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Abstract

We develop a theoretical model to study the effects of an ad valorem taxation regime differentiated according to product characteristics (quality) within an imperfectly competitive market. Then to test our theoretical prediction we use yearly data from the Irish automobile market during the period 2004-2008, and assess the implications of this type of regime on competition and consumer welfare. By emphasizing the role played by the own- versus the cross-price elasticity, we are able to capture an important dimension in which the strategic interactions among firms play out in response to a tax change. The welfare effects of a taxation system that is tailored to product attributes are not trivial. Using a counterfactual analysis based on a homogenous tax rate, we conclude that a differentiated taxation regime benefits consumers who value quality more, while it penalizes those more sensitive to price increments. Our results confirm the extended Ramsey rule predictions. Furthermore, a symmetric increase in taxation narrows the price gap induced by asymmetries in quality and productivity, if the tax regime is homogenous, and widens it, if the tax regime is differentiated.

Keywords: Ad valorem taxation, cross-tax elasticity, differentiated and homogeneous taxation, differentiated products, imperfect price competition, welfare analysis.
JEL classification: *H22, L11, L13, L62.*

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1 Introduction

In recent years, policy makers in developed countries have adopted new taxation systems in the attempt to curb consumers behaviour away from a harmful lifestyle. Both the increase in the tax rate for unhealthy products, and a more general overhaul in the taxation regime have now become standard tools in the implementation of economic policies that aim to influence consumer behaviour.[1] Nevertheless, the extent to which consumers and firms bear the burden or the gain of the tax change, and more specifically the implications for both consumers' and producers' rent, remains unclear, calling for further investigation into the actual efficacy and relative merits of this type of policy intervention.

In this paper, we first develop a theoretical model to disentangle the effects on competition and welfare of the adoption of an ad valorem tax that varies according to product characteristics (i.e. quality) in an imperfectly competitive market. Then, as example of a market where taxation varies by product attributes, we use product-level yearly data on the Irish automobile market between 2004-2008 to validate our theory and quantify the effects generated by such a type of taxation.

While the welfare effect of taxation in competitive and monopolistic markets is well understood (for a review see Anderson, De Palma & Kreider (2001)), its effect in oligopolistic markets poses a challenge to the traditional way of thinking. This is because in an oligopolistic market the impact of taxation on welfare is no longer determined only by the relative slopes of demand and supply, as it is in a competitive market, or by the industry demand and marginal costs, as in the monopolistic case. Instead, the impact is dependent on a non-linear combination of cost and demand primitives, with a crucial role played by the number of active firms, and the degree of asymmetry in their market shares.[2] In a framework where products are differentiated, which is the context of our analysis, the strategic interaction between firms yields a change in welfare that strictly depends on asymmetries in production efficiency and product quality. While a lot of attention has been devoted to the welfare analysis of ad valorem and specific tax in competitive market (with both homogeneous and differentiated products), little attention has been given to the use of differentiated ad valorem taxation regimes in imperfectly competitive markets (see Weyl & Fabinger (2013) and Häckner & Herzing (2016)). The analysis presented in this paper aims to fill this gap, contributing to the longstanding debate on the interaction between indirect taxation and imperfect market structure, and in particular to a growing body of investigation focused on the distributional impact of taxes designed to promote a more desiderable consumer behaviour (see Bonnet & Réquillart (2013) and Muller, Lacroix, Lusk & Ruffieux (2017)).

Currently, policy makers focus on the use of taxation to protect vulnerable consumers against

[1] With its soda tax in 2016, Philadelphia became the first large city in the US to pass a tax on sugary drinks (see https://www.nytimes.com/2016/06/17/upshot/soda-tax-passes-in-philadelphia-advocates-ask-whos-next.html, last access 27/05/2018). A similar type of differentiated taxation was introduced in 2017 in the automobile market in the UK, by taxing cars according to their levels of CO2 emissions (see https://www.gov.uk/vehicle-tax-rate-tables, last access 27/05/2018). Furthermore, in Europe, and particularly in the UK there is an ongoing discussion about the possibility of introducing differentiated taxation on products based on the amount of tobacco, alcohol and sugar content (see https://www.gov.uk/government/consultations/minimum-excise-tax, last access 27/05/2018).

[2] Within the newly developed literature on the analysis of taxation in imperfectly competitive markets we recall the theoretical and the empirical contributions by Fershtman et al. (1999), Verboven (1996), Verboven (2002), Delipalla & ODonnell (2001), Damjanovic & Ulph (2010), Jaffe & Weyl (2013), and Weyl & Fabinger (2013).

unhealthy decisions. Looking at the interaction between a tax system adopted to create a negative incentive, and a subsidy scheme used to promote consumption towards healthy decisions, Muller et al. (2017) use experimental data to show that the generated changes in the prices impact differently across poor and non-poor consumers, broadening the potential health disparities between the two income groups. Taking into account pricing strategies of both manufacturers and retailers, in the food industry, Bonnet & Réquillart (2013) analyse the impact of alternative ways to tax high sugar drinks in France. They highlight the crucial role played by firms' strategic interaction on the effectiveness of food public policy interventions, and show that if those are not properly accounted for, the estimates of the impact of taxation are biased, suggesting misleading predictions of demand changes, and wrong assessment of welfare. Focusing on the welfare impact of taxation in the automobile market, Gulati et al. (2017) offer insight on how green subsidies affect purchases of new hybrid electric vehicles and how this impacts on welfare. In their work, product quality is endogenous and consumers are allowed to negotiate the final price with auto dealers. In this scenario, price effects may downplay consumer gains coming from tax subsidies. Hence, assessing the effects of tax reforms only by looking at changes in the equilibrium price will significantly understate consumer gains from the green subsidies. These three papers are related to our analysis since taxation varies by product attributes and because they study the impact of taxation on welfare. However, the work that it is closer in the spirit to our investigation is Fershtman et al. (1999). They study the Israeli car market and evaluate the effect on market competition caused by a change in the taxation regime, namely from an ad valorem differentiated tax regime on cubic capacity towards a differentiated unit tax regime. Our paper expands their work, as we provide theoretical insight, along with a welfare analysis and a comparison between a homogenous and a differentiated tax regime.

Our analysis begins by building a theoretical model, which we use to highlight how, in an oligopolistic market, a change in regime that imposes a higher tax rate for goods of higher quality (i.e. cars having a low CO2 emission rate, or a large size engine) leads to divergent equilibrium prices. Opposite conclusions are reached, instead, when both high and low quality products are taxed at the same rate, with net prices converging to the common unique equilibrium level. We find that, depending on the taxation system in force, the strategic interactions among firms can either soften or exacerbate market competition, with detrimental welfare effects which are typical of Ramsey-type pricing rules, where products characterized by more (less) elastic demands are being charged less (more). In particular, our model is able to capture the strategic response of the firm to changes in the tax rate of its rival; emphasising in this way the importance of both the own- and cross- tax elasticities.

We test our model predictions empirically by evaluating the use of a differentiated ad valorem tax on engine size, which was in place in Ireland for new automobiles within the period of our data. The tax rate was originally set higher for cars with a larger cubic capacity, and subsequently, in the last half year of our data, changed to a scheme based on CO2 emissions. This differentiated taxation system was triggered by environmental reasons and aimed at encouraging the purchase of cars with smaller engines, and more likely having this latter target in mind, policy makers disregarded the effects on competition and welfare.

When taxation varies according to the quality of a product, it inevitably alters the nature of short-run price competition between products, triggering important consequences on consumer and producer surpluses. To test the impact on total welfare, we create a counterfactual analysis by first estimating product demand and cost primitives under the existing differentiated ad valorem taxation regime. Then, making use of these primitives we derive the producer and consumer surpluses that would occur under a homogeneous taxation regime. We compute the changes in equilibrium prices, sales and tax revenues, which allow us to uncover how differentiated taxation interacts with demand and cost primitives within each market segment. Our results indicate that, although the aim of the tax was to shift demand towards less polluting automobiles (i.e. high quality cars), the reallocation of market rents has mitigated the effects of its introduction. Contrary to the desired goal, the differentiated tax regime generated higher net prices for high quality cars and lower prices for lower quality ones, shifting rents towards the latter car segment because of demand expansion. While, during the sample period, the sale volumes by engine size remained broadly unchanged, in the long run, as predicted by Cremer & Thisse (1994), the presence of such tax is expected to influence the nature of investment in quality. Increased tax revenues and profits could be used to develop more carbon efficient automobiles, also for small engine sizes. Hence, small engine cars can avoid carbon taxation and protect the market share via innovation in product quality, rather than by reducing prices.

The paper is organized as follows. Section 2 outlines a theoretical framework to examine homogeneous and heterogeneous ad valorem tax regimes in differentiated products markets. Section 3 offers a description of the Irish automobile market and our empirical data. In Section 4 and Section 5, we outline the empirical structural model, and the results of our estimation and simulation. Finally, we conclude in Section 6.

2 Theoretical Background

In this section we present a theoretical framework which explores the consequences related to a reform of a taxation regime. By comparing a differentiated with a homogeneous *ad valorem* taxation system, we investigate the effects on market competition and welfare in the presence of differentiated products supplied under an imperfect market structure. To provide intuition of the effects yield by the burden of taxation on market outcomes, we begin with the case of a monopolist, producing a single product. Subsequently, we extend our analysis to a case of imperfect competition with single-product firms, each manufacturing their own differentiated product, i.e. we will look at the case of monopolistic competition.

