Research on The Impact of The Carbon Tax on Social Welfare: A Theoretical Model Based on Internet Enterprises

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Abstract: As carbon dioxide emissions continue to grow in recent years, carbon taxes have been widely levied by countries all over the world. And considering the particularity of the Internet industry, we have constructed a theoretical model of the impact of carbon tax levied on two enterprises on social welfare. It divides the impact of carbon tax on social welfare into three parts: consumer surplus, producer surplus and external impact, and solves each part in turn to draw a conclusion. Compared with previous studies, this study makes a more general discussion on the impact of carbon tax on social welfare based on the relatively emerging Internet industry. However, due to a certain gap between some assumptions of the model and the real market situation, as well as the lack of data, the model still has some limitations, which need to be further improved.

Keywords: Carbon Tax, Social Welfare, Internet Enterprise, Theoretical Model.

1 Introduction

1.1 Background of research

The population of the world has increased a lot over last decades, and in particular, with the significant development of technology, much more coal, oil and gas are burned. Consequently, the situation of over-emitting carbon dioxide is getting worse; according to IEA (2021), the increase of over 1500Mt CO_2 would be the most significant single increase since the carbon-intensive economic recovery from the global financial crisis more than a decade ago [1].

Furthermore, according to BEA (2022), there is a 6.3% average annual growth of U.S. GDP led by the growth in infrastructure and e-commerce, which indicates that the digital economy has

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become a more vital part of the whole economy [2]. Therefore, more electricity would be used, and since most of the electricity is generated by burning fossil fuels, carbon dioxide emissions will rise.

Too much carbon dioxide can cause significant harmful effects on human health. Standing at a broader perspective, an increase in the atmospheric carbon dioxide levels can result in more devastating consequences on the environment, particularly, more heat will be trapped to the ground and this will contribute to the rise in global temperatures, and influence the climate change. Subsequently, extreme weather events will be formed and thus, disrupting plants' growth and animals' natural habits, which would result in long-term damage to human beings.

Countries worldwide consider emitting carbon dioxide a severe problem and have implemented various policies to reduce the emission and achieve a sustainable level. Among the effective approaches, a carbon tax is one policy this essay will mainly introduce. A carbon tax is a tax on carbon emissions generated by the combustion of fossil fuels. The tax is designed to internalize the externalities associated with fuel consumption (Poterba, 1991) [3]. Many countries in the European Union, for example, Netherlands and Denmark, have levied electricity taxes on companies and consumers.

1.2 Purpose of the research

This essay will suggest measures to obtain sustainable economic development and carbon dioxide emission reduction, specifically, raising suggestions for the government to set the reasonable tax rates and increase social welfare.

2 Literature review

In prior studies on the impact of the carbon tax on social welfare, mainly focus on the effects of carbon emissions on traditional manufacturing. Li Xvehui (2019) analyzes of the effect of the carbon tax on China's manufacturing industry from three aspects [4]. Arda Yenipazarli (2019) establishes the carbon tax environmental regulation model for remanufacturing sector [5]. Ouyang Lian Qun (2021) constructs the material utilization decision-making and social welfare model of the express packaging industry under the background of the carbon tax [6].

At the same time, for the previous literature on the relationship between carbon tax and social welfare, there are different research conclusions on the effect of carbon tax on social welfare. Some studies have concluded, contrary to common sense, that implementing a carbon tax will reduce social welfare. Berry (2019) makes sure that the carbon tax on energy-intensive products will increase the burden on low-income groups and cause energy poverty [7]. Liang and Wei (2012) draw a similar conclusion as well [8]. By analyzing the distribution effect of the carbon tax in China, they find that carbon tax will lead to the decline of family living standards and increase the gap between urban and rural areas. Other studies come to the opposite conclusions. Dogbe and Gil (2017) discuss the impact of a carbon tax on the food manufacturing industry, concluding that this impact is relatively weak [9]. Oladosu and Rose (2017) use the general equilibrium model and find that the carbon tax has an apparent positive effect [10].

The existing research primarily focuses on the traditional manufacturing industry, without in-depth discussion on Internet enterprises, and they mainly focused on a single type of market hypothesis and little product differentiation. They did not discuss the carbon tax effect in a more general situation. Therefore, this research attempts to propose a carbon tax model for Internet companies to study its impact on social welfare, and try to take product differentiation into consideration.

