax revenue of tobacco (i.e. $c_t = P_t(\tau + e_t + \tau.e_t)$) the tobacco tax and health adjustment terms in Table 1 cancel each other out and there is no net effect on the optimal excise rate for vape. When tobacco tax revenues are higher than the tobacco health cost, consideration of the tobacco category increases the optimal excise tax on vape, essentially to help prevent people switching from tobacco to vape. The opposite is true of course when tobacco taxes are less than the tobacco externalities. When tobacco sales have vanished completely the tobacco adjustment terms equal zero.

Equivalent consumption of vape and tobacco

As was mentioned already, the framework assumes that a vape consumption unit can be defined which is equivalent to a single cigarette. Because the addictive substance is nicotine one preferably looks at the amount of vape liquid which, when consumed, delivers the same amount of nicotine as the average cigarette. Such equivalence is difficult to establish unequivocally. Nicotine content of vapour depends on the nicotine content of the vape liquid and on the delivery device used, with technology still improving. In addition, absorption of nicotine in the vaper's bloodstream depends on many circumstances including the actual consumption patterns, as shown by Farsalinos et al. (2015). An alternative to product nicotine equivalency is to assume that an average smoker becomes an average vaper. The rationale here is that a user who substitutes one for the other will unconsciously consume the quantity which is sufficient to satisfy their daily craving. Based on observed cigarette and vape liquid consumption it seems that 1 cigarette equals about 0.2 ml of vape liquid. We will use this value in this paper.

Assumptions

The framework relies on a number of assumptions. First, in this paper we do not include the deadweight welfare loss (i.e. loss of economic efficiency) of imposing excise taxes. The deadweight loss is 0 for completely inelastic demand and increases when demand becomes more elastic. Deadweight loss can be included but renders the expressions in Table 1 more complex (the factor $\frac{1}{2}$ in the expressions must be replaced by a factor $\frac{1}{2+f(\phi_{v,v})}$, where $f(\phi_{v,v})$ depends on the price elasticity only). One can show that non-inclusion of deadweight loss causes a maximum overestimation of the optimal excise rates by a factor $\frac{1}{2}(1-\ln(2)) \approx 0.15$. For the price elasticity in this paper (-1.2, see next section) the overestimation is a factor of 0.14. Second, we assume constant price and cross-price elasticities of vape and tobacco demand with respect to vape prices. Although this assumption could be relaxed and price and income dependencies could be considered, little information is available on the demand curve for vape products and any information can be expected to change as the rate of product innovation is still high. Moreover, a more complex elasticity formulation will likely prohibit closed-form expressions. A third assumption is that the framework is a partial equilibrium approach which only captures the demand side for two products and not the supply side. It has been shown Hamilton (2008) that changing excise rates on different products are likely to affect firm behaviour, something which is not considered here. The fourth assumption is that vape and tobacco externalities are expressed on a unit product basis whereas it is well known that they depend on actual usage patterns. For example, doubling consumption may more than double the cost of externalities. Finally, we assume tobacco excise rates to be exogenous in order to have one variable (Δe_v) to optimise. The optimal excise rates derived in this way are thus local optima and it is possible that a different mix of tobacco and vape excise rates may achieve higher fiscal or welfare outcomes.

Data and parameter specification

VAT or sales tax rates and data on vape and tobacco pricing are available for all EU countries and for individual states in the USA. It is convenient to write the ratio of tobacco and vape sales in the expressions in Table 1 in terms of a single variable, the market share of vape γ

$$\frac{S_t}{S_v} = \frac{1}{\gamma} - 1 \tag{2}$$

When using the vape market share as a variable, the four excise rate expressions depend on one or more of four remaining parameters: the price elasticity of vape demand ($\phi_{v,v}$); the cross price elasticity of tobacco demand with respect to the price of vape ($\phi_{t,v}$); the unit costs of tobacco externalities (c_t); and the relative harmfulness of vaping (α). Each of these is discussed in more detail below. Because of the estimations involved; uncertainty in the data; and because we just aim for some reasonable parameter values to illustrate the framework, the quantification of the parameters is high-level rather than detailed.