2.1 Single Product Market

In contrast to a perfectly competitive market where, under constant marginal costs, consumers sustain the entire tax burden, a monopolist absorbs part of it, restricting in this way the pass-through to consumers (Hindriks & Myles 2013), to an extent which depends on the demand and cost primitives of the product (RBB 2014).

To illustrate this, we focus on the case when taxation varies according to the quality of the product. Assuming that consumers have preferences over quality à la Mussa & Rosen (1978), we let an ad valorem tax rate $0 < \tau < 1$ be imposed on a monopoly producer supplying a unique quality-type product. Denoting with p the gross price paid by consumers, and with $\widehat{p}$ the net price received by the manufacturer, the indirect utility of a consumer-type υ buying one unit of quality product k is defined as $\upsilon k - p$, with $p = \widehat{p}\,(1+\tau)$, $k > 0$, and $\upsilon \in [\underline{\upsilon}, \overline{\upsilon}]$.[3]

In a market where consumers' taste for quality is uniformly distributed along a line of unitary length, i.e. $\underline{\upsilon} \equiv 0$ and $\overline{\upsilon} \equiv 1$, we define the consumer who is indifferent between buying or not the product as $\widetilde{\upsilon} = p/k$. It follows that the profit of a monopoly firm with a constant marginal cost c is defined as:

$$\pi_M = \int_{\widetilde{\upsilon}}^{1} (\widehat{p} - c)\, d\upsilon = (1 - \widetilde{\upsilon})\,(\widehat{p} - c)\,/k. \tag{1}$$

For a given net price, an increment of the tax rate drives market demand down. The monopolist operates on the inelastic part of the demand curve, then for an optimal net price $\widehat{p}^* = [k + c\,(1+\tau)]\,/2\,(1+\tau)$, we observe that the taxation will be partially absorbed by the firm without passing it entirely onto consumers, both when the quality of the supplied product improves or worsens. This consequence shows how a fall in the firm net price will protect its market shares.

Making use of the proportional price-cost margin (PCM) as a measure of firm market power, defined as the difference between price and marginal cost as a proportion of the price, we observe that a positive change in the tax rate reduces the firm's monopoly power. This result is confirmed also when the quality of the supplied product increases, which in this case magnifies the taxation effect on the net price.[4]

Finally, in a monopolistic market the welfare structure, given by the sum of consumer and producer surpluses, is defined as

$$W_M = \int_{\widetilde{\upsilon}}^{1} (\upsilon k - p)\, d\upsilon + \int_{\widetilde{\upsilon}}^{1} (\widehat{p} - c)\, d\upsilon = \frac{(3+\tau)\,[k - c\,(1+\tau)]^2}{8\,(1+\tau)\,k}. \tag{2}$$

We observe that, for a positive change in the taxation rate, total welfare decreases at an increasing speed, i.e. $\frac{\partial W_M}{\partial \tau} < 0$ and $\frac{\partial^2 W_M}{\partial \tau^2} > 0$. As the tax rate rises, it is true that the monopoly does internalize some parts of the tax burden, however the consumer price goes up and therefore the demand for the product gets smaller at an increasing rate. It follows that the tax pushes some consumers (those on the right-side of the indifferent consumer) out of the quality-market segment, expanding deadweight loss.

To identify the consequences of a tax reform within an imperfectly competitive market, in the next subsection we analyze the effect of a similar type of tax when there are differentiated products offered by competing firms, highlighting the role of cross-tax effects.

[3]When the product is supplied in a monopolistic market, consumers also have the option of not buying the product, obtaining a reservation utility normalized to zero. Instead, when products are supplied under imperfect competition, consumers can choose between different quality products, and the outside option. This latter case is studied in the next section.

[4]The monopolist tends to increase (decrease) its optimal net price when the quality of the supplied product rises (drops), i.e. $\frac{\partial \widehat{p}^*}{\partial k} > 0$. In the next section, we are going to focus on this latter feature, exploring in details the effects of a change in the taxation regime when the market is characterized by the presence of differentiated quality products, supplied by rival firms.

2.2 Differentiated Products Market

For our analysis, we develop a stylized model of spatial monopolistic competition with an outside good as advanced by Salop (1979). In this framework a consumer can either buy the most preferred good, or the closest outside option.[5] Active consumers are positioned uniformly on a circle with a circumference of $1-\mu$, where $0<1-\mu<1$. This identifies the market interval where a consumer always prefers one of the inside market products.

Firms can manufacture products of high and low quality defined by $k \in \{\bar{k}, \underline{k}\}$, and each firm is allowed to be located at one point only of the circle. Along the $1-\mu$ circle line, firms are located symmetrically, thus for each quality k all firms charge the same price. Let J denote the number of firms in the market, then their location is exogenously determined at an equal distance of $(1-\mu)/J$ from another. Product types (of high and low quality) alternate along the circle line, so that in clockwise order we find $\bar{k} \in \{1,3,...,J-3,J-1\}$ and $\underline{k} \in \{2,4,...,J-2,J\}$, where J is assumed to be an even number for convenience. Consumers prefer either the low or the high quality product, and they buy at most one unit among all available J products.

This set-up allows us to study firms' behavior in an environment where competition is softened by the presence of adjacent discriminated quality products. We are aware that clustering products of the same type would intensify competition, but would also reduce the neighbouring consumer choice. Thus we look at competition between high and low quality products, rather than the competition between products of the same quality (i.e. within the same market segment).

In this setting a consumer who wishes to buy one unit of product of quality k gets a non-negative monetary utility described as

$$\max_{k} \{\upsilon_k - td_k - p_k\} \geq 0, \;\; k \in \{\bar{k}, \underline{k}\}, \tag{3}$$

with $\upsilon_k \equiv \upsilon k$ identifying the effective reservation price for a product of quality k, d_k defining the distance of the consumers to the closest firm, and t measuring the disutility faced by the consumer to travel up to the firm's location (also known as "love for a product" in the closely related literature).[6]

We denote the homogeneous ad valorem tax rate with τ and the differentiated tax rate for the k^{th} product-type with τ_k. Hence, letting taxation be discriminated according to the quality of products, when the government introduces an ad valorem differentiated taxation, a consumer is indifferent to buy either the high or the low quality good when

$$\upsilon_{\bar{k}} - td_{\bar{k}} - \underbrace{\widehat{p}_{\bar{k}}\left(1+\tau_{\bar{k}}\right)}_{p_{\bar{k}}} = \upsilon_{\underline{k}} - t\left(\frac{1-\mu}{J} - d_{\bar{k}}\right) - \underbrace{\widehat{p}_{\underline{k}}\left(1+\tau_{\underline{k}}\right)}_{p_{\underline{k}}}, \tag{4}$$

where $p_{\bar{k}}$ and $p_{\underline{k}}$ are the gross prices paid by consumers for the alternative quality product $\bar{k}$ and $\underline{k}$, whereas $\widehat{p}_{\bar{k}}$ and $\widehat{p}_{\underline{k}}$ identify the net (of taxation) prices set by firms, with $\upsilon_{\bar{k}}$ and $\upsilon_{\underline{k}}$

[5] For this analysis consumers choosing the outside option can either buy a homogeneous product supplied by another industry, or purchase a used car.

[6] For the imperfect competitive market, consumers' willingness to pay includes also the disutility yielded by travelling up to firm's location, thus $\upsilon_k - td_k$ corresponds to υ as defined in the monopoly market case, as there $d_k = 0$.

characterizing the effective reservation prices for the two quality-type products.

For a firm that produces quality $k = \bar{k}$ its market demand is defined as

$$D_{\bar{k}}\left(\widehat{p}_{\bar{k}}, \widehat{p}_{\underline{k}}\right) = 2x_{\bar{k}} = \left[\frac{1-\mu}{J} + \frac{\upsilon_{\bar{k}} - \upsilon_{\underline{k}} + \widehat{p}_{\underline{k}}\left(1+\tau_{\underline{k}}\right) - \widehat{p}_{\bar{k}}\left(1+\tau_{\bar{k}}\right)}{t}\right]. \tag{5}$$

Within the same quality market segment, we assume that all firms have the same constant marginal cost of production c_k, and write firm's k maximization programme as

$$\max_{\widehat{p}_k} \pi_k : \left\{\left(\widehat{p}_k - c_k\right) D_k\right\}.$$

Differentiating firm k's profit with respect to its own net price $\widehat{p}_k$ gives us the firm's best response function, which for example for firm $\bar{k}$ is expressed as the composite intercept $a_{\bar{k}}$ and the slope $b_{\bar{k}}$

$$R_{\bar{k}}\left(\widehat{p}_{\underline{k}}\right) = \frac{1}{2}\left[\underbrace{\frac{t(1-\mu)}{J\left(1+\tau_{\bar{k}}\right)} + \frac{\upsilon_{\bar{k}} - \upsilon_{\underline{k}}}{1+\tau_{\bar{k}}} + c_{\bar{k}}}_{a_{\bar{k}}} + \underbrace{\frac{1+\tau_{\underline{k}}}{1+\tau_{\bar{k}}}}_{b_{\bar{k}}}\widehat{p}_{\underline{k}}\right]. \tag{6}$$