3 Model setup

3.1 Method of constructing the model

Referring to Zi-yue Chen and Pu-yuan Nie(2016), we mainly divide the model into three parts [11]. Firstly, we find the difference in the consumer surplus. Secondly, we obtain the change in the producer surplus. Finally, we see the external benefit we can gain from the reduced carbon emission.

As figure 1 shows, we construct the model similar to the structure of a Cournot model, a duopoly market. It cannot match the needs in the real world. The reason why we use this structure is that it can show a correlated tendency or effect due to some policies in the natural world [12]. In the market, two firms are producing the same goods, or we say two goods are close substitutes. One firm is creating with high quality, and another is producing with a relatively low quality. The external benefit is estimated by using a specific formula. To make it works, we need some parameters. From the article published by EPA in 2018, we can calculate the carbon emission level to determine the level of carbon emission we should pay for the tax [13]. Determine the quantity demanded is necessary. In this model, we use the utility formation to limit on people’s consumption of two firms to define the quantity demand of each firm. With the help of the consumption level defined, With the help of the consumption level defined we then find the rest two parts. Firstly, for the Producer surplus, due to the fact that there are only two firms in the market, the change in producer surplus is the change in a total profit of two firms before levying tax and the total gain after taxation. We will find the optimal price of two firms at different periods and the corresponding maximum profit of two firms during these periods to find the final equation. Secondly, the Consumer surplus, the most critical and complicated part of the model. Sum up the utility of each consumer, we get the consumer surplus. Do calculations on the different periods, we get the change in consumer surplus. The difference in social welfare will be the sum of the change in consumer surplus, producer surplus and external benefit.

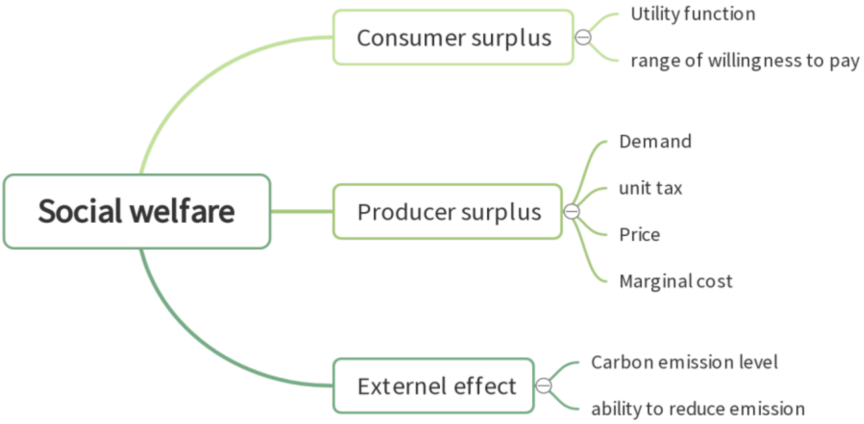

Figure1 Model Construction Framework

3.2 Variable list and Assumption

Table 1 Overall Variable List

Variable Name	SYMBOL	Description
Marginal cost	C	The unit cost of production of two firms
Quality	S	The quality of the products
Willingness to pay	W	The maximum price the consumer wants to pay for the products
Sense to quality	I	An index for determining the utility different consumers can gain from the quality of the products
Price	P	Price of the products
Unit tax	T	Unit carbon tax the firm need to pay
Function of unit tax	$f(\cdot)$	This function of unit tax for determining its value of it due to correlated parameters
Current carbon emission level	B	The current carbon emission level
Standard carbon emission level	β_s	The maximum level of carbon emission level a firm can produce
Carbon emission index	G	the index of defining a carbon emission level
average electricity consumed per hour	E	Average usage of electricity as a component of calculation of final

		electricity usage
Hours usage	C_e	A component of calculation of final electricity usage
Utility	U	Utility of consumer
Ability to shift	A	The percentage of carbon emission a firm can reduce by its own allocation of resources.
The upper boundary of willingness to pay	M	The maximum price consumer are willing to pay
Translation index of external effect	Θ	It translates a unit of emission into a monetary unit.

