A SOCIAL WELFARE ANALYSIS OF CALIFORNIA'S CAP & TRADE

By

JOHN BRUNOLLI

A thesis submitted in partial fulfillment of
the requirements for the degree of

MASTER OF SCIENCE IN APPLIED ECONOMICS

WASHINGTON STATE UNIVERSITY
School of Economic Sciences

MAY 2020

To the Faculty of Washington State University:

The members of the Committee appointed to examine the thesis of JOHN BRUNOLLI find it satisfactory and recommend that it be accepted.

Ana Espinola-Arredondo, Ph.D., Chair

Felix Munoz-Garcia, Ph.D.

Liang Lu, Ph.D.

ACKNOWLEDGMENT

I would like to dedicate this section to my amazing advisor, Dr. Espinola-Arredondo. Without her support and guidance, I would not have been able to write this paper. I am extremely grateful for her guidance and expertise.

A SOCAL WELFARE ANALYSIS OF CALIFORNIA'S CAP & TRADE

Abstract

by John Brunolli, M.S.
Washington State University
May 2020

Chair: Ana Espinola-Arredondo

This paper evaluates California's (CA) cap & trade program (C&T) and its social welfare implications. I utilize a theoretical simultaneous move game to determine the optimal outcome for C&T. The outcome for such policy indicates that CA will implement C&T inducing firms to invest in abatement technology. To analyze if the theoretical results are occurring in practice, I collected data from the California Air Resources Board (CARB), Bureau of Economic Statistics (BEA), and the U.S. Energy Agency (USEIA), and used a standard OLS regression to measure social welfare. I found that there is a downward trend in the profits of the firms in the CA industry and emissions have increased under C&T.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

SECTION ONE: INTRODUCTION

Ninety-seven percent of scientists agree that climate change is real and human activity is the main contributor to the problem[1]. It is undeniable that policy makers must enact regulations that curbs the flow of emissions and encourages investments in cleaner technology. The difficulty then begins in the economic and political realm. Many countries have enacted carbon taxes in which they tax the emissions released with the intention of curbing emissions. Other countries seek a free market approach, subsidies in clean technology or C&T. In the United States, it is rather interesting. Certainly, there are environmental regulations such as the Clean Air Act and the Clean Water Act. However, in terms of economic policy, the United States has no strong program such as C&T and is decentralized.

In 2013, Governor Jerry Brown decided to implement a C&T program in CA attempting to reduce its emissions. The program has many criticisms[2]; however, the program is being deemed a success. This paper analyzes the social welfare implications of the program by first developing a theoretical model using game theory representing the interaction between oil refineries and the regulating agency in CA. The game consists of three players, composed by two firms and the regulator. The regulator sets a policy that maximizes the social welfare outcome for the state. The firms choose their optimal production when facing a C&T policy or when they are not facing the policy. The oil refineries according the CARB produces the majority of the industrial pollution. This fact makes the oil refineries an excellent candidate to model the social welfare implications of the C&T program. To do this I obtained data from the USEIA, CARB,

[1] "Scientific Consensus: Earth's Climate is Warming", https://climate.nasa.gov/scientific-consensus/
[2] Richard Sexton and Steven Sexton, "The Fatal Flaw in California's Cap-and-Trade System", The Washington Post https://www.wsj.com/articles/the-fatal-flaw-in-californias-cap-and-trade-program-1508538322

and the BEA. I will implement a standard OLS estimator of the industry's profits and emissions determine the social welfare benefits. There has been a decline in profits under the C&T system and the emissions have increased, but the number is statistically insignificant and the graphs demonstrate otherwise. That could potentially imply my theoretical game practicality by illustrating that firms are investing in abatement technology.

SECTION TWO: LITERATURE REVIEW

Many of the previous literature analyzing the social welfare effects from environmental tools are carbon taxes & C&T. Most of the literature is split evenly between using more theoretical early on in the beginnings of the literature, though some empirical. More recently the literature has shifted to a more empirical approach, though with some theoretical in the cases in which a policy is at first being developed. Pethig (1976) analyzed a theoretical concept of an economy implementing environmental policies to combat pollution. He demonstrates that a single economy not within a trade agreement gains in the overall social welfare due to the fact of the net positives from the environmental policies. However, when the model expanded to two theoretical countries entered in a trade agreement, he discovers that the country without the environmental regulations is the net winner from the policy. Cornes (1985) paper analyzes Pigouvian taxes on externalities under a Nash and a non-Nash behavior. In a Nash behavior, there would have to be larger corrective measures to get the optimal social outcome, since Nash implies that the actions of others have no effect on an individual firm. Non-Nash may experience an external problem if the corrective actions are too great and should implement in a smaller increment to minimize the damage since the others will follow suit.

Böhringer and Rutherford (1997) examines the welfare loss if the German economy issues exemptions from a carbon tax. They gathered 58 industries and implemented six scenarios and examine what the overall effects are. They found that a uniform carbon tax, no exemptions, is the most optimal solution because of the increased welfare benefits from the policy compared to the other five scenarios. This is different to my paper since I am focusing on one industry. In addition, I am brining in the profits effects from the policy. Aronsson (1999) establishes the cost benefits rules about green taxes. He examined the reforms, simulated some alternatives, and established social welfare outcomes. My paper will be different because I am focusing on a single industry and have empirical justifications. Komen (1999) implemented an applied general equilibrium model of the Netherlands energy tax they implemented. The results showed carbon taxes and energy taxes reduced energy consumption by 2.6% and reduced CO_2 emissions by 2%. The sensitivity tests showed an energy tax at a low rate yields net social welfare benefits. My research is different because I am examining on a highly polluting industry and not households.