From above it emerges that an increase of the ad valorem taxation on the own quality product $\tau_{\bar{k}}$ yields a drop in both the intercept and the slope of firm $\bar{k}$'s best response (i.e. own-taxation effects). Instead, a change of the other product's quality taxation $\tau_{\underline{k}}$ on the rival's best response (firm $\bar{k}$) makes this latter slope steeper (i.e. cross-tax effect), leaving the intercept unchanged.[7] In our setting a key feature of a differentiated taxation consists of a reciprocal variation of both best response slopes. It follows that, under the assumption of a linear demand function,[8] in a market characterized by the presence of J pairs of firms which supply heterogeneous quality products, a change in the ad valorem product taxation (for example of firm $\underline{k}$) leads to an increase in the firm's rival net price (for example of firm $\bar{k}$).[9]

The overall strategic effect is better captured by the following equilibrium outcomes

$$\widehat{p}^*_{\bar{k}} = \frac{1}{3}\left[\frac{M + \Delta\upsilon + c_{\underline{k}}\left(1+\tau_{\underline{k}}\right)}{\left(1+\tau_{\bar{k}}\right)} + 2c_{\bar{k}}\right], \quad \widehat{p}^*_{\underline{k}} = \frac{1}{3}\left[\frac{M - \Delta\upsilon + c_{\bar{k}}\left(1+\tau_{\bar{k}}\right)}{\left(1+\tau_{\underline{k}}\right)} + 2c_{\underline{k}}\right], \tag{7}$$

with $\widehat{p}^*_{\bar{k}}$ and $\widehat{p}^*_{\underline{k}}$ indicating the net equilibrium prices of the high and low quality products, respectively when $\tau_{\underline{k}} \neq \tau_{\bar{k}}$, with $M \equiv 3(1-\mu)t/J$, and $\Delta\upsilon \equiv \upsilon_{\bar{k}} - \upsilon_{\underline{k}}$. From above we observe that the impact on the net price of a change in the taxation system depends on the sum of own-tax and cross-tax effects (augmented Ramsey rule), i.e. effects yielded by change in the taxation rate of its own and other firms, respectively. Hence, having in place a taxation system whose tax rate varies according to the quality of the product allows us to study the outcome on

[7] More precisely, a change of $\tau_{\bar{k}}$ leads to a change in both the intercept $a_{\bar{k}}$, that is $\frac{\partial a_{\bar{k}}}{\partial \tau_{\bar{k}}} < 0$, and the slope $b_{\bar{k}}$, i.e. $\frac{\partial b_{\bar{k}}}{\partial \tau_{\bar{k}}} < 0$, while a change of the competitor product tax, $\tau_{\underline{k}}$ only yields a positive effect on $b_{\bar{k}}$, i.e. $\frac{\partial b_{\bar{k}}}{\partial \tau_{\underline{k}}} > 0$, whereas it does not affect the intercept, which remains neutral to any variation of the tax rate, i.e. $\frac{\partial a_{\bar{k}}}{\partial \tau_{\underline{k}}} = 0$.

[8] In line with the empirical analysis, when the demand is defined as a logit-type, results remain qualitatively unchanged.

[9] This is an important feature of the indirect strategic complementarity inherited in this classical modelling of product differentiation.

firm competition, along with consumer decisions. In a market where the supplied products are possible substitutes, as for the case investigated in this analysis, changes in the rate of taxation of a firm's competitor can induce manufacturer to readjust its own-price accordingly (i.e. the cross-tax effect).

In the next subsection we analyze price reactions to a change in ad valorem differentiated taxation, characterizing its effect in terms of changes in economic equilibria in a market with ad valorem differentiated taxation by product quality.

2.2.1 Differentiated *Ad Valorem* Taxation

In this subsection we study the effects yielded by an increase in the tax rate on price competition between products discriminated according to their quality and tax. Without loss of generality, we maintain the assumption that in the current market there are only two quality-type products (i.e. high and low).

Recalling the equilibrium prices defined in equation (7), we begin the analysis by focusing on the case when positive changes of both taxation rates occur one at a time, isolating in this way own- and cross-taxation effects. Under the same cost structure $c_{\bar{k}} = c_{\underline{k}} = c$, when high-quality products are taxed at a greater rate, i.e. $\tau_{\bar{k}} > \tau_{\underline{k}}$, a symmetric increment of the ad valorem differentiated taxation for the high-quality product makes firms supplying that product reduce their price in equilibrium i.e. $\frac{\partial \widehat{p}^*_{\bar{k}}}{\partial \tau_{\bar{k}}} < 0$, when $d\tau_{\bar{k}} > 0$ and $d\tau_{\underline{k}} = 0$. By contrast, an increment in the low quality tax rate spurs firms in the high-quality side of the market to raise their price in equilibrium, i.e. $\frac{\partial \widehat{p}^*_{\bar{k}}}{\partial \tau_{\underline{k}}} > 0$, when $d\tau_{\underline{k}} > 0$ and $d\tau_{\bar{k}} = 0$. From the above, the result is that, in the high-quality product segment, the own- and cross-tax effects move in the opposite direction.

We repeat the same analysis in the low-quality side of the market and we find that for positive changes in the own-taxation rate, in equilibrium, firms are inclined to drop their prices only when the difference between the two quality-types of products is larger or at least equal to the augmented marginal cost, i.e. $\frac{\partial \widehat{p}^*_{\underline{k}}}{\partial \tau_{\underline{k}}} < 0$ if $\Delta \upsilon \geq c\,(1 + \tau_{\bar{k}})$, when $d\tau_{\underline{k}} > 0$ and $d\tau_{\bar{k}} = 0$. Analogously, for positive changes in the high quality rival-taxation rate, firms supplying the low-quality product increase their net prices, $\frac{\partial \widehat{p}^*_{\underline{k}}}{\partial \tau_{\bar{k}}} > 0$, when $d\tau_{\bar{k}} > 0$ and $d\tau_{\underline{k}} = 0$. For a simultaneous change in both taxation rates the final outcome on equilibrium prices depends on the total effect between own- and cross-taxation rates. For the high-quality product the total effect on the equilibrium net price is positive. Hence, when both taxes increase symmetrically, firms supplying the high quality product tend to increase their equilibrium price, i.e. $\frac{\partial \widehat{p}^*_{\bar{k}}}{\partial \tau_{\bar{k}}} d\tau_{\bar{k}} + \frac{\partial \widehat{p}^*_{\bar{k}}}{\partial \tau_{\underline{k}}} d\tau_{\underline{k}} > 0$. On the other hand, on the low quality side of the market, it is only when the difference between the two quality prices is sufficiently large that the overall effect yielded by a increment of the own- and cross-taxation rates leads to a drop in the new equilibrium price, i.e. $\frac{\partial \widehat{p}^*_{\underline{k}}}{\partial \tau_{\bar{k}}} d\tau_{\bar{k}} + \frac{\partial \widehat{p}^*_{\underline{k}}}{\partial \tau_{\underline{k}}} d\tau_{\underline{k}} < 0$ when $\Delta \upsilon \geq c\left(2 + \tau_{\bar{k}} + \tau_{\underline{k}}\right) + M$. We can state our first result.

Proposition 1. *Under a common cost structure, in a market characterized by monopolistic competition with two alternative quality products taxed differently, with a high tax rate for the higher quality product, a symmetric increment in differentiated ad valorem taxation leads to a divergence in equilibrium net prices.*

To make a welfare analysis possible, we define the government revenues under a regime where tax rates are discriminated according to a product quality. We first define the optimal demands for both product quality-type in equilibrium as follows

$$D^*_{\bar{k}} = \frac{1}{3t}\left[M + \Delta\upsilon + c_{\underline{k}}\left(1 + \tau_{\underline{k}}\right) - c_{\bar{k}}\right], \quad D^*_{\underline{k}} = \frac{1}{3t}\left[M - \Delta\upsilon + c_{\bar{k}}\left(1 + \tau_{\bar{k}}\right) - c_{\underline{k}}\right]. \tag{8}$$

Under a differentiated taxation regime, by increasing both tax rates the government is able to collect total tax revenues $R_{Dif} = \left(\widehat{p}^*_{\bar{k}} D^*_{\bar{k}}\right)\left(\tau_{\bar{k}} + d\tau_{\bar{k}}\right) + \left(\widehat{p}^*_{\underline{k}} D^*_{\underline{k}}\right)\left(\tau_{\underline{k}} + d\tau_{\underline{k}}\right)$, where the net optimal prices are given in equation (7).

Having explored the implications of changes in a differentiated taxation regime, we move towards the next subsection where we investigate the effects on market outcomes when asymmetries in ad valorem taxes are abolished, and thus where the taxation rate is homogeneously applied across all products.

2.2.2 Homogeneous *Ad Valorem* Taxation

In this subsection we discuss the policy environment of a classic scenario, when the same tax rate is uniformly applied to all quality-types products, leading to $\tau_{\bar{k}} = \tau_{\underline{k}} = \tau$. This taxation regime simplifies the equilibrium prices given in equation (7) to

$$\widehat{p}^*_{\bar{k}} = \frac{1}{3}\left[\frac{(M + \Delta\upsilon)}{(1 + \tau)} + c_{\underline{k}} + 2c_{\bar{k}}\right], \quad \widehat{p}^*_{\underline{k}} = \frac{1}{3}\left[\frac{(M - \Delta\upsilon)}{(1 + \tau)} + c_{\bar{k}} + 2c_{\underline{k}}\right]. \tag{9}$$

From above we observe that a change of the tax rate leads to a drop in all prices in equilibrium, i.e. $\frac{\partial \widehat{p}^*_k}{\partial \tau} < 0$ with $k = \underline{k}, \bar{k}$. As is the case of a monopoly market, under monopolistic competition when the same tax rate is applied consistently across all products, regardless of their quality levels the manufacturer will internalize some of the burden of the tax. From equation (9) we observe that under the same marginal production costs, i.e. $c_{\bar{k}} = c_{\underline{k}} = c$, the equilibrium price (and demand) of high quality products is higher than that of low quality products, once we agree that consumers are willing to pay more for quality, i.e. $\widehat{p}^*_{\bar{k}} > \widehat{p}^*_{\underline{k}}$, and $D^*_{\bar{k}} > D^*_{\underline{k}}$, when $\Delta\upsilon > 0$.