Price elasticity of vape demand

Most studies indicate that demand for vape products is more price elastic than tobacco, which is typically in between -0.4 and -0.8 (Chaloupka & Warner, 2000). A range between -1.2 and -1.9 has been reported by Huang et al. (2014) whereas Stoklosa et al. (2016) found a range from -0.82 to -1.15. We use a value of -1.2 in the remainder of this paper, meaning that demand for vape decreases by 12% when prices increase by 10%. This value is roughly double the demand elasticity observed for tobacco.

Cross-Price elasticity of tobacco demand

Not much evidence exist on the cross elasticity of tobacco demand with respect to vape prices. Using a simulated rather than revealed demand experiment in New Zealand, Grace et al. (2015) find a cross elasticity of e-cigarette demand with respect to tobacco price of 0.16. One can argue that the price elasticity of tobacco demand with respect to vape prices, i.e. switching in the other direction, is likely be lower due to health and other considerations playing a role. Marti et al. (2016) collected stated demand preference data for three groups: smokers, vapers and dual users. From this data we infer a cross elasticity of tobacco demand for all three categories together of 0.05 (ranging from 0 for smokers to 0.16 for dual users), which we use in this paper.

Cost of tobacco externalities

A considerable body of literature exists on the costs of externalities of tobacco. The unit cost of tobacco externalities consists of several components: direct externalities experienced by other individuals; collectively borne cost, like publicly funded healthcare; and revenue externalities, e.g. absence and sickness-related productivity loss. Although considered controversial accounting, these negative externalities are partially offset by savings in public health and pension costs due to premature mortality. Based on estimates of the various externalities Vicusi (1995) concludes that on balance "overall cigarette taxes exceed the associated externalities." Some have even argued that smoking lowers public spending because many smokers do not live long enough to incur the health and pension expenditures that come with old age. But this conclusion is not undisputed (Rasmussen et al., 2005). One may also consider the loss of so-called quality adjusted life years (QALY) resulting from premature death. Strictly spoken this is not an externality but rather a so-called internality because the costs are borne by the individual. When individuals are sufficiently aware of this and thus rationally consider it in their decision making, this internality cannot serve as a purely economic justification for tobacco taxes, although there can of course be other reasons. In this respect, Gruber & Koszegi (2008) point to the time inconsistency of smokers: many would prefer to stop smoking tomorrow but also want a cigarette now and forget about future health effects. Such individuals need commitment devices to overcome lack of self control. But the private market cannot provide such devices since it lacks the power of compulsion of the government with its ability to tax and make tobacco consumption more costly to oneself.

Because we are interested in the application of the taxation framework to individual EU countries and USA states, we quantify the tobacco externalities based largely on information from DG SANCO in the EU (Jarvis et al. , 2012) and the Center for Disease Control (CDC) in the USA (see Table 2). These sources state healthcare expenditures of €25.7 billion in the EU and $133.4 billion in the USA, which comprise 2.9% and 4.2% of total health spending respectively. This is somewhat below the 5.7% share of smoking attributable diseases of total worldwide health expenditures (in PPP terms) found in Goodchild et al. (2017). The DG SANCO estimates are probably on the low side. For example, healthcare expenses of €7.5 billion in Germany in 2003 are reported by Neubauer et al. (2006), which is about double of DG SANCO's 2012 estimate for Germany of €4.8 billion when taking into account annual inflation of 3% inflation.

Productivity losses are caused by smoking-related absenteeism and incapacity. The €7.3 billion reported by Jarvis et al. (2012) seems low compared to other studies. For example, Neubauer et al. (2006) estimated smoking-attributable absenteeism and early retirement costs at €8.8 billion

Table 2: **Quantification of smoking externalities (data is available for each EU country and USA state)**

	Smoking-attributable health care expenses	Smoking-attributable productivity losses	Smoking-attributable premature mortality losses
EU27 (2012)	€ 25.7 billion	€ 7.3 billion	€ 516.7 billion
USA (2016)	$ 133.4 billion	$ 30.0 billion	$ 318.0 billion

in Germany, which is almost 8 times the DG SANCO estimate of € 1.1 billion. Estimates in the USA vary considerably: Stewart et al. (2003) found smokers to have 75% higher loss of productive time than non-smokers, equivalent to about $1,200 per year; Bunn et al. (2006) report a difference in productivity between smokers and non-smokers of $1,807; and the best estimate of productivity loss by Berman et al. (2014) is $4,056 (with a lowest estimate of $2,282). Using the average 16.7% incidence of smoking among USA adults and a workforce of 150 million this translates into a range of $30 - $100 billion. Even before discounting for inflation since time of publication, these numbers seem high compared to the $3.8 million per 10,000 workers (i.e. $57 billion for all employees in the USA) in total health and productivity related work loss found by Mitchell & Bates (2011). We will therefore adopt the lower value ($30 billion) in the remainder of this paper.