Strand (2013) uses game theory to determine the optimal equilibrium between carbon tax and cap & trade. Strand conducted six scenarios and determined that carbon tax is strictly preferred unless if the country is an importing oil country, then cap and trade would be the most favored. My research is different due to the fact that my paper focuses on a state.

Not only did Strand (2013) contributed to the C&T literature, Fowlie (2010) also influenced the C&T policy by laying out how CA should structure the permit system. She demonstrates the efficiencies and clarity that a C&T program must hold to be considered a success. Along with Fowlie (2010), Robert Hahn and Robert Stavins (2011) used a theoretical approach with Coase Theorem to establish the efficiencies within a C&T system. They provided seven cases in both containing where Coase Theorem held and cases where it did not hold demonstrating the efficiencies within their system. Johannes Jarke and Grischa Perino (2017) contributed by demonstrating inter industry leakage effect under a C&T system. The authors used a two-sector general equilibrium model to demonstrating that if the cap does not capture all sectors, then there presents a likely inter industry leakage. Consequently depending on the structure of the subsidy, revenues raised from a lump-sum tax can greatly determine if negative leakage will arise.

Yamazaki's (2017) paper addresses the potential employment effects of British Columbia's carbon tax policy the providence enacted in 2008. He uses a simple model to illustrate the carbon tax imposed in 2008 did not negatively influence unemployment but instead caused a redistribution effect throughout the industries. Yamazaki's equation attempts to capture the effect of employment, GHG, and the overall impact of the carbon tax implementation through the years he modeled obtained from Statistics Canada. His paper overall demonstrates that carbon taxes will not adversely decline employment, trade intensity certainly can negatively affect employment, but if the redistribution holds then it will influence the employment positively. My idea is different from Yamazaki's because I am focusing on one specific industry. In addition, I study the C&T policy.

SECTION THREE: THEORECTICAL RESULTS

I develop a complete information sequential move game to model strategic interactions in the oil industry. I assume the industry produces a homogenous product. In the first stage, the regulator observes firms' production cost and chooses to implement C&T or not implement the policy. In the second stage, every firm moves simultaneously and independently regarding to invest or not in a filter which is costly, $F > 0$. In the last stage, each firm will produce the optimal amount of output, competing a la Cournot, after observing the decision of the regulator. Operating by backward induction I first focus on the firms optimal production. Firms face a linear demand function, $P = 1 - Q$, in which P denotes the price of the good, Q represents the quantity for both firms, $(q_i + q_j)$. In addition, firms face the same marginal production cost c.

Subgame 1a. The regulator set C&T and both firms invest

Each firm i faces the following profit maximization problem if the regulator chooses C&T.

$$\max_{q_i} \pi_i = \left(1 - \left(q_i + q_j\right)\right) q_i - c q_i - \overline{p}\left(\left(q_i - a\right) - \overline{q}\right) - F$$

where the first term represents the total revenue, the second term is the total production cost, and the third term denotes the cost of abating $(q_i - a)$ units of pollution when the firm receives $\overline{q}$ permits and the price of each additional permit is $\overline{p}$. Finally F represents the fixed investment cost in abatement technology. Taking the first order conditions with respect to $q_{i\,\mathrm{I}}$ find.

$$\frac{d\pi_i}{dq_i} = 1 - 2q_i - q_j - c - \overline{p}$$

$$\frac{d\pi_j}{dq_j} = 1 - 2q_j - q_i - c - \overline{p}$$

Solving the equations for q_i yields the best response function.

$$q_i(q_j) = \frac{1 - c - \overline{p}}{2} - \frac{1}{2} q_j$$

Substituting $q_j(q_i)$ into $q_i(q_j)$ yields the quantity each firm produces.

$$q_i = \frac{1 - c - \overline{p}}{3}$$

The firms will produce this amount if CA implements C&T. Plugging both of these quantities back into the profit maximization function yields the profits.

$$\pi^* = \frac{1 + c^2 - 2c(1 - \bar{p}) - \bar{p}(2 - \bar{p} - 9a - 9b)}{9} - F$$

For simplicity, I consider $\bar{p}$=a=$\overline{q}$=$\frac{1}{2}$ yielding the following profits.

$$\pi^* = \frac{1 + a}{2} - F$$

Subgame 1b. The regulator sets C&T but no firm invests.

Then I proceeded to solve the firms production if CA chooses to implement C&T, however the firms opts not to make an investment despite the fact that they will be subject to larger abatement cost since the firm emits more emissions per output produced. Every firm solves.

$$\max_{q_i} \pi = \left(1 - \left(q_i + q_j\right)\right) q_i - c q_i - \overline{p}(q_i - \overline{q})$$

.

This case is equivalent to that in subgame 1a but evaluated at *a=0* and *F=0*. The firms are still faced with the fees and are captured by the new equation representing the production the firm produces and the aggregate production. Implying firms will face more costly abatement if it chooses not to invest in abatement technology. Consequently, the firm's best response functions will be:

$$q_i(q_j) = \frac{1 - c - \overline{p}}{2} - \frac{1}{2} q_j$$

Repeating the same process as in the first case will yields equilibrium output.

$$q_i = \frac{1 - \mathrm{c} - \overline{p}}{3}$$

Plugging these values back into the profit maximization in this subgame yields the following profit.

$$\pi^* = \frac{1 + c^2 - 2c(1 - \bar{p}) - \bar{p}(2 - \bar{p})}{9}$$

This results in not capturing the abatement cost. Evaluating the profit equation at $\bar{p}$=$\overline{q}$=$\frac{1}{2}$ generates.

$$\pi^* = \frac{\frac{1}{4} + c^2 - c}{9}$$

Subgame 1c. The regulator sets C&T and only one firm invests.