The difference between the two equilibrium prices becomes smaller as the homogeneous taxation rate increases, i.e. $\frac{\partial \Delta\widehat{p}^*}{\partial \tau} < 0$ with $\Delta\widehat{p}^* = p^*_{\bar{k}} - p^*_{\underline{k}} = \frac{2\Delta\upsilon}{3(1+\tau)}$ defining the difference between the two optimal prices. In equilibrium, each price increases as its own-quality level increases, and firms reduce their prices as the product quality of their rivals rises (i.e. $\frac{\partial \widehat{p}^*_{\bar{k}}}{\partial \upsilon_{\bar{k}}} > 0$ and $\frac{\partial \widehat{p}^*_{\bar{k}}}{\partial \upsilon_{\underline{k}}} < 0$ for firms $\bar{k}$, and analogously for firm $\underline{k}$).

Following the above analysis we are able to identify our second result.

Proposition 2. *In a market characterized by monopolistic competition with two alternative quality products and one outside option, an increase in the homogeneous ad valorem tax rate leads to a convergence in the equilibrium net price of high and low quality products.*

By decomposing firm k's best response function given in equation (6), we retrieve the difference between the two taxation systems. In particular, under a homogeneous taxation scheme a change in the tax rate τ leads to a negative change in the intercept only, with no effect on the slope, whereas under differentiated taxation two effects are at work: cross- and own-tax. The slope of each firm's best response function faces a drop due to an increase of their own taxation and a rise in response to an increase in rivals' ad valorem taxes. Thus, the final effect on the slope depends on the magnitude of these two opposite outcomes, which is a peculiarity of the market structure, where firms are competing in an oligopoly setting.[10] Looking at the equilibrium conditions defined in equation (9), it emerges that a parallel increment in the tax rate does not modify the potential asymmetries in terms of market power.[11]

Finally, the current regime of taxation guarantees the government total tax revenues of $R_{Hom} = \left(\widehat{p}^*_{\bar{k}} D^*_{\bar{k}} + \widehat{p}^*_{\underline{k}} D^*_{\underline{k}}\right)(\tau + d\tau)$, where the demands in equilibrium for both product-types are

$$D^*_{\bar{k}} = \frac{1}{3t}\left[M + \Delta\upsilon + (1+\tau)\left(c_{\underline{k}} - c_{\bar{k}}\right)\right], \quad D^*_{\underline{k}} = \frac{1}{3t}\left[M - \Delta\upsilon + (1+\tau)\left(c_{\bar{k}} - c_{\underline{k}}\right)\right]. \tag{10}$$

Increments of such a type of taxation induce a convergence in producer rent, consumer surplus and tax revenue coming both from the low and high quality segments of the market.

In the next section, we present a comparison between the two taxation systems, identifying the dimension of the deadweight loss yielded by the introduction of a tax reform.

2.3 Comparing Differentiated and Homogeneous *Ad Valorem* Taxation

Having outlined the impact of own- and cross-tax effects on market competition, consumer and government revenues, we hold all elements for making a comparison between the two taxation regimes. Our assessment makes use of the assumption that the rate of taxation applied under a homogeneous system is lower than the differentiated rate on the high quality product, but higher than the differentiated rate on the low quality product, i.e. $\tau_{\underline{k}} < \tau < \tau_{\bar{k}}$. We look first at government revenues, and contrast the changes induced by the two alternative tax regimes.

Recalling the equilibrium prices and demands defined in equations (7) and (8), we have that the total tax revenues of an ad valorem differentiated taxation system are $R_{Dif} = \left(\tau_{\bar{k}} + d\tau_{\bar{k}}\right)\left(\widehat{p}^*_{\bar{k}} D^*_{\bar{k}}\right) + \left(\tau_{\underline{k}} + d\tau_{\underline{k}}\right)\left(\widehat{p}^*_{\underline{k}} D^*_{\underline{k}}\right)$. Instead, when different quality products are taxed using the same ad valorem rate, the government gains total tax revenues $R_{Hom} = (\tau + d\tau)\left(\widehat{p}^*_{\bar{k}} D^*_{\bar{k}} + \widehat{p}^*_{\underline{k}} D^*_{\underline{k}}\right)$, with optimal equilibrium prices and demands defined in (9) and (10).[12]

By comparing government revenues extracted within the same quality market-segment between the two taxation regimes, we observe that, by introducing analogous changes in the taxation rates, i.e. $d\tau = d\tau_k$ with $k = \underline{k}, \bar{k}$, the low-quality side of the market generates positive and increasing tax revenues, whereas for the high-quality segment of the market, government revenues fall under a differentiated tax system, that is $\partial \Delta R_{\underline{k}} / \partial \tau_{\underline{k}} > 0$ and $\partial \Delta R_{\bar{k}} / \partial \tau_{\bar{k}} < 0$ where for all quality products $\Delta R_k \equiv (\tau_k + d\tau_k)\left(\widehat{p}^*_k D^*_k\right)_{Dif} - (\tau + d\tau)\left(\widehat{p}^*_k D^*_k\right)_{Hom}$ when in equilibrium $\left(\widehat{p}^*_k D^*_k\right)_{Dif} \neq \left(\widehat{p}^*_k D^*_k\right)_{Hom}$, for all $k = \underline{k}, \bar{k}$.

From this simple comparison it is possible to gain insight on the social dilemma that the government faces when choosing its taxation regime. Revenues, indeed, can be shifted from the high tax (high quality) segment down to the low tax (low quality) segment when moving from a homogeneous to a differentiated ad valorem taxation regime. In Proposition 1 we have seen that imposing a lower tax on lower quality and higher tax on higher quality a symmetric increase

[10] A complete analysis is offered in Appendix A.2, where we make use of the concept of incidence of taxation and show how the pass-through varies in the two alternative tax regimes.

[11] Making use of the PCM rule we observe that as the homogeneous tax increases the PCM decreases, i.e. $\frac{\partial \widehat{p}^*_k}{\partial \tau} < 0$ and $(\partial \mathrm{PCM}^*_k / \partial \tau) < 0$ with $k = \underline{k}, \bar{k}$.

[12] Notice that optimal prices and equilibrium demands are different for both product-types under the two taxation regimes.

in taxation leads to net producer price increases in the low quality segment, outstripping the decline in the net producer price in the high quality segment. Such net price movements created by own- and cross-tax elasticities lead to the possibility that tax revenues can, in theory, go up in the low-quality segment and down in the high-quality one. This is more likely to happen if the market share of the low quality segment expands and that of high quality contracts. We consider tax revenues to be welfare neutral, although they will increase overall under the differentiated ad valorem taxation regime.

In terms of consumer surplus, recalling the equilibrium demands under the homogeneous and differentiated taxation regimes, equations (10) and (8), respectively, we know that once consumers value the quality product sufficiently, both demands are below what it is assumed to be optimal from a social point of view. This is a feature of imperfect competition, which combined with the presence of asymmetries in quality results in having the demands for both quality products being (in equilibrium) lower than what is socially optimal, i.e. $D_k^*\left(\widehat{p}_{\overline{k}}^*, \widehat{p}_{\underline{k}}^*\right) < D_k^*(c, c)$ with $k = \underline{k}, \overline{k}$. In particular, focusing on the optimal demands in equilibrium, we detect that the loss of welfare is larger under a differentiated taxation system for both quality products, i.e. $\left[D_k^*(c, c) - D_k^*\left(\widehat{p}_{\overline{k}}^*, \widehat{p}_{\underline{k}}^*\right)\right]_{Dif} > \left[D_k^*(c, c) - D_k^*\left(\widehat{p}_{\overline{k}}^*, \widehat{p}_{\underline{k}}^*\right)\right]_{Hom}$. Assessing the dimension of these two deadweight losses, we observe that when a taxation system which applies different rates to differentiated quality products is in place, the loss is higher than that when an homogeneous taxation system is enforced.[13]

Focusing on the consumer welfare we compute the consumer surplus, for consumers choosing either the low or the high quality product, in our Salop model as the sum of consumption benefit minus aggregate transportation cost, as

$$CS_k = \sum_{j=1}^{J}\left[\left[\upsilon_k - \widehat{p}_k(1+\tau_k)\right] \times D_k - \int_0^{x_k} txdx - \int_0^{(1-\mu)/J - x_{k-1}} txdx\right] \text{ with } k = \underline{k}, \overline{k}$$

where from equation (5), $D_k = x_k + \left(\frac{1-\mu}{J} - x_{k-1}\right)$ defines the mass of x_k consumers located on the right and on the left of product k). To measure the deadweight loss yielded by the introduction of a taxation, we compare and contrast both consumer surpluses before and after a tax is introduced for both taxation regimes, i.e. $CS_k(\widehat{p}_k)$ versus $CS_k(\widehat{p}_k, \tau_k)$, with $k = \underline{k}, \overline{k}$. We apply this method both for the homogeneous and differentiated taxation system. Within the same taxation system we note that consumers who choose the low quality good are penalized more under a homogeneous taxation system, whereas consumers who buy the high quality product face a higher loss under a differentiated taxation system. Finally, looking at the total effect, by comparing and contrasting the two taxation regimes, it emerges that the loss of consumer surplus is higher when a differentiated taxation system is imposed. Hence, from the above analysis here we state our next result.