The monetised value of premature mortality is considered the largest burden of smoking. According to the DG SANCO report (Jarvis et al. , 2012), 695,000 deaths (i.e. 15% of all deaths in the EU) in 2009 were attributable to smoking, which was equivalent to a QALY loss of 9.9 million years. Using a value of one QALY of €52,000, the report values smoking-attributable premature mortality at €517 billion, an order of magnitude larger than the health care expenditures and productivity loss estimates. The CDC reports that in 2016 there were 441,680 smoking-attributable premature deaths in the US. Using the same number of QALYs per premature death this means a loss of 6.3 million years. Adopting a value of one QALY as the customary (but arbitrary) $50,000, this means a cost of premature death of $318 billion. We note however that much higher values of up to $200,000 seem justified as well (Neumann et al., 2014).

Finally, the values in Table 2 must be translated into a cost per cigarette. Although for productivity losses using the current cigarette consumption is justified, this is not so for the health care costs and premature mortality because they depend on historic consumption, which was about 2-3 times higher than current consumption. For example, the gap between peak cigarette consumption (1960) and peak lung cancer mortality (1990) is 30 years. On the other hand, cigarettes have become deadlier over the last decades because of additives and filter systems (US Dept. Health and Human Services, 2014). For reasons of simplicity we therefore assume the cigarette consumption used for normalising the health care and premature mortality costs as double the 2016 consumption, which amounted to 581 billion cigarettes in the EU and 254 billion in the US. However, for the smoking-attributable health care expenses in the EU we have omitted this correction because the data provided in the DG SANCO report seem very low, as mentioned before. The resulting costs per cigarette are provided in Table 3.

In dollar terms, the values for smoking-attributable healthcare spend-

Table 3: **Quantification of smoking externalities per cigarette (data is available for each EU country and USA state)**

	Smoking-attributable health care expenses	Smoking-attributable productivity losses	Smoking-attributable premature mortality losses
EU27 (2012)	€ 0.044	€ 0.013	€ 0.445
USA (2016)	$ 0.263	$ 0.118	$ 0.626

ing between the EU and the USA differ by a factor 4.5. When considering the 1.5x difference between per capita GDP and the 1.7x factor in healthcare spending as percentage of GDP, the difference reduces to 1.8x which is not unreasonable given the different methodologies and measurements used. Even when corrected GDP per capita, the productivity loss in the USA is about 5.0x times higher than in the EU. As stated before, the EU-level data reported by Jarvis et al. (2012) are probably a considerable underestimation. Apart from the substantial uncertainty of the data used, we re-emphasise the tentative nature of our estimates of the societal cost of tobacco. But for the purpose to illustrate the framework we think it is adequate.

Relative harmfulness of vape

Few studies have been done on the harmfulness of vaping. In addition to the nicotine-related health risks of vaping, experts point to inhaling cancer-causing chemicals like formaldehyde or toxic metals like nickel. Because of the many uncertainties and for reasons of simplicity we here adopt the finding of Public Health England (McNeill et al., 2015) that vaping is 95% safer than smoking. In terms of the framework this means that the residual risk or relative harmfulness of vape (α) is 0.05. This residual risk does not account for the possibility that e-cigarettes could be a gateway product for (youth) smoking (Watkins, 2018), although there is no consensus in the academic literature on this (Kozlowski & Warner, 2017).

Results and discussion

Optimal excise rates for a vape market share of 10%

Using the parameter values as discussed in the previous section and assuming a vape market share of 10% (which is higher than current market shares in all EU and USA markets), Table 4 quantifies all the excise rate expressions presented in Table 1. In addition to the weighted average EU and USA values we provide the minimum and maximum rates for individual EU countries or USA states. The quantification of tobacco externalities at the individual country or state level, however, is subject to more uncertainty than at the EU and USA level. The weighted average pre-tax price of one cigarette used in the calculation is €0.041 (€0.192 market price) in the EU and $0.192 ($0.345 market price) in the USA. The pre-tax prices of the equivalent vape consumptions are €0.042 and $0.059 respectively.