To evaluate the effects if one firm invests in abatement technology but the other did not, I rewrote the formula to represent what would happen if firm *i* opted to invest in abatement technology, while firm j did not. This is represented by the following equations.

$$\max_{q_i} \pi = \left(1 - \left(q_i + q_j\right)\right) q_i - c q_i - \bar{p}\left((q_i - a) - \bar{q}\right) - F$$

$$\max_{q_j} \pi = (1 - (q_j + q_i))q_j - c q_j - \bar{p}\left(q_j - \bar{q}\right)$$

where the difference is firm *i* is investing in abatement technology while firm *j* is not investing. Taking the partial derivatives of these two equations yields the following and rearranging the equation to obtain the best response functions.

$$q_i\left(q_j\right) = \frac{1 - c - \bar{p}}{2} - \frac{1}{2} q_j$$

$$q_j(q_i) = \frac{1 - c - \bar{p}}{2} - \frac{1}{2} q_i$$

Now plugging the best response function for q_j into the best response function for q_i yields.

$$q_i = \frac{1 - \mathrm{c} - \bar{p}}{3}$$

$$q_j = \frac{1 - \mathrm{c} - \bar{p}}{3}$$

Then I proceeded by inserting these equations into the profit equations and that yields.

$$\pi_i = \frac{(1 - c - \bar{p})(1 - c - 2\bar{p}) - \bar{p}(2 - \bar{p} - 9a)}{9} - F$$

$$\pi_j = \frac{(1 - c)(1 - c - 2\bar{p}) - \bar{p}(2 - \bar{p})}{9}$$

Evaluating these profits at the same parameter values as subgames 1a and 1b ($\bar{p}$=a=$\bar{q}$=$\frac{1}{2}$) yields.

$$\pi_i = \frac{c^2 - \frac{1}{2}c + \frac{3}{4}}{9} - F$$

$$\pi_j = \frac{c^2 - \frac{1}{2}c + \frac{3}{4}}{9}$$

Subgame 2a.

Consider now, that in the first stage, the regular chooses not to implement C&T and the firms respond with investing in abatement technology. The every firm *i* faces.

$$\max_{q_i} \pi = \left(1 - \left(q_i + q_j\right)\right) q_i - cq_i - F$$

Ever firm *i's* best response functions is.

$$q_i(q_j) = \frac{1-c}{2} - \frac{1}{2}q_j$$

Substituting firm *j's* into firm *i's* yields the equilibrium output.

$$q_i = \frac{1 - \mathrm{c}}{3}$$

Inserting these quantities into the profit equation yields the following profit.

$$\pi^* = \frac{(1 + c^2 - 2c)}{9} - \mathrm{F}$$

Evaluating the profits at $\bar{p}$=a=$\bar{q}$=$\frac{1}{2}$ will yield the same equation as above. Therefore the firms will have little incentive to invest in abatement technology.

Subgame 2b. The regulator does not implement C&T and no firm invests.

If firms opt not to invest then, the abatement term drops and as a consequence they will only be subjected to a cost of operation. Now every firm *i* solves.

$$\max_{q_i} \pi = \left(1 - (q_i + q_j)\right) q_i - c q_i$$

Taking the first order conditions and rearranging yields the best response functions.

$$q_i(q_j) = \frac{1-c}{2} - \frac{1}{2} q_j$$

Using the best response function, I find the quantity produced by every firm in this case:

$$q_i = \frac{1 - \mathrm{c}}{3}$$

Then substituting these into the equation yields the profits.

$$\pi^* = \frac{(1 + c^2 - 2c)}{9}$$

Subgame 2c. The Regulator does not implement C&T and only one firm invests.

But in the instance that firm *i* invests in abatement technology and firm *j* does not, firms solve.

$$\max_{q_i} \pi = \left(1 - (q_i + q_j)\right) q_i - c q_i - F$$

$$\max_{q_j} \pi = (1 - (q_j + q_i)) q_j - c q_j$$

Taking the first order conditions and solving to yield the best response functions.

$$q_i(q_j) = \frac{1-c}{2} - \frac{1}{2}q_j$$

$$q_j(q_i) = \frac{1-c}{2} - \frac{1}{2}q_i$$

Now solving for the best response functions yields the following equilibrium output.

$$q_i = q_j = \frac{1-\mathrm{c}}{3}$$

Plugging these equations into the profit equation will yield.

$$\pi_i = \frac{(1+c^2-2c)}{9} - F$$

$$\pi_j = \frac{(1+c^2-2c)}{9}$$

Profit comparisons after C&T

If the regulator implements C&T and firm *j* invests, firm *i* responds investing if and only if.

$$\frac{1+a}{2} - F \geq \frac{\frac{1}{4} + c^2 - c}{9}$$

which, solving for F yields.

$$F \leq \frac{9a + \frac{15}{2} - 2c^2}{9}$$

If, still in the context of C&T, firm *j* does not invest, firm *i* responds invest if and only if.

$$\frac{c^2 - \frac{1}{2}c + \frac{3}{4}}{9} - F \geq \frac{\frac{1}{4} + c^2 - c}{9}$$

which solving for *F*, yields.

$$F \leq \frac{\frac{1}{2} + \frac{1}{2}c}{9}$$

If these conditions are met, then firm *i* will chose invest. Likewise as highlighted in subgame 1c, if firm *j* decides to not invest then they will not maximize their profits under C&T. Therefore, it is in the best interest of both firms to invest in abatement technology.