3.3 Assumptions

1) We assume consumers have the same maximum willingness to pay for products of firm one and firm two. That means we can consider it as when we consume a close substitute; if we do not know the quality, we have the same willingness to pay for these two products.

2) Two firms neither can reduce their carbon emission to the standard level. Due to the obvious problem of excessive carbon emissions and the demand to solve it, it is obviously not allowed to make it higher than the carbon emissions, otherwise the carbon tax policy will lose its effect.

3) Referring to the existing literature and for the convenience of calculation, willingness to pay and sense to quality are both uniformly distributed. This random assumption made to consumers is also consistent with the actual market.

3.4 Model Setup

a) Carbon emission level (β):

The overall variable list is shown in Table 1, according to the formula published by EPA [14], we get the general view of it to be:

$$\beta \ = g \times C_e \times E \tag{1}$$

g denotes the index of defining a carbon emission level with parameters of average electricity consumed per hour, which is E, and the hours' usage of electricity which is C_e.

b) Utility function(U):

According to Belleflamme, Paul, and Martin Peitz (2015) [15], the utility function is

$$U \ = \ W + I \times S - P \tag{2}$$

W denotes the willingness to pay. Denotes the index of utility consumers can gain from the quality of products, and S denotes the quality of products

c) Consumption

In two firms are with different prices and different quality. There will be a person with no difference in consuming the good produced by firm one and the good produced by firm two.

We construct the equation $W + I \times S_1 - P_1 = W + I \times S_2 - P_2$ and get the result:

$$I^* = \frac{P_1 - P_2}{S_1 - S_2} \tag{3}$$

A consumer with me that bigger than I^* will consume goods of firm one and the group of I smaller than I^* will consume good of firm two.

Quantity demanded of goods in firm one:

$$Q = 1 - I^* \tag{4}$$

Quantity demanded of goods in firm two:

$$Q = I^* \tag{5}$$

d) Tax per unit product(t):

Firms can allocate their production strategy of redistributing factors of production to reduce carbon emission. Can compare it to standard level, the excess carbon emission will be supposed be paying a tax. A tax function is used to calculate unit tax.

Unit tax:

$$t = f((1 - \alpha)\beta - \beta_s) \tag{6}$$

f (·) denotes the tax function of carbon emission, α denotes the percentage of carbon emission that can be reduced by allocating its factors of production, and β_s denotes the standard carbon emission level.

e) Profit

$$\pi = (P - C)Q \tag{7}$$

Put the calculated quantity equation into the formula we get:

Profit of firm one:

$$\pi = (P_1 - C - t_1)(1 - I^*) \tag{8}$$

Profit of firm two:

$$\pi = (P_2\text{-C-}t_2)\ \ I^* \tag{9}$$

f) optimal price

Set the first derivatives of firm1's profit and firm2's profit be zero, we get the best response of the price set by each firm

$$\frac{d\pi}{dP_1} = 1\text{-}\frac{2P_1-P_2-c-t_1}{S_1-S_2} \tag{10}$$

$$\frac{d\pi}{dP_2} = \frac{P_1-2P_2+C+t_2}{S_1-S_2} \tag{11}$$

$$P_1*(P_2*) = \frac{S_1-S_2+C+t_1+P_2}{2} \tag{12}$$

$$P_2^*(P_1^*) = \frac{P_1+C+t_2}{2} \tag{13}$$

Combine these two equations together we get:

$$P_1 *= \frac{2}{3}(S_1 - S_2) + C + \frac{1}{3}(2t_1 + t_2) \tag{14}$$

$$P_2 *= \frac{1}{3}(S_1 - S_2) + C + \frac{1}{3}(t_1 + 2t_2) \tag{15}$$

g) Maximum profit of each firm

$$\pi_1 = (P_1\text{- C - }t_1)\ (1\text{- }\frac{P_1-P_2}{S_1-S_2}\ ) \tag{16}$$

$$\pi_2 = (P_2\text{- C - }t_2) \times \frac{P_1-P_2}{S_1-S_2} \tag{17}$$

Taking $P1^*$ and $P2^*$ into the formula, we find the results:

$$\pi_1\ ^* = \frac{(\frac{2}{3}(S_1-S_2)-\frac{1}{3}(t_1-t_2))^2}{S_1-S_2} \tag{18}$$

$$\pi_2^* = \frac{(\frac{1}{3}(S_1-S_2)-\frac{1}{3}(t_1-t_2))^2}{S_1-S_2} \tag{19}$$

h) Consumer surplus

$$U = W + I \times S - P \quad (20)$$

According to Metin Ç Akanyıldırım (2018) [16], Utility of consuming goods of firm1:

$$U=\int_0^1 W + IS_1 - P_1 \, dI = W - \frac{1}{2}S_1 - P_1 \quad (21)$$

From U > 0, we get the lower boundary of W of consuming products of firm 1, for $W > P_1 - \frac{1}{2}S_1$

$$U = \int_{P_1-\frac{S_1}{2}}^{M} W + \frac{1}{2}S_1 - (\frac{2}{3}(S_1 - S_2) + C + \frac{1}{3}(2t_1 + t_2)) \, dW \quad (22)$$

Utility of consuming goods of firm2:

From U > 0, we get the lower boundary of W of consuming goods in firm 2, for

$$W > \frac{P_2 - S_2}{2} \quad (23)$$

$$U=\int_{P_2-\frac{S_2}{2}}^{M} W + \frac{S_2}{2} - (\frac{1}{3}(S_1 - S_2) + C + \frac{1}{3}(t_1 + 2t_2)) \, dW \quad (24)$$

i) Before tax

Profit of firm1:

$$\pi = (P_1 - C)(1 - \frac{P_1 - P_2}{S_1 - S_2}) \quad (25)$$

Profit of firm2:

$$\pi = (P_2 - C) \times \frac{P_1 - P_2}{S_1 - S_2} \quad (26)$$

Differentiate the formulas we get:

$$\frac{d\pi}{dP_1} = 1 - \frac{2P_1 - P_2 - C}{S_1 - S_2} \quad (27)$$

$$\frac{d\pi}{dP_2} = \frac{P_1 - 2P_2 + C}{S_1 - S_2} \quad (28)$$

Let the first derivatives of firm1's profit and firm2's profit be zero. We can find the best response of the price set by each firm,

$$P_1^*(P_2^*) = \frac{S_1 - S_2 + C + P_2}{2} \;;\; P_2^*(P_1^*) = \frac{P_1 + C}{2} \tag{29}$$

Combine these two equations we get:

$$P_1 *= \frac{2}{3}(S_1 - S_2) + C \tag{30}$$

$$P_2 *= \frac{1}{3}(S_1 - S_2) + C \tag{31}$$

Taking the dominant price into the profit function, we get the maximum profit for the two firms,

$$\pi_1 *= \frac{4}{9}(S_1 - S_2) \tag{32}$$

$$\pi_2 *= \frac{1}{9}(S_1 - S_2) \tag{33}$$

j) Change in producer surplus

Using the profit before tax minus the profit after taxing, we get:

$$\Delta\pi_1 = \frac{4}{9}(S_1 - S_2) - \frac{(\frac{2}{3}S_1 - S_2) - \frac{1}{3}(t_1 - t_2))^2}{S_1 - S_2} \tag{34}$$

$$\Delta\pi_2 = \frac{1}{9}S_1 - S_2) - \frac{(\frac{1}{3}S_1 - S_2) - \frac{1}{3}(t_1 - t_2))^2}{S_1 - S_2} \tag{35}$$

Change in producer surplus is the change in the profit of two firms. We sum up these factors and get the result:

$$\Delta PS = \frac{2}{3}(t_1 - t_2) - \frac{2}{9}(t_1 - t_2)^2 \tag{36}$$

k) Change in consumer surplus

Sum up the utility of each consumer:

Utility of consuming goods in firm1 before levying tax:

$$U = \int_{P_1 - \frac{S_1}{2}}^{M} W + \frac{1}{2}S_1 - (\frac{2}{3}(S_1 - S_2) + C)\, dW \tag{37}$$