The expressions that depend solely on the sales and excise taxes ($\Delta e_v^{MaxVapeF}$ and Δe_v^{MaxF}) exhibit fairly little variation within the EU and the USA because tax rates are comparable. For example, all EU countries have VAT rates in between 18% (Malta) and 27% (Hungary) and the sales tax rates in the USA (including local taxes) vary from 0% (e.g. New Hampshire) to 10% (Louisiana). Because VAT rates in EU countries are higher than sales

Table 4: **Quantification of the excise expressions in Table 1 assuming a vape market share γ of 10%. Excise rates are given as a percentage of the before tax prices of vape liquid**

Excise tax component	**Calculation**	**EU27**			**USA**		
		Avg	**Min**	**Max**	**Avg**	**Min**	**Max**
$\Delta e_v^{MaxVapeF}$	I	**33%**	**31%**	**34%**	**39%**	**37%**	**42%**
$\Delta e_v^{VapeExtAdj}$	i	25%	5%	79%	40%	29%	65%
$\Delta e_v^{TobFisAdj}$	ii	15%	14%	17%	9%	6%	12%
$\Delta e_v^{TobExtAdj}$	iii	-52%	-103%	-16%	-58%	-132%	-30%
$\Delta e_v^{MaxVapeW}$	I+i	**58%**	**34%**	**113%**	**78%**	**67%**	**103%**
Δe_v^{MaxF}	I+ii	**48%**	**46%**	**50%**	47%	**44%**	**50%**
Δe_v^{MaxW}	I+i+ii+iii	**21%**	**-19%**	**93%**	**29%**	**-18%**	**72%**

Note: Average value is weighted with market size. Calculations indicated are valid for the average (except for small rounding errors) but not necessarily for the minimum and maximum values because the latter reflect different countries/states.

tax rates in the USA, the vape excise duty which maximises fiscal revenues ($\Delta e_v^{MaxVapeF}$) is lower in the EU. But the higher tobacco excise rates in the EU cause the tobacco tax adjustment term to be higher as well. The net result is that the vape excise rate which maximises fiscal revenues (Δe_v^{MaxF}) is virtually identical in the EU and USA. Because tobacco externalities in Table 4 are larger, the vape health adjustment terms (which are 5% of the tobacco externalities) are higher in the USA. Similarly the tobacco health adjustment is more negative in the USA as well. The welfare maximising excise rate on vape (Δe_v^{MaxW}) however is very similar in the EU and the USA. The EU value of 21% of the pre-tax price of vape liquid is equivalent to 14% of the market price, a value that can be compared to the EU minimum tobacco excise rate of 60%.

The size of the tobacco externalities adjustment term in Table 4 highlights the importance of whether only externalities are taken into account or internalities as well. Non-inclusion of the costs of premature mortality, which are born by the smoker and not by society, causes $\Delta e_v^{TobExtAdj}$ to decrease from -52% to -6% in the EU and from -58% to -22% in the USA. This increase is partially offset because the externality cost of vape would decrease as well but the social welfare maximising excise rate on vape increases from 21% to 45% in the EU and from 29% to 41% in the USA.

Market share dependence of welfare maximising excise rate

The social welfare maximising excise rate is strongly dependent on the market share of vape, as is shown in Figure 1. For smaller vape market shares the tobacco related tax and externality adjustments increase rapidly in magnitude. Of these two the externalities adjustment is the larger one which explains the rapid drop (to even negative values, i.e. Pigouvian subsidies) of the optimal excise rate for small vape market shares. When all tobacco sales have ceased and vaping has captured the entire market the welfare maximising vape excise ($\Delta e_v^{MaxVapeW}$) in the EU is 58% (see Table 4) which is equivalent to 30% of the market price, half of the 60% EU minimum for tobacco, due to the higher demand elasticity (i.e lower Ramsey taxation) and lower cost of externalities (i.e. smaller Pigouvian correction). Similarly, in the USA the welfare maximising excise will go up to 78%.