Though this may not always be the case. As long as the cost for abatement, *F*, holds then both firms have plenty incentives to invest in abatement technology. If the total cost parameter *c*, is different from my assumption, then this could drastically alternate the abatement cost. For example, if firm *j* is drilling deeper for oil, then that implies that they will be faced with a higher total cost. That could mean that for firm *j* they have little incentive to invest in abatement technology. Likewise, if firm *j* is drilling offshore for their oil, that could still alternate the cost and motivation for investing in abatement technology. With a demonstrated change in cost could change the condition for *F*.

Another factor that could change the condition for *F* or the firm's decision is the costs for other oil sources. In my example, I assume for simplicity that all oil is the same. Though that is not always the case. In the United States, customers for the oil refineries could potentially choose oil from the Gulf States because it may be cheaper. That could influence the decision and condition by unearthing the competition factor. If investing in abatement technology would cause clients to deviate towards foreign or domestic competitors, which could cause the condition for *F* to be drastically lowered in order for firms to choose invest. Also, the *c* parameter must be lower too or the *a* in the profit equation in subgame 1a. must be significantly higher than the costs.

Profit comparison after no C&T

If the regulator decides not to implement C&T and firm *j* invests, firm *i* invests if and only if.

$$\frac{(1 + c^2 - 2c)}{9} - F \geq \frac{(1 + c^2 - 2c)}{9}$$

which solving for *F* yields, $F \leq 0$, which cannot hold by assumption. Consequently, firm *i* responds with no invest when its rival invests.

If in the context of no C&T, and firm *j* does not invest, firm *i* responds with invest if and only if

$$\frac{(1 + c^2 - 2c)}{9} - F \geq \frac{(1 + c^2 - 2c)}{9}$$

which solving for *F* yields $F \leq 0$, which cannot hold by assumption. Therefore, under a no C&T game, it is in the best interest in firms to not invest. This signals in this branch a dominant strategy for both firms is no invest. Therefore, the regulator knows how this game will develop and will evaluate their best interest.

In terms of varying cost within the industry, the solution will not change as drastically as in the instance where firms are facing C&T. Since the condition for *F* does not hold in this case, the only element that would change is just the profits, the solution will not change. Since there are similar results really a change in parameter *c* would just cause firms to just lose profits. Since in the instance when both firms choose not to invest in abatement technology, firms still do not have incentive to switch their decision to invest because in that instance they will actually lose more profits if the parameter *c* is different. Therefore, the only change will be one firm will make less profit, otherwise they will not change their decision not to invest.

In the instance in which nationally oil is different, when the firms do not face C&T, both the solution and condition for *F* does not alternate. If anything perhaps profit would and quantity produced would, however this would not significant alternate the outcome. First, the condition cannot hold by assumption, therefore, nationally different oil will not affect the firms decision to choose invest. Finally, under the national differences between oil, this does not change their chose of not investing in abatement technology because even when the differences are present firms are still making more profit under that chose. Consequently, under this condition the outcomes are not going to be effected.

Welfare analysis

Then I proceed to solve the regulators game. The regulator will use the following equation to capture the social welfare of CA.

$$\max_{Q} SW = PS + TR - ENV$$

Where this maximization represents the producer surplus represented by the firms profits from the industry and the environmental damage is represented by$-\delta(q_i + q_j)$. Where $q_i + q_j$ is the aggregate output of the firms. I am not considering consumer surplus for this social welfare maximization problem because CA oil is widely sold outside of the state and considering consumer surplus may cause an issue with fully capturing the social welfare within CA. Within social welfare there could be some crossovers, such as a change in the price of oil, therefore in order to gain a purer insight into the oil refineries I just solely focusing on the producer surplus. I substituted the aggregate profits and production into the social welfare equation for the regulator and now the equation is:

$$\max_{Q} SW = \left(\frac{1 + c^2 - 2c(1 - \overline{p}) - \overline{p}(2 - \overline{p} - 9a - 9b)}{9}\right)Q$$

$$- \delta(\frac{1 + c^2 - 2c(1 - \overline{p}) - \overline{p}(2 - \overline{p} - 9a - 9b)}{9})Q$$

Since I know what the quantities of the industry are and the parameters of interest I took a comparative static with respect to the permits and abatement technology. Taking the derivative with respect to $\bar{p}$ and solving for $\bar{p}$ yields the following.

$$\bar{p} = \frac{4c + 18a + 18b}{4}Q$$

The comparative statics shows that the permits are increasing social welfare by this equation. In other words, the revenues generated by the permits will be allocated to decrease emission standards. Then I conducted another comparative static but with the environmental damage δ.   Doing this yielded the following result for δ.

$$\delta = 1$$

Overall this is a good sign for C&T because that means the environmental damages are being reduced when there is regulation present. This result captures that social welfare is maximized when both firms reduce their production. What is the main driver for the reduction in environmental damage is the permits that the firms will purchase and that is overall yes reducing the profits of the firms, but the result is also greatly reducing the environmental damage. Within the equation, the investment is captured and that will decrease the production from the firm. As a consequence, will reduce the pollution from the firms. Next, I examined the regulators other option, when they do not implement cap and trade, they are faced with the following maximization problem.

$$\max_{Q} SW = \left(\frac{(1 + c^2 - 2c)}{9}\right)Q - \delta\left(\frac{(1 + c^2 - 2c)}{9}\right)Q$$