Proposition 3. *In a market characterized by asymmetric competition with heterogeneous products, a taxation system whose tax rates are discriminated according to quality products yields lower consumer welfare and larger producer rent than that when a homogeneous taxation system*

[13] The magnitude of the loss for a differentiated taxation system depends on the difference between tax rates applied to both quality-type products.

is imposed. Consumer surplus is shifted down the quality ladder when a differentiated ad valorem taxation regime is instituted.

Because of the own-tax effect sales expand in the low quality segment and shrink in the high quality segment. Cross-tax effects in short run price competition mitigate the own-tax effect, as the net producer price increases in the low quality segment and decreases in the high quality segment to protect market shares. The tax is designed to shift sales, but the strategic pricing behavior causes rents to be transferred down the quality ladder. The low quality product segment exploits it. The tax induces market power to increase net producer prices at the expenses of market shares. While demand for the high quality product drops, prices act to protect market shares in the face of higher taxation, and we observe more aggressive price competition within the low quality segment.

In the following sections of the paper we present our empirical analysis where we test the results highlighted in our propositions, by evaluating the impact of a differentiated ad valorem taxation introduced in the Irish new automobile market between 2004-2008.

3 Market and Data

Our empirical analysis focuses on the use of the Vehicle Registration Tax (VRT) in place in the Irish automobile market during the period of our data 2004-2008. It is an ad valorem tax paid at the time that a new vehicle is registered in the state. It has been defined according to the size of the new car's engine until June 30th 2008, then replaced by a new system whose discrimination is based on the amount of CO2 emissions generated by the vehicle sold. We observe that the retail price p per model of car is the result of the net retail price $\widehat{p}$ augmented by the value added tax (VAT) rate, τ_{VAT}, and by a model-specific vehicle registration tax rate, τ_{VRT}, such that $p = \widehat{p}(1+\tau_{VAT})(1+\tau_{VRT})$. Hence, fixing the net producer price at 1, we present in Table 1 the percentage of the two sources of ad valorem taxation, and the resulting compound taxation.

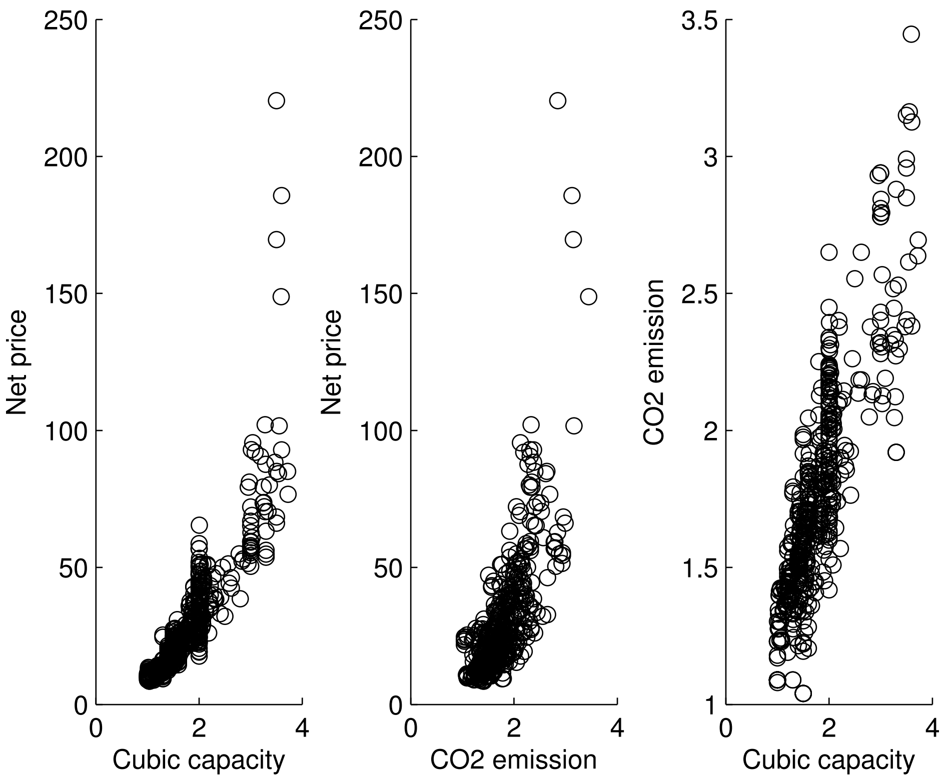
Table 1: *Tax rates*

Cubic capacity	***%VAT***	***%VRT***	***%TAX***
$cc \leq 1400$	21	22.5	48.23
$1400 < cc <= 1900$	21	25	51.25
$cc > 1900$	21	30	57.30

CO2 emissions	***%VAT***	***%VRT***	***%TAX***
A: 0 – 120g	21	14	37.94
B: 121 – 140g	21	16	40.36
C: 141 – 155g	21	20	45.20
D: 156 – 170g	21	24	50.04
E: 171 – 190g	21	28	54.88
F: 191 – 225g	21	32	59.72
G: 226g and over	21	36	64.56

On the top panel of Table 1 we show the tax system determined by variation in engine cubic capacity (in force until June 30th 2008), and on the panel at the bottom, we report the CO2 emission classes adopted by the new taxation system. From the above, a substantial heterogeneity in taxation emerges. To characterize the products in our dataset we make use of the cubic capacity and CO2 emissions, which are considered good indicators of product quality. In Figure 1 we map the net price against cubic capacity and CO2 emissions, respectively in the first two sub-plots, and then display the relationship between these two product characteristics in the last sub-plot. The positive relationship between net price and cubic capacity and CO2 emissions does not contradict our initial prediction on the two being proxies of product quality. However, it has to be acknowledged that higher net prices could also be the result of higher production and distribution costs. Interestingly, there is high positive correlation between CO2 emissions and cubic capacity. This is an important fact for our work as, in 2008, VRT has shifted from being calculated on cubic capacity to being computed on CO2 emissions. Thus, high values of cubic capacity and high values of CO2 emissions both correspond to high tax rates, and possibly high quality products.

Figure 1: Net price, cubic capacity and CO2 emission



We focus on the Irish automobile market, as it is an example of an ad valorem tax differentiated on product attributes proxy of quality. In our model quality refers to that perceived by consumers, with no adjustment for possible externalities. According to our longitudinal data on new car sales, a yearly average of 172,091 drivers purchased new cars in Ireland over the period 2004-2008, paying an average net list price of almost 30,000 Euros (at 2011 prices). Representing around 3 per cent of tax revenues in Ireland, this taxation system has generated yearly revenues of four billion Euros to be shared among manufacturers, wholesalers and retailers. The government raised taxation via a combination of a differentiated VRT, and VAT on new car sales of approximately 11,660 Euros per new car sold. The introduction of this type of taxation was motivated by environmental purposes, with the final objective to replace old with new automobiles, whose technology is greener.[14]

The data that we use in our analysis come from two main sources. First, the volume data on product sales is provided by the Central Statistics Office, which collects data from the Revenue Department for tax reasons.[15] Second, prices and model characteristics have been compiled from specialized press (mostly from Car Buyer Guide). In Table 2 we outline all variables of interest to get a snapshot of the automobile market in Ireland for the period 2004-2008. In the top panel of Table 3, we highlight the overall market structure, and the within segment market structure, where the automobile models have been allocated into seven segments according to European Competition Commission's (1999) classification: Mini, Small, Medium, Large, Sports, SUV, Multi-purpose. We can observe that while the top four companies cover about 50 per cent of the market, the top four companies in each segment have almost full control of the segment, suggesting that potentially competition is more limited within segment. This can lead to market power in the absence of price competition within and between segments of the industry, and the structural nested model adopted to estimate the Irish automobile market takes into account such market segmentation. Since we do not know how dealers, wholesalers and producers share their profits, in our empirical analysis we use the word company/firm/producer to include all three type of agents. As documented in the bottom panel of Table 3, the original dataset consists of an unbalanced panel of 9,485 automobile versions produced by 31 different companies. To make the counterfactual analysis tractable, but also to minimize the issues faced by the presence of many repeated versions that differ by secondary observable or unobservable characteristics, we aggregate all different versions at the product level, reducing the original sample to 507 models.

4 The Empirical Model

In our dataset, an observation is a new automobile model marketed in Ireland over the time period which spans from 2004 to 2008. Each automobile model/product is differentiated according to a bundle of characteristics. Firms are multiproduct, hence they can partly internalize pricing behavior, along with asymmetries in taxation. The competitive constraint on pricing is determined by the degree of substitutability between models produced by the same manufacturer and those marketed by the competitors. In order to map multiproduct firms operating over different product attributes into market power, and then run a counterfactual analysis, we adopt a structural approach. We simultaneously estimate a demand and pricing (supply) systems of differentiated products, in the presence of the VAT and the differentiated VRT taxation imposed on retail prices. Firms are assumed to observe the tax rate established by the government and

[14]For full details see http://taxpolicy.gov.ie/wp-content/uploads/2011/04/TSG0712.pdf [Accessed 20 May 2018]

[15]These data are also available from the SIMI, Society of the Irish Motor Industry, more details on http://www.simi.ie/ [Accessed on 20 May 2018].