Figure 1: **Social welfare maximising excise rate on vape liquid (percentage of pre-tax price) as a function of vape market share. EU and USA lines are based on their respective average VAT, sales tax and tobacco excise duties.**

Effect of parameter uncertainty on the welfare optimising excise rate

For small market shares the welfare optimising excise depends strongly on the net effect on the two large but opposite tobacco effects. This implies that the overall tobacco effect on the optimal vape excise rate is very sensitive to the parameter values used. However, as already mentioned, there is considerable uncertainty about their quantification. To analyse the effect of parameter uncertainty we have conducted a Monte Carlo simulation using 25,000 random combinations of parameter values for the own and cross price elasticity; the costs of tobacco externalities; and the relative harm factor of vape. The parameters are drawn from uniform distributions around the parameter values used for the EU calculations. The minimum and maximum values are taken as respectively half and one-and-a-half times the above-used parameter values (hence the averages are equal to the above-used used parameter values). The cumulative distribution functions (CDFs) of the social welfare maximising excise rates are shown in Figure 2. for different market shares of vape.

Figure 2: **Cumulative distribution functions of social welfare maximising excise rate on vape in the EU derived from Monte Carlo simulations for different values of market share** γ

Consistent with Figure 1, the CDFs move toward higher excise rates for increasing vape market shares. For vape market shares lower than 6%, at least 50% of the probability mass is for negative excise rates (i.e. Pigouvian subsidies). This means that a policy to impose vape excise rates for market shares below 6% has at least a 50% chance of being wrong. On the other hand, above market shares of 12% there is a 95% certainty that imposition of excise rates is the right policy. Although pre-tax prices, tax rates and the cost of smoking externalities are all different in the USA, the same analysis yields very similar thresholds. Because we did not include deadweight welfare loss, these market share thresholds indicated should possibly be somewhat higher. We also caution against drawing country or state specific conclusions from this: the variation between states in the USA and, especially, between countries in the EU is very substantial, both with respect to the costs of externalities used in the Monte Carlo simulations but also cigarette and vape equivalent prices.

Summary and conclusions

Electronic cigarettes (vape) and tobacco cigarettes are imperfect substitutes. By assuming tobacco excise rates as exogenous, four closed-form expressions have been derived for the tax revenue or social welfare maximising ad-valorem excise rates on vape under partial equilibrium conditions. Using parameter specifications based largely on DG SANCO and CDC dataas well as selected other sources, application of these expressions to the EU and the USA shows that the vape excise rates that maximise fiscal revenues or social welfare are substantially lower than current tobacco excises, due to higher demand price elasticity and lower costs of externalities. Although intra EU and USA variation is substantial, parameter uncertainty makes excise rates defensible above vape market shares of 12% while for market shares below 6% there is a more than 50% chance that excise imposition decreases social welfare. Little research has been done regarding the cross price elasticities of demand between vape and tobacco. Given the sensitivity of our results to this elasticity we encourage additional experiments in this area. Finally we recommend further research to be undertaken on how the vape externalities depend on the nicotine content (or of other ingredients) of vape liquid. A better understanding of that would allow the framework to be useful for quantifying specific rather than ad-valorem excises. The framework can also be applied to other sets substitute goods with different externality costs such as sugary and sugarfree drinks.

References

Baumol, W. (1972). On taxation and the control of externalities. *Am. Econ. Rev., 62*, 307–322.

Berman, M., Crane, R., Seiber, E., & Munur, M. (2014) Estimating the cost of a smoking employee. *Tob. Control, 23*, 428–43.

Bunn, W.B., Stave, G.M., Downs, K.E., Alvir, J.M., & Dirani, R. (2006). Effect of smoking status on productivity loss. *J. Occup. Environ. Med., 48*, 1099–1108.

Chaloupka, F.J., & Warner K.E. (2000). The economics of smoking. In

Handbook of health economics, A.J. Culver & J.P. Newhouse (eds.), 1539–1627.

Farsalinos, K.E. et al. (2015). Nicotine absorption from electronic cigarette use: comparison between experienced consumers (vapers) and nave users (smokers). *Sci. Rep. 5*, doi:10.1038/srep11269.

Goodchild, M., Nargis, N., & d'Espaignet, E.T. (2017), Global economic cost of smoking- attributable diseases. Tob. Control, doi:10.1136/tobaccocontrol-2016-053305.

Grace, R.C., Kivell, B.M., & Laugesen, M. (2015). Estimating cross-price elasticity of e-cigarettes using a simulated demand procedure. *Nic. Tob. Res., 17*, 592–598.