Where when the regulator opts not to implement cap and trade, the permits are not being purchased and are dropped from the equation. Therefore, failing to capture the benefits of the revenues generated from the environmental damage and not minimizing the environmental damage. Taking the derivatives with respect to δ will the effects on the social welfare.

$$\frac{dSW}{d\delta} : \frac{(1 + c^2 - 2c)}{9}Q$$

The pollution variable is implicitly captured within the output level and therefore implies that the pollution will be worse. Therefore, will exhibit a lower social welfare since the environmental damages will be greater in this solution compared to the implemented cap and trade social welfare solution. Though the production is up and the firms are capturing more profits, the environmental damages are highly consequential. Hence the introduction of regulation produces higher welfare when the damage is sufficiently high and induces the firms to invest in abatement technology. Thus, the optimal solution for this game is.

$$(CT, Invest, Invest)$$

SECTION FOUR: EMPIRICAL RESULTS

This result is what I theoretically would expect. Depending upon the outcomes such as in Hahn (2010)[3] regarding competition and incentives structure within the policy, upholding Coase Theorem, and a realistic expectation. Nevertheless, I examine empirically how the program is currently working. I use the following dataset:

Table 1

```
##              vars  n      mean       sd    median   trimmed      mad
## Year*           1 18   2008.50     5.34   2008.50   2008.50     6.67
## CO2             2 18  86260.07 37012.20  85938.56  86062.95 35711.82
## CH4             3 18     87.47    37.53     87.15     87.27    36.22
## N2O             4 18    208.54    89.48    207.75    208.06    86.33
## Sales           5 18  10909.68   613.83  10909.70  10866.08   579.62
## Production      6 18 218312.67 27630.56 210897.50 217818.31 21061.82
## Profits_GDP     7 18  11392.98  5976.94  12096.40  11168.13  8350.00
## YD              8 18      0.28     0.46      0.00      0.25     0.00
##                    min       max     range  skew kurtosis      se
## Year*          2000.00   2017.00     17.00  0.00    -1.40    1.26
## CO2           26189.83 149484.11 123294.28 -0.18    -1.11 8723.86
## CH4              26.56    151.59    125.03 -0.18    -1.11    8.85
## N2O              63.33    361.38    298.06 -0.18    -1.11   21.09
## Sales         10193.00  12324.10   2131.10  0.76    -0.35  144.68
## Production   173403.00 271132.00  97729.00  0.42    -1.05 6512.59
## Profits_GDP    4046.50  22337.10  18290.60  0.15    -1.58 1408.78
## YD                0.00      1.00      1.00  0.91    -1.23    0.11
```

I obtained the data from the BEA, CARB, and EIA. Within this dataset I originally had seven variables. I created a dummy variable where 1 = every year greater than or equal to 2013, 0 if otherwise. That way I am capturing the effect of the policy within the years 2013 to 2017. Unfortunately, I was not able to obtain 2018 or a monthly breakdown due to limitations within the reporting in the agencies. However, I am able to obtain the best possible data to measure this policy. I only have 18 observations because this is yearly data ranging from 2000 to 2017. I

[3] Hahn, Robert W., and Robert N. Stavins. "The Effect of Allowance Allocations on Cap-and-Trade System Performance." The Journal of Law and Economics 54, no. S4 (2011). https://doi.org/10.1086/661942.

obtained the yearly carbon, methane, and nitrous oxide releases into the atmosphere from CA's oil refineries. I obtained the sales, production and profits from the industry. This will add value to the theory through obtaining an inference of how the policy is operating. I expect the emissions to decrease over the years of the policy. I foresee a profit decrease because of the theory I established regarding the consequences of reducing production.

To measure social welfare, I modeled the profits and emissions of the firms by the following equations.

$$\pi = \alpha + \beta_1 \Theta + \beta_2 \rho + \varepsilon$$

$$CO2 = \alpha + \beta_1 \Theta + \beta_2 \rho + \varepsilon$$

$$CH4 = \alpha + \beta_1 \Theta + \beta_2 \rho + \varepsilon$$

$$N20 = \alpha + \beta_1 \Theta + \beta_2 \rho + \varepsilon$$

where π is the profits of the firms, $CO2$ is the amount of carbon dioxide emitted by the industry emitted into the atmosphere, $CH4$ is the amount of methane the industry emits into the atmosphere, $N20$ is the amount of nitrous oxide the industry emits, Θ is the C&T policy implemented in 2013, and ρ is the total production of the oil industry. I used the different emissions in the equations because of concerns regarding if $CO2$ decreases does not mean that $CH4$ decreases too. Θ is the variable of interests because this will be an indicator of how the profits of the firms are being affected by C&T. I implemented this regression in R and developed the following results on Table 2:

```
                              Table 2

##
## =========================================================
##                             Dependent variable:
##              -------------------------------------------
##               Profits_GDP      CO2        N2O      CH4
##                   (1)          (2)        (3)      (4)
## ---------------------------------------------------------
## YD           -8,907.003***  10,019.250   24.214   10.160
##               (2,891.775)  (24,083.200) (58.222) (24.422)
##
## Production     -0.185***      0.535      0.001    0.001
##                 (0.048)      (0.402)    (0.001)  (0.0004)
##
## Constant     54,174.560*** -33,292.170  -80.448  -33.761
##              (11,071.300)  (92,203.660) (222.907) (93.500)
##
## ---------------------------------------------------------
## Observations      18            18         18       18
## =========================================================
## Note:                          *p<0.1; **p<0.05; ***p<0.01
```