Table 2: *Variables description*

Variable[†]	***Description***	***Mean***	***SD***	***Min***	***Max***
acl[††]	Acceleration: seconds 0-100km/h	10.62	2.19	4.40	18.20
cc[††]	Engine cubic capacity	1.84	0.55	1.00	6.00
CO2[††]	Total CO2 emissions in 0:120g/km	1.74	0.36	0.99	3.62
door	Number of doors in car	4.22	0.87	2.00	5.00
lit × 100 km[††]	Liters per 100 kilometers in city driving conditions	7.09	1.57	3.80	15.10
s	Product market share, calculated as number of unit sales for each model of car over number of total unit sales	5.27e-03	1.87e-02	7.43e-06	0.04
p	Average recommended retail price in euro thousands	35.28	20.38	9.52	315.99
petrol	Dummy variable: 1 for petrol and 0 for diesel	0.51	0.50	0	1
serv[††]	Number of days of free service	41.13	24.40	0	200
tran	Dummy variable: 1 for automatic and 0 for manual				
trunk[††]	Trunk (boot) size in cubic meters	3.97	1.13	1.39	16.70
warranty	Categorical variable from 1 to 4 for warranty duration	1.34	0.65	1	6
t	Identifier for each year in the dataset	3.29	1.37	1	5

Note: [†]The summary statistics refer to the original versions of the models. In the econometric analysis we use data aggregated at the model (product) level. One obvious consequence of the aggregation is that the original binary variables become proportions between 0-1. [††]In the econometric analysis the variable is standardized.

choose the optimal net price for each product in their portfolio, given their competitors' prices. Demand has a nested logit structure, as derived in Berry (1994).

We estimate primitives of demand and each firm profit and use those to calculate the elasticity of firm prices for the own- and cross-differentiated taxation for low and high quality products. The sign of these outcomes will be compared to those predicted by our theoretical model. The estimated primitives of supply and demand are then also used to undertake a counterfactual analysis, where homogeneity in the VRT taxation is imposed under the constraint that the homogeneous tax revenue has to preserve the original differentiated tax revenue, prior to the new equilibrium in the market. In this way we are able to compare the distortion in the market that can be ascribed to the differentiated taxation schedule. We will measure that in terms of consumer surplus, producer profits and tax revenues.

Table 3: *Top 4 firm concentration index and number of models by time*

	Period					
Segment	2004	2005	2006	2007	2008	All
1 (Mini)	NA	1.00	1.00	1.00	1.00	
2 (Small)	0.72	0.72	0.68	0.65	0.59	
3 (Medium)	0.78	0.69	0.77	0.83	0.86	
4 (Large)	0.96	0.94	0.84	0.91	0.90	
5 (Sports)	0.96	0.99	0.92	0.98	0.91	
6 (Executive)	0.99	0.98	0.83	0.79	0.78	
7 (Multi-purpose)	0.89	0.87	0.88	0.86	0.91	
All	0.45	0.47	0.41	0.39	0.38	
N. versions	1,314	1,651	1,887	2,254	2,379	9,485
N. models	82	89	99	113	124	507

The Demand Equation There are Υ_t consumers in the economy in period t. Each consumer selects one of the $J_t + 1$ differentiated products marketed in the period, where the +1 product is the outside good. In the following analysis we omit the time subscript for notational convenience, as the empirical analysis that follows is static in its nature.[16] For a consumer type υ we specify a random indirect utility function made of the observed and unobserved mean utility of the product supplied by firm j, collectively denoted by δ_j, plus an idiosyncratic unobserved consumer and product shock,

$$U_{\upsilon j} = \underbrace{\mathbf{x}_j \boldsymbol{\beta} + \alpha \widehat{p}_j \left(1 + \tau_j\right) + \xi_j}_{\equiv \delta_j} + \varepsilon_{\upsilon j}. \tag{11}$$

The term $\mathbf{x}$ is a vector of observed product characteristics. The variable p denotes the retail gross price, whereas $p_j = \widehat{p}_j \left(1 + \tau_j\right)$ is the net price, and the variable ξ describes an aggregate value of the demand characteristics, not observed by the researcher. We interpret the additive component $\mathbf{x}_j \boldsymbol{\beta} + \xi_j$ as a proxy of the product perceived quality. The variation in consumer tastes enters only through the composite error term, $\varepsilon_{\upsilon j}$.

Berry (1994) shows how to derive the nested logit demand function below from an indirect utility function as

$$lns_j - lns_0 = \mathbf{x}_j \boldsymbol{\beta} + \alpha \widehat{p}_j \left(1 + \tau_j\right) + \sigma lns_{j/g} + \xi_j \tag{12}$$

where s_j is product j's share of the total market (inside goods plus outside good), s_0 is the outside good's share of the entire market, $s_{j/g}$ is product j's share of the group g to which it belongs, and ξ_j is the aforementioned unobserved (to the econometrician) product characteristic, assumed to be mean independent of $\mathbf{x}_j$. In each $\mathbf{x}$ we include number of doors, liters per 100 kilometers, trunk (boot) size, type of transmission (manual vs automatic), acceleration, and cubic capacity. To facilitate the interpretation of the results, all continuous variables, except for prices, are standardized.

[16] However, in our empirical work the time dimension is present at the product-level.

Since prices and the within group shares are endogenous variables, they must be instrumented and the instruments need to vary by product. We now consider the supply side and derive the Lerner Index for each product j.

The Pricing Function A fully structural approach to estimating market power requires specifying the cost function to be estimated, thus we define

$$c_j = \mathbf{w}_j \boldsymbol{\gamma} + \omega_j, \tag{13}$$

where c_j is a constant marginal cost, $\mathbf{w}_j$ is a vector of observed product characteristics that determine manufacturing costs and ω_j is a cost unobservable to the econometrician.

In a multi-product firm setting, firms maximize the sum of profits accruing from their set of products, $\mathcal{J}_f$, as

$$\max_{\widehat{p}_j} \sum_{b \in \mathcal{J}_f} (\widehat{p}_b - c_b)\, s_b\,(p_j, p_{-j})\,, \quad j \in \mathcal{J}_f, \tag{14}$$

where $b \in \mathcal{J}_f$. A firm j chooses for each product its net price, $\widehat{p}_j$, given the prices of all other products' firms, $\widehat{p}_{-j}$, with a simple expedient: demand are a function of gross prices. A firm can internalize the cross-price effect on market share of the products it owns in the price setting of an individual product. The first-order condition for each profit maximizing product (brand) has the general form as following

$$s_j + \sum_{b \in \mathcal{J}_f} (\widehat{p}_b - c_b) \frac{\partial s_b}{\partial \widehat{p}_j} = 0, \quad j \in \mathcal{J}_f. \tag{15}$$

Given the marginal cost c_b, assuming multi-product price setting firms without symmetry, a multi-product Nash equilibrium is given by the system of J first-order conditions. Using our J demand primitives the first-order condition in equation (15) implies product price equals marginal cost plus a mark-up, so we get estimates of a Lerner index per firm's product j. With the primitives of the demand system and the price we will be able to calculate the marginal cost for each product.

To write equation (15) in compact form, we define the d_{jb} cell of the matrix D

$$d_{jb} \equiv \begin{cases} -\frac{\partial s_b}{\partial \widehat{p}_j}, & \text{if models } b, j \in \mathcal{J}_f \\ 0 & \text{otherwise} \end{cases},$$

so that the net pricing equation can be expressed as the sum of the marginal cost and the markup vector as

$$\widehat{\mathbf{p}} = \mathbf{c} + \underbrace{\mathbf{D}^{-1}\mathbf{s}}_{\equiv \mathbf{m}(\mathbf{markup})}. \tag{16}$$

By relating the product-level version of equation (16) to the observable and unobservable product characteristics it is possible to derive the cost function (13) as

$$\widehat{p}_j - m_j = \mathbf{w}_j \gamma + \omega_j. \tag{17}$$

5 Results

The approach that we adopt in our empirical analysis relies on the Lancasterian literature, which assumes that individuals choose a specific product based on some physical and non-physical attributes, in addition to the product's price.

Table 4: *Results*

Variable	***Demand side***		***Cost side***	
constant	-7.570***	(1.413)	-34.547***	(1.208)
cc	0.528**	(0.257)	19.348***	(0.065)
lit$\times$ *100km*	0.155	(0.185)	-0.162***	(0.062)
diesel	0.232	(0.188)	2.691***	(0.110)
trunk	-0.066	(0.067)	-1.981***	(0.065)
tran	0.172	(0.286)	-2.775***	(0.162)
acl	0.025	(0.072)		
CO2	-0.082	(0.214)		
door	0.016	(0.111)		
qual	0.067	(0.136)		
warranty	0.039	(0.132)		
serv	0.026	(0.060)		
p (α)	-0.018***	(0.008)		
within segment (σ)	0.854***	(0.071)		
Company dummies	yes		yes	
Time dummies	yes		yes	
Segment dummies	yes		yes	
Pseudo-R^2	0.944		0.829	
N.		507		
P-value overid.		0.391		
Average $(\widehat{p}-c)/\widehat{p}$		0.299		

Note: Robust standard errors in parenthesis. ***, ** and * denote parameters which are significant at 1%, 5%, or 10%, respectively. *Demand-side instruments* (in addition to the exogenous variables): tax rate and the BLP-type instruments: average cubic capacity, average fuel consumption, average quality, average trunk size, average car service, and average CO2 emission of other products by the same firm. *Pricing-side instruments* (in addition to the exogenous variables): tax rate, quality index and warranty. All variables are expressed in thousand Euros.