Gruber, J,. & Koszegi, B. (2008). A modern economic view of tobacco taxation. *International Union Against Tuberculosis and Lung Disease*, p.25.

Hamilton, S.F. (2008). Excise taxes with multiproduct transactions. *Am. Econ. Rev., 99*, 458–471.

Huang, J., Tauras, J., & Chaloupka, F.J. (2014). The impact of price and tobacco control policies on the demand for electronic nicotine delivery systems. *Tob. Control, 23*, iii41–iii47.

Jarvis, A., Vincze, M.P., Falconer, B., Garde, A., Geber, F., & Daynard, R. (2012) A study on liability and the health costs of smoking (Updated final report 2012). *DG SANCO 2008/C6/046*, p.134.

Kozlowski, L.T., & Warner, K.E. (2017). Adolescents and e-cigarettes: Objects of concern may appear larger than they are. *Drug and Alcohol Dependence*, doi.org/10.1016/j.drugalcdep.2017.01.001

Marti, J., Bucknell, J., Maclean, C., & Sindelar J.L. (2016). To 'vape' or smoke? A discrete choice experiment among U.S. adult smokers. *NBER Working Paper 22079*, p.34. www.nber.org/papers/w22079.pdf.

McNeill, A., Brose, L.S., Calder, R., & Hitchman, S.C. (2015) E-cigarettes: an evidence update. *Public Health England, PHE Pub. Gateway Nr. 2015260*, p.113.

Mitchell, R.J., & Bates, P. (2011). Measuring health-related productivity loss. *Pop. Health Mgt., 14*, 93–98.

Neubauer, S., Welte, R., Beiche, A., Koenig, H.H., Buesch, K., & Leidl, R. (2006). Mortality, morbidity and costs attributable to smoking in Germany: update and a 10-year comparison. *Tob. Control, 15*, 464–471.

Neuman, P.J., Cohen, J.T., & Weinstein, M.C. (2014). Updating cost-effectiveness - The curious resilience of the $50,000-per-QALY threshold. *New Engl. J. Med, 371*, 796-797.

Ramsey F.P. (1927). A Contribution to the theory of taxation. *Econ J., 37*, 47–61.

Rasmussen, S.R., Prescott E., Sorensen, T.I.A., & Sogaard, J. (2005). The total lifetime health cost savings of smoking cessation to society. *Eur. J. Publ. Health, 15*, 601–606.

Sandmo A. (1975). Optimal taxation in the presence of externalities. *Swed J. Econ., 77*: 86–98.

Stewart, F., Ricci, J., Chee, E., & Morganstein, D. (2003). Lost productive work time ocsts from health conditions in the United States: Results from the american productivity audit. *J. Occup. Environ. Med., 45*, 1234–1246.

Stoklosa, M., Drope, J., & Chaloupka, F.J. (2016). Prices and e-cigarette demand: Evidence from the European Union. *Nic. Tob. Res. 18*, 1973–1980.

U.S. Department of Health and Human Services. (2014). The Health Consequences of Smoking: 50 Years of Progress *A Report of the Surgeon General*, p.943.

Viscusi, W.K. (1995). Cigarette taxation and the social consequences of smoking. *NBER Tax Policy and the Economy, 9*, 51–101.

Watkins, S.L., Glantz, S.A., & Chaffee, B.W. (2018) Association of Noncigarette Tobacco Product Use With Future Cigarette Smoking Among Youth in the Population Assessment of Tobacco and Health (PATH) Study, 2013-2015. *JAMA Pediatrics, 172*, 181-187. doi:10.1001/jamapediatrics.2017.4173.