As one-year progresses, the oil industry loses a profit margin of $8,907. This result is as expected because this is what theoretically I predicted the initial loss of profits by the firms. But the emissions have increased, though statistically insignificant. These results is unexpected due to the trends within the data. To confirm that these measurements can be a reliable measure I executed some diagnostics. I tested for heteroskedasticity within my models by generating a graph with the fitted values and residuals to see if heteroskedasticity is present. I observed some potential probability that heteroskedasticity is in the model and I ran a Breusch-Pagan test (BP test). Based on the BP test, I could not determine that the model is heteroskedastic. Next, I tested normality by using quartile lines and ran a Shapiro-Wilks test. The tests confirmed that the model is following a normal distribution. Given the limited observations this may be troublesome, however the tests confirm that these are the best possible models. To illustrate the questionable results regarding emissions, I generated the following graphs:

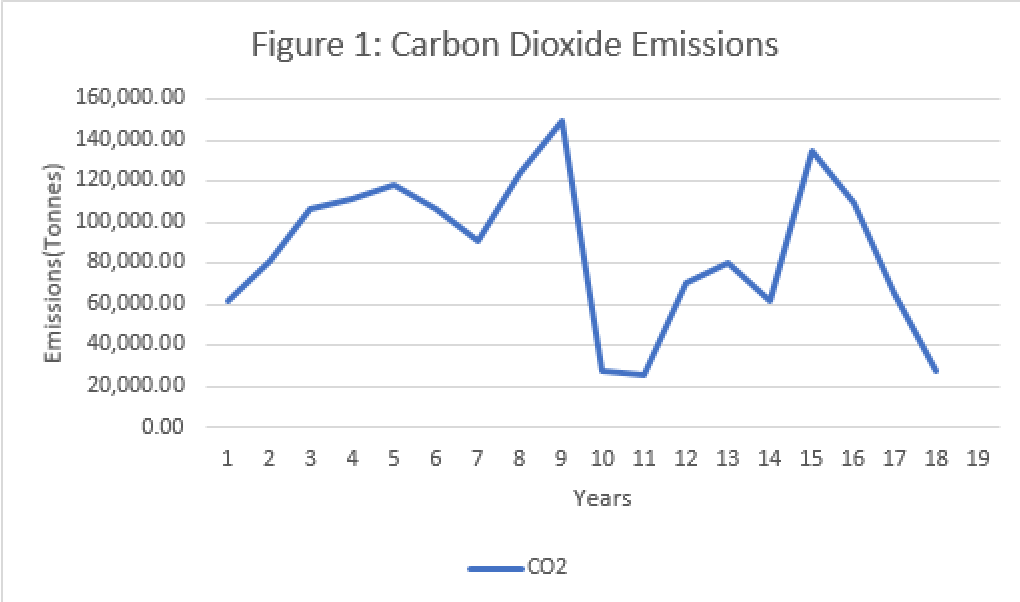


Figure 1: Carbon Dioxide Emissions
160,000.00
140,000.00
120,000.00
100,000.00
80,000.00
60,000.00
40,000.00
20,000.00
0.00
Emissions(Tonnes)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
Years
CO2

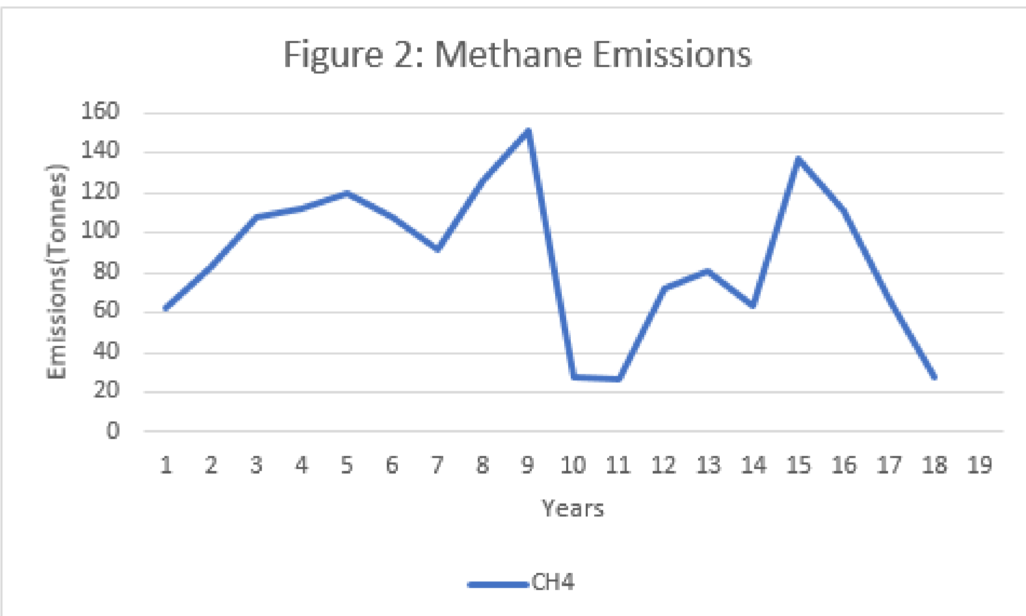
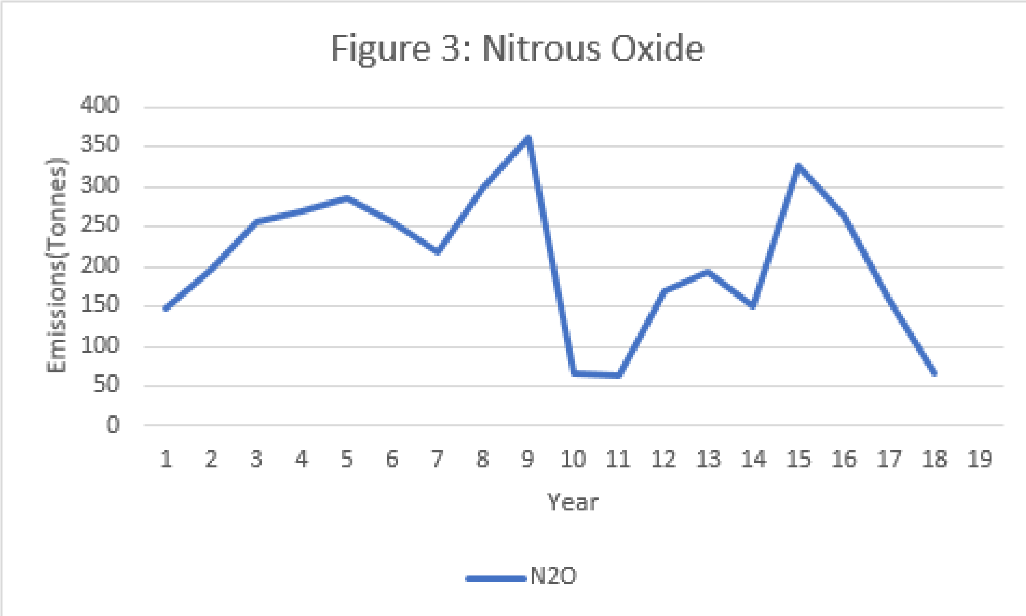