We estimate our system of demand and pricing equations simultaneously, so to deal with the correlation between error terms. We also deal with the endogeneity of the price and the within segment market share variable. The estimates are presented in Table 4 and the list of instruments is given in the footnote of the same table. In our estimates we control for company, time and segment dummies as documented in the table.[17] Starting the discussion with the marginal cost side, the model predicts that one standard deviation increase in engine cubic capacity (for example a rise in the mean value of standardized cubic capacity from 1800 to 2400) increases the cost of production and distribution of a car by Euros 19,348, all else equal. In line with our a priori expectations, diesel cars are more expensive than petrol cars to produce (a Euros 2,691 of difference). The coefficient on the trunk size variable indicates that a car with more empty space is cheaper to manufacture than one filled out with some sort of material. Furthermore, automatic cars are on average Euros 2.775 more expensive to produce than manual cars. Looking at the overall effect on market power, our estimates report an average net price-cost margin around 30 per cent.

Table 5: *Estimated tax semielasticities (median percentage)*

			Quality					
mc	*variable*	*statistics*	*low*	*high*	*all*	*low*	*high*	*all*
			fact: differentiated taxation			*cft: homogeneous taxation*		
low	OT	avg	-15.550	-9.935	-14.081	-16.338	-11.381	-15.170
		sd	(6.662)	(3.742)	(6.769)	(6.634)	(3.747)	(6.663)
	CT	avg	10.307	12.283	10.307	11.848	13.071	11.848
		sd	(16.639)	(13.596)	(16.222)	(27.251)	(24.981)	(27.205)
		N	54	8	62	54	8	62
high	OT	avg	-9.707	-3.834	-4.603	-10.242	-4.671	-5.771
		sd	(2.127)	(3.278)	(3.638)	(2.264)	(3.860)	(4.095)
	CT	avg	3.849	4.696	4.218	3.790	2.989	3.258
		sd	(10.795)	(12.226)	(11.880)	(11.698)	(20.616)	(19.012)
		N	13	49	62	13	49	62
all	OT	avg	-13.507	-4.179	-9.710	-14.336	-5.329	-10.442
		sd	(6.691)	(3.747)	(7.425)	(6.692)	(4.336)	(7.580)
	CT	avg	8.975	5.089	6.268	8.584	4.119	5.922
		sd	(15.703)	(12.476)	(14.259)	(24.925)	(21.597)	(23.390)
		N	67	57	124	67	57	124

Note: OT identifies the own-net price semielasticity when the tax rate on own-product increases by 5 base points (about 10%, e.g. from 0.50 to 0.55). CT captures the sum of cross-net price semielasticities when the tax rates on all other products increase by 5 base points.

Shifting the attention to the demand side, we observe that, for a one percent increase in the standardized engine cubic capacity, our model predicts an increase in the market share of 52.8 per cent, relative to the outside option. Perhaps this is a feature of the Irish market before the financial recession that hit the Irish economy in late 2008, a period when the economy was known as the "Celtic Tiger". We note that because of quasi-multicollinearity only some of the estimates are significant. Nevertheless, as our objective is to include variables that we believe could affect

[17] Complete details of the structural own and cross-tax effects along with full characteristics of the estimator are provided in Appendix A.3.

individual choice, we do not worry much about lack of individual significance, knowing that the coefficients are jointly significant, and that the magnitude and sign of the variables are consistent with a priori information.

Table 6: *Divergence vs convergence of net prices: OLS and Nearest neighbour matching (NNM)*

	OLS				***NNM***				
	Dif		*Hom*		*Dif*		*Hom*		
Percentile taxation (proxy for quality)	*I*		*II*		*III*		*IV*		*Obs.*
$<= 10\%, >= 90\%$	0.031**	(0.014)	-0.003	(0.012)	0.032***	(0.012)	-0.002	(0.008)	19
$40\% - 50\%, 50\% - 60\%$	0.031	(0.025)	-0.024	(0.019)	0.009	(0.045)	-0.010	(0.028)	41
$<= 20\%, >= 80\%$	0.031*	(0.013)	-0.042**	(0.020)	0.100***	(0.014)	-0.096***	(0.021)	59
$30\% - 50\%, 50\% - 70\%$	0.031	(0.020)	-0.021	(0.015)	0.006	(0.035)	-0.006	(0.022)	48
$<= 30\%, >= 70\%$	0.024**	(0.012)	-0.030*	(0.017)	0.194***	(0.024)	-0.226***	(0.031)	75
$20\% - 50\%, 50\% - 80\%$	0.027	(0.017)	-0.015	(0.012)	0.009	(0.010)	0.001	(0.009)	64
$<= 40\%, >= 60\%$	0.022**	(0.011)	-0.024*	(0.014)	0.179***	(0.021)	-0.204***	(0.027)	82
$10\% - 50\%, 50\% - 90\%$	0.028**	(0.011)	-0.026**	(0.011)	0.011	(0.013)	-0.008	(0.018)	104

Note: Dependent variable (outcome) is the difference between the new and the original net price. . Treatment is high quality, control is low quality. Robust standard errors in parenthesis. ***, ** and * denote parameters which are significant at 1%, 5%, or 10%, respectively.

Having estimated the demand and cost primitives we can construct the own-price and cross-price effect of taxation by product. This requires us to compute each statistic numerically by marginally raising the existing compound differentiated taxation, according to the formula displayed in equation (A7). We limit the empirical simulations to the last period of our data, which happens to be the year when vehicle registration tax changes from being differentiated according to the cubic capacity, toward a more environmental friendly differentiation based on CO2 emissions (recalling that the two measures are highly correlated as shown in Figure 1). The summary statistics of the results is documented for different classes of marginal cost and quality in Table 5. Quality is proxied by the tax rate, whereas marginal cost is defined from the pricing equation. The panel on the left depicts the effect of a proportional price change in a differentiated taxation regime, namely our factual analysis, instead on the right there is the counterpart for the counterfactual analysis based on a homogeneous taxation regime. We observe that an increase in the own-taxation (OT) tends to reduce the own-net price of the car across all quality and marginal cost segments, and that the sum of the cross-tax price effect (CT) is positive. What the results indicate is that prices in low quality segments are more sensitive to own- and cross-tax changes, relative to the high quality segments. The tax regime matters most for products already in a disadvantageous quality situation. Net producer prices respond to taxes demonstrating the nature of short-run price competition in the market. The effect on net prices of an own-tax change is largely offset by the presence of cross-taxation; an effect that is confirmed by values of the own-incidence of taxation in the proximity of one.[18]

[18]The incidence of taxation is the change in net equilibrium price induced by a change in the per-unit tax level, relative to the change in the unitary tax revenue. Its matrix formula is:

$$\mathbf{IT}^* = \left[\left(\hat{\mathbf{p}}+\frac{\mathbf{d}\hat{\mathbf{P}}}{\mathbf{d}\boldsymbol{\tau}}\mathbf{d}\boldsymbol{\tau}\right)(\mathbf{i}+\boldsymbol{\tau}+\mathbf{d}\boldsymbol{\tau})'-\hat{\mathbf{p}}(\mathbf{i}+\boldsymbol{\tau})'\right]./\left[\left(\hat{\mathbf{p}}+\frac{\mathbf{d}\hat{\mathbf{P}}}{\mathbf{d}\boldsymbol{\tau}}\mathbf{d}\boldsymbol{\tau}\right)(\boldsymbol{\tau}+\mathbf{d}\boldsymbol{\tau})'-\hat{\mathbf{p}}\boldsymbol{\tau}'\right], \quad (18)$$

where ./ indicates an element-by-element division and $\mathbf{i}$ denotes a $J \times 1$ column vector of ones, and capital letters denote matrices. Results based on the incidence of taxation are not reported in our table, but available upon request.

In the counterfactual analysis we take the minimum taxation applied in our factual scenario as our starting point and impose it on all products. Hence, in the counterfactual relative to the factual we decrease the taxation for the high quality products proportionately to the low quality products.

In this new counterfactual regime, we calculate what net prices would have been if the taxation was homogeneous rather than differentiated. By comparing the factual and counterfactual analysis we find that in the factual scenario the sign of the sum of own-tax and cross-tax is negative for low quality product and positive for high quality products. This confirms our Proposition 1, which states that under a differentiated taxation regime an increase in the tax rate leads to further divergence in equilibrium prices. By contrast, in the counterfactual state when an indiscriminate rate of taxation is applied, the sign of the own-tax effect is negative both for the class of low marginal cost and quality, and that of high marginal cost and quality.

A more thorough testing of our theoretical prediction is provided in Table 6, where we control for marginal costs and present different thresholds of quality cuts. The idea is to investigate the behaviour of various extreme thresholds of quality checks and compare those to more intermediate intervals of quality. Quality is again proxied by taxation, where in the counterfactual scenario quality refers to what has been defined in the factual state, which is if in the factual situation a product was charged the highest tax rate, then this same product will be considered of high quality in the counterfactual as well.