Utility of consuming goods in firm2 before levying tax:

$$U = \int_{P_2 - \frac{S_2}{2}}^{M} W + \frac{1}{2}S_2 - \frac{1}{3}(S_1 - S_2) + C\ dW \tag{38}$$

From the equation:

$\Delta \quad CS_1 \quad = \quad \int_{P_1-\frac{S_1}{2}}^{M} W + \frac{1}{2}S_1 - (\frac{2}{3}(S_1 - S_2) + C)\, dW - \int_{P_1-\frac{S_1}{2}}^{M} W + \frac{S_1}{2} - (\frac{2}{3}(S_1 - S_2) + C + \frac{1}{3}(2t_1 + t_2))\ dW$

(39)

$\Delta \quad CS_2 \quad = \quad \int_{P_2-\frac{S_2}{2}}^{M} W + \frac{1}{2}S_2 - \frac{1}{3}(S_1 - S_2) + C\ dW\ - \int_{P_1-\frac{S_1}{2}}^{M} W + \frac{1}{2}S_1 - (\frac{2}{3}(S_1 - S_2) + C + \frac{1}{3}(2t_1 + t_2))\ dW$

(40)

We get the result:

$$\Delta CS_1 = \frac{1}{3}(2t_1 + t_2)M - \frac{1}{18}S_1 - 4S_2)(2t_1 + t_2) - \frac{1}{3}(2t_1 + t_2)C - \frac{1}{18}(2t_1 + t_2)^2 \quad (41)$$

$$\Delta CS_2 = \frac{1}{3}(t_1 + 2t_2)M - \frac{1}{18}(2S_2 - S_1)(t_1 + 2t_2) - \frac{1}{3}(t_1 + 2t_2)C - \frac{1}{18}(t_1 + 2t_2)^2 \quad (42)$$

Add these two factors together, we get the change in consumer surplus:

$$\Delta CS = (t_1 + t_2)(M - C) - \frac{1}{18}(t_1S_1 - 6t_1S_2 - t_2S_1) - \frac{1}{18}(5t_1{}^2 + 8t_1t_2 + 5t_2{}^2) \quad (43)$$

l) External benefit

From A. Yenipazarli (2016) [17], we use the reduced carbon emission level multiple its index to get the final effect,

$$EB = \theta\alpha\beta \quad (44)$$

m) Overall change in social welfare

$$\Delta SW = \Delta PS + \Delta CS + \Delta EB \quad (45)$$

To make a simple calculation, we firstly find the value of unit tax (t1 and t2) from the equation in the section4, then take the value calculated in section10, section11 and section12 in the formula, we conclude:

$$\Delta SW = \frac{2}{3}(t_1 - t_2) + (t_1 + t_2)(M - C) - \frac{1}{18}(t_1S_1 - 6t_1S_2 - t_2S_1) - \frac{1}{2}(t_1{}^2 + t_2{}^2) + \theta\ (\alpha_1 \times g \times C_{e1} \times \mathbf{E_1} + \boldsymbol{\alpha_2} \times g \times C_{e2} \times \mathbf{E_2})$$

(46)

3.5 Evaluation

The model structure used is the Cournot model, and is not the real market. Therefore, the result might not be that accurate for the real market. However, the general effect of the carbon tax on the market is what we can get from the model. The willingness to pay is assumed to be uniformly distributed, but due to the distribution of income, it cannot be that case. It will show a very complex distribution so that this assumption might cause some error.

Another case is that the marginal cost of production was assumed to be exact the same, but the products are of different quality. Indeed, it cannot be the exact cost, but the consequence here can be ignored.

On the other hand, the difference in qualities makes a more reasonable model view. It shows the reaction of consumers choosing products between a high-quality product with a higher price and a lower one with a lower price.

Finally, due to the lack of data, as there is not much the data about the carbon tax, the data we input need to be estimated by ourselves. This will cause the uncertainty; also the information we choose to input might be that close to the reality.

4 Conclusion

Due to the reason that there is not a clear sign, we cannot find whether the tax is beneficial or not directly from the equation. To find the final result, we need to input data into the formula to make a graph to show the general trend. This trend will be what we want to find. Our expected value is with a positive sign, so if the result shows a negative sign, we will make further modelling to find possible uncertainty led and is shown potential errors in our model.

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