Appendix: Mathematical Framework

Table 5: **Mathematical framework specifying all parameters and variables**

	Vaping	**Tobacco**
Volume (units)	V_v	V_t
Pre-tax unit price	P_v	P_t
Excise rate	e_v	e_t
VAT or sales tax rate	τ	τ
Effective tax rate	$T_v = (1 + e_v).(1 + \tau) - 1$ $= e_v + \tau + e_v.\tau$	$T_t = (1 + e_t).(1 + \tau) - 1$ $= e_t + \tau + e_t.\tau$
Unit market price	$P_v^m = P_v(1 + T_v)$	$P_t^m = P_t(1 + T_t)$
Market sales	$S_v = V_v.P_v^m = V_v.P_v(1 + T_v)$	$S_t = V_t.P_t^m = V_t.P_t(1 + T_t)$
Tax income	$F_v = V_v.P_v.T_v$	$F_t = V_t.P_t.T_t$
Unit externality costs	$c_v = \alpha.c_t$	c_t
Costs of externalities	$C_v = V_v.c_v = V_v.\alpha.c_t$	$C_t = V_t.c_t$
Own-price elasticity	$\phi_{v,v} = \frac{dV_v}{dP_v^m}.\frac{P_v^m}{V_v} = \frac{dV_v}{dT_v}.\frac{1+T_v}{V_v}$	$\phi_{t,t} = \frac{dV_t}{dP_t^m}.\frac{P_t^m}{V_t}\frac{dV_t}{dT_t} = \frac{dV_t}{dT_t}.\frac{1+T_t}{V_t}$
Cross-price elasticity	$\phi_{v,t} = \frac{dV_v}{dP_t^m}.\frac{P_t^m}{V_v} = \frac{dV_v}{dT_t}.\frac{1+T_t}{V_v}$	$\phi_{t,v} = \frac{dV_t}{dP_v^m}.\frac{P_v^m}{V_t} = \frac{dV_t}{dT_v}.\frac{1+T_v}{V_t}$
Volume change	$\Delta V_v = \phi_{v,v}.\frac{dP_v^m}{P_v^m}.V_v + \phi_{v,t}.\frac{dP_t^m}{P_t^m}.V_v$ $= V_v(\phi_{v,v}.\frac{\Delta T_v}{1+T_v} + \phi_{v,t}.\frac{\Delta T_t}{1+T_t})$	$\Delta V_t = \phi_{t,t}.\frac{dP_t^m}{P_t^m}.V_t + \phi_{t,v}.\frac{dP_v^m}{P_v^m}.V_t$ $= V_t(\phi_{t,t}.\frac{\Delta T_t}{1+T_t} + \phi_{t,v}.\frac{\Delta T_v}{1+T_v})$
Fiscal revenues change	$\Delta F_v = V_v.P_v.\Delta T_v + \Delta V_v.P_v.T_v +$ $\Delta V_v.P_v.\Delta T_v$ $= V_v.P_v(\Delta T_v + [\phi_{v,v}.\frac{\Delta T_v}{1+T_v} +$ $\phi_{v,t}.\frac{\Delta T_t}{1+T_t}].[T_v + \Delta T_v])$	$\Delta F_t = V_t.P_t.\Delta T_t + \Delta V_t.P_t.T_t +$ $\Delta V_t.P_t.\Delta T_t$ $= V_t.P_t(\Delta T_t + [\phi_{t,t}.\frac{\Delta T_t}{1+T_t} +$ $\phi_{t,v}.\frac{\Delta T_v}{1+E_v}].[T_t + \Delta T_t])$
Externalities cost change	$\Delta C_v = \Delta V_v.\alpha.c_t$ $= V_v.\alpha.c_t(\phi_{v,v}.\frac{\Delta T_v}{1+E_v} + \phi_{v,t}.\frac{\Delta T_t}{1+E_t})$	$\Delta C_t = \Delta V_t.c_t$ $= V_t.c_t(\phi_{t,t}.\frac{\Delta T_t}{1+T_t} + \phi_{t,v}.\frac{\Delta T_v}{1+T_v})$
Welfare change	$\Delta W_v = \Delta F_v - \Delta C_v$ $= V_v.P_v(\Delta T_v + (T_v + \Delta T_v -$ $\frac{\alpha.c_t}{P_v}).[\phi_{v,v}.\frac{\Delta T_v}{1+T_v} + \phi_{v,t}.\frac{\Delta T_t}{1+T_t}])$	$\Delta W_t = \Delta F_t - \Delta C_t$ $= V_t.P_t(\Delta T_t + [T_t + \Delta T_t -$ $\frac{c_t}{P_t}].[\phi_{t,t}.\frac{\Delta T_t}{1+T_t} + \phi_{t,v}.\frac{\Delta T_v}{1+T_v}])$