Looking at the difference between the equilibrium prices, in Table 6 we report our analysis for both the differentiated (the factual Dif), and the homogeneous (the counterfactual Hom) taxation regimes. In the factual analysis we calculate the new equilibrium price by increasing the tax rate by 5 base points and then compute the difference between the new prices and the observed prices, which will serve as dependent variable in the robust OLS regression (set of columns on the left) and as outcome variable in the nearest neighbouring matching analysis (NNM, set of columns on the right). A similar exercise is conducted for the counterfactual scenario. For this latter the equilibrium prices are used as starting values and then new prices are computed by increasing taxation by 5 base points. Here again, the difference between the new prices and the original counterfactual prices is used as main variable in the analysis. The interpretation of the results in Table 6 is as follows. Taking the second set of rows as an example, we have that high quality products are those associated with a top 20% tax rate, and low quality those with a bottom 20% tax rate. For this definition of quality we see that accounting for marginal cost, the net price of high quality products is Euros 31 higher than that of low quality products, if the taxation is differentiated, but it is Euros 42 lower if the taxation is homogeneous. The magnitudes are amplified when the nearest neighboring matching method is used. Then, to ensure that quality is the driving source of difference between the two taxation regimes, as robustness check, we repeat the exercise by compacting the quality interval. We define low quality products those with taxation between 30% and 50% of the tax range, and high quality those with taxation between 50% and 70% of the tax rate, and note that quality has no longer an effect in explaining net prices. In other rows of the table we repeat the analysis for different quality intervals. Given the statistically significant signs of the effect of quality in the two tax regimes, we draw the conclusions that in a differentiated tax regime an increase in the tax rate leads to divergence in net prices, confirming the theoretical prediction stated in Proposition 1. By contrast, in a homogeneous taxation regime we have that the gap between the two net price levels shrinks, yielding to convergence, which confirms our Proposition 2.

Table 7: *Welfare Analysis*

		Profit			*Net Price*			*Firm Mark-up (%)*		
mc	*tax*				*Quality*					
		low	*high*	*total*	*low*	*high*	*total*	*low*	*high*	*total*
low	*Dif*	728.50	83.56	812.05	17.77	23.85	18.30	20.27	65.75	21.35
	Hom	713.69	85.60	799.29	17.96	23.72	18.49	19.53	64.93	20.64
	N.	54	8	62	54	8	62	54	8	62
high	*Dif*	96.63	127.35	223.98	26.42	40.43	35.14	7.83	1.72	2.93
	Hom	103.46	181.51	284.97	26.74	15.59	39.51	8.17	2.26	3.45
	N.	13	49	62	13	49	62	13	49	62
total	*Dif*	825.13	210.90	1036.00	18.77	35.35	22.35	18.04	3.43	11.79
	Hom	817.14	267.12	1084.30	19.02	39.86	24.34	17.47	3.99	11.72
	N.	67	57	124	67	57	124	67	57	124

		Mk Share (%)			*Cons. Welfare*			*Tax Rev.*		
mc	*tax*				*Quality*					
		low	*high*	*total*	*low*	*high*	*total*	*low*	*high*	*total*
low	*Dif*	6.93	0.66	7.59	6039.70	576.08	6615.80	953.70	133.81	1087.60
	Hom	6.73	0.69	7.42	5872.90	600.55	6473.40	835.27	112.82	948.09
	N.	54	8	62	54	8	62	54	8	62
high	*Dif*	0.91	1.50	2.41	790.93	1304.70	2095.60	191.15	537.90	729.05
	Hom	0.92	1.94	2.86	805.15	1691.80	2496.90	170.51	610.74	781.26
	N.	13	49	62	13	49	62	13	49	62
total	*Dif*	7.84	2.16	10.00	6830.60	1880.80	8711.40	1144.90	671.71	1816.60
	Hom	7.65	2.63	10.28	6678.00	2292.30	8970.30	1005.80	723.56	1729.30
	N.	67	57	124	67	57	124	67	57	124

Note: *Dif* and *Hom* identify the factual and the counterfactual analysis, respectively. Values in *Profit*, *Cons. Welfare* and *Tax Rev.* are expressed in million of Euros, and *Net Price* in thousand of Euros.

Welfare analysis We conclude this section with a discussion of the welfare implications due to a change in taxation rate under the two regimes, homogeneous and differentiated ad valorem taxation. In Table 7 we display a complete welfare analysis organized by profits, net prices, mark-up, market share, consumer welfare and tax revenue for the last year of observations in the data. Our results are documented for both the factual (differentiated taxation) and the counterfactual (homogeneous taxation), and are displayed against firm efficiency and product quality (characterized according to the applied tax rate). This approach allows us to study the effects of market competition inter-regime, in addition to proving us with estimates within regimes. This is an important part of our study, as by comparing the two alternative taxation systems we are able to identify which agent in the economy has faced the burden of the tax, capturing eventually possible shifts. In particular, considering the effects on consumer surplus we are able to identify possible transfers across segments, which may affect some type of consumers more than others.

From a first glance, along the line of our theoretical predictions, from Table 7, we confirm that when a taxation regime is discriminated according to product quality, in equilibrium (net) prices tend to diverge, whereas under a taxation system that does not discriminate across quality products, (net) equilibrium prices converge, despite firms' level of efficiency. Hence, when a homogeneous tax rate is adopted, the high quality product segments experience a fall in the net producer prices as cross-tax and own-tax effects reinforce each other. When no discrimination is introduced in the taxation rates, the deadweight loss observed in the low quality market segment (in levels a loss of 152.6 million Euros) is counterbalanced by the gain fostered in the upper side of the quality spectrum (in levels we observe an improvement of Euros 412 million Euros), producing overall a positive effect on total consumer welfare. Moreover, when a non-differentiated taxation rate is adopted, a drop in the net prices in the high product market segment expands firms market share, and then their profits. Whereas, when discrimination in the tax rate is applied, low quality segments take advantage of a favourable tax and put net prices down, without expanding much firms' sales. Net producer prices dump in the high quality segment, causing an increase in the market shares. When profit or tax revenue gains are used to direct R&D into more efficient engines, as for example by developing greener technology that reduces the amount of CO2 emissions, this will generate welfare improving results in the medium term, despite in the short term we cannot see the beneficial effect.

Finally, from our analysis it emerges that by introducing a taxation regime whose tax rate is defined according to the quality product, we observe that for a marginal increment in the tax revenues (almost 87 million Euros), the loss in terms of consumer welfare (259 million Euros) is almost three times larger than the positive result in total revenues. This output reflects the classical dilemma of a government, when a tax regime is defined.

Summing up, our estimates of equilibrium net prices together with the results on consumer welfare and market share, corroborate the three propositions put forward in our theory.

6 Conclusions

The aim of this paper was to analyse how a change in taxation would affect market competition and welfare. We have developed a theoretical framework and empirically tested its predictions using data on the Irish automobile market. The central focus of our paper is on the case of a Vehicle Registration Tax (VRT), which is an ad valorem tax charged on the registration of all new automobiles in Ireland. This type of tax is differentiated according to a proxy for quality (engine size), and it is higher for new cars with a larger cubic capacity. We embedded this heterogeneity in taxation into an oligopolistic industry where differentiated quality products are supplied. In our theoretical model we showed the interaction between the proposed taxation with primitives of products. Focusing on a change in the taxation system from a homogeneous to a quality-differentiated product, we highlighted the nature of price competition between market segments, emphasizing the different own- and cross-elasticity effects on pricing, sales, and welfare.

We tested our predictions using a panel of data on new cars marketed in Ireland, by making use of a structural model of equilibrium inclusive of the effect of an ad valorem tax discriminated according to the engine size of the new cars. This approach allowed us to disentangle the important changes in the pivotal variables of our analysis, namely product pricing, consumer welfare, sales and tax revenue distinguishing between the alternative segments of the industry.

By accounting for the strategic interaction between firm rivals, our analysis has validated two important results. Firstly, according to the taxation regime in place, which either can discriminate according to product characteristics or alternatively recognize a homogeneous tax rate, the own- and cross- tax effects generate on the net pricing opposite results. By adopting an extended Ramsey Rule, we found that low quality market segments are much more price sensitive to the effects generated by their own- and cross- taxation, compared to the effect of taxation across segments. Second, the implications deriving from the cross-tax effects are pivotal. Controlling for proxies of cost, the net price divergence or convergence can fingerprint the offsetting nature of cross-tax effects on pricing. Own-tax effects predict one way, but the cross-tax effects move antithetically generating conflicting and a priori unknown results.

To assess the final outcome generated by a change in taxation regimes, we proposed a welfare analysis, which providing details on consumers and sale rent, shows the counterbalance results of the cross-tax effect. A differentiated taxation system, which taxes bigger engines more did not lead to a significant shift in sales structure, as was its objective, rather it shifted profits and consumer surplus away from bigger to smaller engines, as a result of a tax induced strategic change in the nature of short run price competition.

While tax revenue is considered neutral, assuming redistribution to other segments of society is free, the desired benefits on CO2 emissions is likely not be so great due to the net price responses as a reaction to the tax asymmetry. Small engine segments take advantage of a favorable tax to drop net producer prices to protect sales. Large engine segments bring net price up rather than expanding sales. If profits or tax revenue gains are used to invest R&D into more efficient engines in terms of CO2 emissions the environmental benefit may come in the medium run, but in the short run carbon dirty engines would be cheaper, and clean engines more expensive.

Our analysis provides an understanding on the changes in short run price competition, sub-market sales and welfare structure, in a way that one can expect from taxing an environmentally unfriendly aspect of a product. This is one first step towards an informed policy recommendation for which further investigations are needed.

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