Figure 2: Methane Emissions
160
140
120
100
80
60
40
20
0
Emissions(Tonnes)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
Years
CH4



The graphs demonstrate a downwards reduction in the emissions by the industry as I expected. Which is counterfactual to the regression I generated. The graphs are illustrating a downwards trend after the policy was enacted. In 2014 and 2015 there was a sharp increase in emissions, however after 2015 the emission are sharply declining. Consequently, illustrating a good sign for C&T.

SECTION FIVE: DISCUSSION

The results are providing mixed evidence for C&T in CA. Certainly profits of firms is an important measure, however looking at the emissions, there have been a downward trend in emissions. Especially around the implementation of C&T. This potentially could indicate that the social welfare within CA is increasing because this implies that the atmosphere is less polluted. With much improved air quality, will lead to more optimal health outcomes within the state. Therefore, increases the social welfare of the state.

In addition, other economic factors may result in the decrease in profits. What could explain the loss in profit is the initial investment in a filter. Firms investing in abatement technology could be an indicator for the loss in profits. Also, the industry losing its profits can result from substitution effects generated from the cleaner alternative energy resources in CA. For example, CA is a unique state in the sense of how different the demographics of the state is. In the Los Angeles area, the area possesses a strong car culture and that could drive the demand for oil in the area, leading to potential increases in profits and pollution. However, Los Angeles does represent the entire state of CA. The oil refineries in the San Francisco Bay Area, are competing with other transportation methods such as public transits and electric cars. Therefore, in areas such as the bay area, firms will exhibit an area where oil is not in high demand, thus will decrease their profits. The initial decrease in oil production among firms is not necessarily a negative thing, especially since the emissions cannot be emitted when the oil is in the ground. That implies that the cost to society is actually minimized with the loss of production. Of course, the purpose of C&T is not to cease production of oil, but the point is to attempt to reduce emissions by investing in an emission reducing filter or could be by reducing the amount of oil barrels produced.

Nevertheless, my models have some limitations. First, the models do not address the employment factor. One potential argument against C&T is the employment will be too costly. I referred to Yamazaki (2017)[4] paper on the British Columbia's carbon tax and employment and he found that the employment actually transitioned to cleaner industries. This paper is in a carbon tax setting and Canada is not necessarily comparable to the United States, but I expect that this would be the outcome in a C&T setting. As illustrated by neoclassical economic theory, people will act rationally according to what presented to them. Therefore, just applying the theory to employment, when the oil refineries become too costly for them to hire additional workers, people will adjust and enter into another industry. In addition, as illustrated by Jarke (2017)[5] depending on how CA is using the funds raised from an emission permits program that can be a major implication of C&T. CA according to the CARB is giving some of the revenues back to the consumer to offset some of the energy costs. Along with the redistribution back to the consumers, CA is investing in cleaner energy solutions too as well.

[4] Yamazaki, Akio. "Jobs and Climate Policy: Evidence from British Columbias Revenue-Neutral Carbon Tax." Journal of Environmental Economics and Management 83 (2017): 197–216. https://doi.org/10.1016/j.jeem.2017.03.003.

[5] Jarke, Johannes, and Grischa Perino. "Do Renewable Energy Policies Reduce Carbon Emissions? On Caps and Inter-Industry Leakage." Journal of Environmental Economics and Management 84 (2017): 102–24. https://doi.org/10.1016/j.jeem.2017.01.004.

SECTION SIX: CONCLUSION

Overall, social welfare is making strides in CA. This is what I was expecting especially since the emissions have been in a downwards trend. This is overall a good indication for policy makers because my analysis provides valuable insight for potential consequences after implementing C&T policy. Even though this is a solid stepping-stone for C&T in the U.S, my paper has some limitations. First, I am only focusing on one industry and that may not be reflective of the entire effects of C&T. Especially since emissions have decreased and this industry is still strong in CA. Next, there could be some unmeasurable attributes associated within the model I am not holding constant. In addition, consumer demand for oil in California could factor into the negative profits, since the state is implementing stronger clean energy incentives. In addition, there could be aspects I am not addressing in my study; however, I think the literature possesses an explanation of what could potentially happen. Especially the Yamazaki (2017)[3], Jarke (2017)[4], Böhringer (1997)[6], and Hahn (2011)[2] papers explain the allocations and the way that a policy like this should operate. Social welfare is important to regulators and this paper successfully illustrates the potential outcomes associated with a major policy.