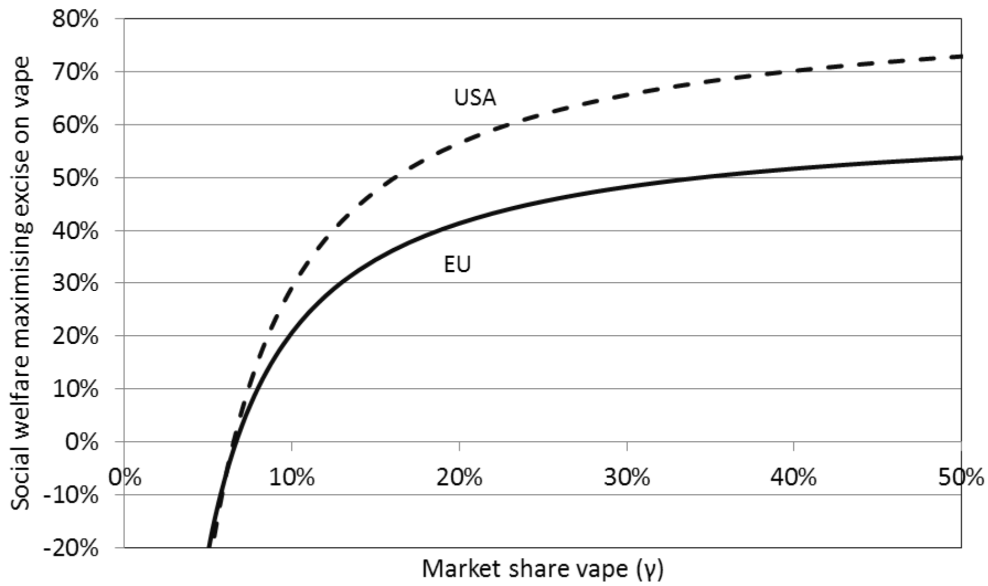
80%
70%
60%
50%
40%
30%
20%
10%
0%
-10%
-20%
Social welfare maximising excise on vape
USA
EU
0%
10%
20%
30%
40%
50%
Market share vape (γ)

Fig. 1

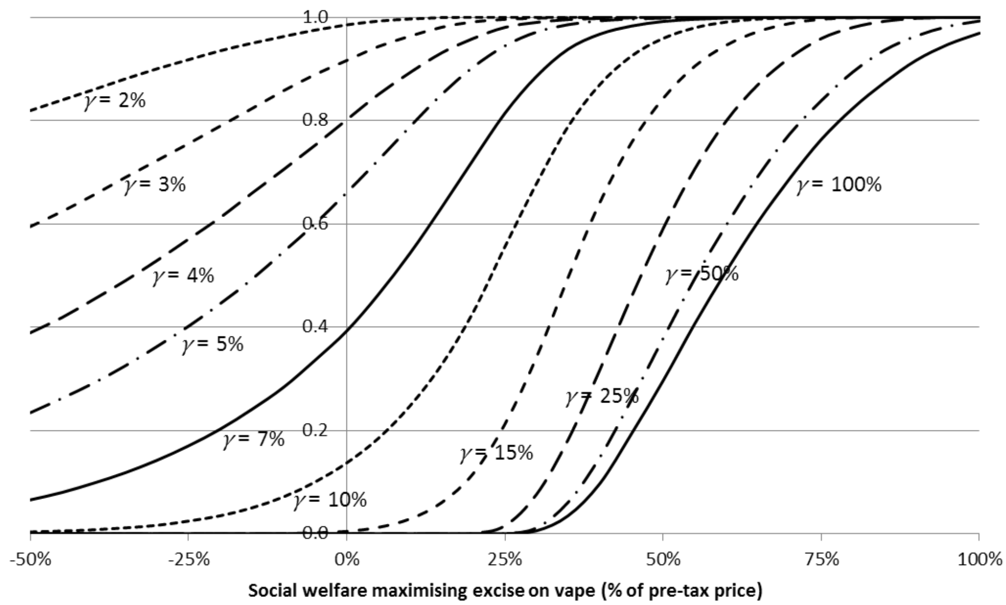
1.0
0.8
0.6
0.4
0.2
0.0
γ = 2%
γ = 3%
γ = 4%
γ = 5%
γ = 7%
γ = 10%
γ = 15%
γ = 25%
γ = 50%
γ = 100%
-50%
-25%
0%
25%
50%
75%
100%
Social welfare maximising excise on vape (% of pre-tax price)

Fig. 2