[6] Böhringer, Christoph, and Thomas F. Rutherford. "Carbon Taxes with Exemptions in an Open Economy: A General Equilibrium Analysis of the German Tax Initiative." Journal of Environmental Economics and Management 32, no. 2 (1997): 189–203. https://doi.org/10.1006/jeem.1996.0962.

REFERENCES

Aronsson, T. “On Cost Benefits Rule for Green Taxes.” Environmental and Resource Economics (1999) 13: 31. https://doi.org/10.1023/A:1008253417906

Berman, Eli, and Linda T. Bui. “Environmental Regulation and Labor Demand: Evidence from the South Coast Air Basin.” SSRN Electronic Journal, 1997. https://doi.org/10.2139/ssrn.45244.

Böhringer, Christoph, and Thomas F. Rutherford. “Carbon Taxes with Exemptions in an Open Economy: A General Equilibrium Analysis of the German Tax Initiative.” Journal of Environmental Economics and Management 32, no. 2 (1997): 189–203. https://doi.org/10.1006/jeem.1996.0962.

Cornes, Richard, and Todd Sandler. “Externalities, Expectations, and Pigouvian Taxes.” Journal of Environmental Economics and Management 12, no. 1 (1985): 1–13. https://doi.org/10.1016/0095-0696(85)90012-9.

Cremer, Helmuth, Firouz Gahvari, and Norbert Ladoux. “Environmental Tax Design with Endogenous Earning Abilities (with Applications to France).” Journal of Environmental Economics and Management 59, no. 1 (2010): 82–93. https://doi.org/10.1016/j.jeem.2009.04.009.

Cushing, Lara, Dan Blaustein-Rejto, Madeline Wander, Manuel Pastor, James Sadd, Allen Zhu, and Rachel Morello-Frosch. “Carbon Trading, Co-Pollutants, and Environmental Equity: Evidence from California’s Cap-and-Trade Program (2011–2015).” PLOS Medicine 15, no. 7 (October 2018). https://doi.org/10.1371/journal.pmed.1002604.

Fowlie, Meredith. “Updating the Allocation of Greenhouse Gas Emissions Permits in a Federal Cap-and-Trade Program.” National Bureau of Economic Research Working Paper NO 16307 2010. https://doi.org/10.3386/w16307.

Hahn, Robert W., and Robert N. Stavins. “The Effect of Allowance Allocations on Cap-and-Trade System Performance.” The Journal of Law and Economics 54, no. S4 (2011). https://doi.org/10.1086/661942.

Harberger, Arnold C. “The Incidence of the Corporation Income Tax Revisited.” National Tax Journal 61, no. 2 (2008): 303–12. https://doi.org/10.17310/ntj.2008.2.07.

Jarke, Johannes, and Grischa Perino. “Do Renewable Energy Policies Reduce Carbon Emissions? On Caps and Inter-Industry Leakage.” Journal of Environmental Economics and Management 84 (2017): 102–24. https://doi.org/10.1016/j.jeem.2017.01.004.

Komen, M.H. & Peerlings, J.H. “Energy Taxes in the Netherlands: What are the Dividends?” Environmental and Resource Economics (1999) 14: 243-268. https://doi.org/10.1023/A:1008350101841

Landis, Florian, Sebastian Rausch, and Mirjam Kosch. “Differentiated Carbon Prices and the Economic Cost of Decarbonization.” Environmental and Resource Economics 70, no. 2 (2017): 483–516. https://doi.org/10.1007/s10640-017-0130-y.

Mackenzie, Ian A., and Markus Ohndorf. “Cap-and-Trade, Taxes, and Distributional Conflict.” Journal of Environmental Economics and Management 63, no. 1 (2012): 51–65. https://doi.org/10.1016/j.jeem.2011.05.002.

Martin, Ralf, Laure B. De Preux, and Ulrich J. Wagner. “The Impact of a Carbon Tax on Manufacturing: Evidence from Microdata.” Journal of Public Economics 117 (2014): 1–14. https://doi.org/10.1016/j.jpubeco.2014.04.016.

Meng, Sam, Mahinda Siriwardana, and Judith Mcneill. “The Environmental and Economic Impact of the Carbon Tax in Australia.” Environmental and Resource Economics 54, no. 3 (December 2012): 313–32. https://doi.org/10.1007/s10640-012-9600-4.

Pethig, Rüdiger. “Pollution, Welfare, and Environmental Policy in the Theory of Comparative Advantage.” Journal of Environmental Economics and Management 2, no. 3 (1976): 160–69. https://doi.org/10.1016/0095-0696(76)90031-0.

Strand, Jon. “Strategic Climate Policy with Offsets and Incomplete Abatement: Carbon Taxes versus Cap-and-Trade.” Journal of Environmental Economics and Management 66, no. 2 (2013): 202–18. https://doi.org/10.1016/j.jeem.2013.03.002.

Yamazaki, Akio. “Jobs and Climate Policy: Evidence from British Columbias Revenue-Neutral Carbon Tax.” Journal of Environmental Economics and Management 83 (2017): 197–216. https://doi.org/10.1016/j.jeem.2017.03.003