Carbon Taxes and Productivity: Lessons from Canadian Manufacturing Plants[1]

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Camp Resources XXV

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UNIVERSITY OF CALGARY

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Motivation

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Job killing

Loss in competitiveness

↓ profit/ market share

Climate policy

Too much burden on

- Low-income families
- Small businesses

Motivation

Job killing

Investment

Loss in competitiveness

↓ profit/ market share

Climate policy

Innovation

Reduction of GHG emission

Productivity-enhancing

Too much burden on

Low-income families

Small businesses

Research Question

Q: How does climate policy affect productivity (TFP) of manufacturing?

$\Rightarrow$ Revenue-neutral carbon tax in British Columbia, Canada

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What We Know ...

Environmental regulation and productivity:

US Clean Air Act – Gollop & Roberts (1983), Gray & Shadbegian (2003), Greenstone et al (2012), etc

Southern CA Air Quality Regulation – Berman & Bui (2001)

⇒ **Command-and-control** policy hampers productivity

Climate policy and productivity:

EU-ETS

Commins et al (2011) – decline in TFP growth by 0.06% in Phase I

Lutz (2016) – rise in TFP by 0.6% in Phase I, but no effect in Phase II

UK energy tax

Martin et al (2014) – no effect

⇒ **Market-based** policy may not hamper productivity, but evidence is mixed and limited

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My Contributions

- First to study the productivity effect of revenue-neutral carbon tax using plant-level data
  - Plant-level adjustments (within-plant)
  - Plant entry & exit (market dynamic)
- First to isolate the revenue-recycling effect from the overall effect of the carbon tax

Overview of BC carbon tax

- **Surprise implementation** – Announced on February 19th, 2008, and then implemented on July 1st, 2008
- **Most broad-based tax** – it taxes the uses of **all** fossil fuel, and no industries are exempted from the tax initially.
- **High** tax rate – started at \$10/t CO_2e, then increased annually by \$5 until 2012 (\$30). It increased to \$35 in April, 2018, will increase annually by \$5 until 2021 (\$50).
- **Revenue-neutral** — tax revenues are returned to citizens of BC in the form of reduction of other taxes, such as personal and **corporate income taxes**.

Empirical strategy

I. Estimate TFP using a revised Levinsohn & Petrin algorithm

⇒ Allowing TFP to endogenously reflect on R&D and energy efficiency (De Loecker, 2013) Detail

II. Estimate the productivity effect by exploiting the variations in policy stringency:

1. BC vs. ROC
2. Pre-policy (2004-2007) vs. Post-policy (2008-2012)
3. **Plant-level policy exposure intensity**
   - More energy intensive plants are likely to bear higher costs → Direct effect
   - Plants with positive income are likely to benefit more from the reduction of CIT rate → Indirect revenue-recycling effect

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Estimation

Productivity Equation

$$\ln TFP_{ijpt} = \boldsymbol{\beta_1 (EI_i \times CTax_{pt}) + \beta_2 (\mathbb{1}(\mathrm{TI}_i > 0) \times (1 - CIT_{pt}))} + \lambda_i + \eta_{jt} + X_{pt} + \epsilon_{ijpt}$$

TFP_{ijpt} = TFP for plant i in industry j in province p at time t

$CTax_{pt}$ = Carbon tax variable, i.e., 0 if $t < 2007$, 10 if $t = 2008$, ...

EI_i = Pre-policy average plant-level energy intensity level

TI_i = Pre-policy average plant-level taxable income

CIT_{pt} = Corporate income tax for province p at time t

X_{pt} = provincial GDP

$\beta_1 \Rightarrow$ Direct carbon tax effect

$\beta_2 \Rightarrow$ Indirect revenue-recycling effect

Data

New confidential dataset with longitudinal plant- & firm-level information from 2004 to 2012

- Merged Annual Survey of Manufactures (ASM) and General Index of Financial Information (GIFI)
- Covers all manufacturing locations in Canada
- Contains the rich set of plant characteristics
  $\Rightarrow$ Allow me to compare very similar treated and untreated plants

Detail

Propensity-score weighting (PSW)

To ensure the similarity between BC and ROC plants (i.e, common trends),

I redistribute the control plants based on the propensity score (PS)

- Estimate PS ($p(X)$) for both BC and ROC plants
- Using $p(X)$, I calculate weights for ROC plants, $\frac{p(X)}{1-p(X)}$
- Estimate the estimation equation using these weights

I estimate PS using the pre-policy plant characteristics: output, labor, wage, capital, intermediates, **taxable income**, TFP, **energy expenditure by fuel types**, int'l and intra-provincial exports, R&D, industry ID, age, multi-plant firm ID, and etc ...

Results

lnTFP	(1)	(2)	(3)
EI x CTax (β_1)	-0.00744*	-0.00788**	-0.00727*
	(0.0038)	(0.0039)	(0.0038)
$\mathbb{1}(\text{TI}_i > 0)$ x (1-CIT) (β_2)	0.077***	0.076***	0.075***
	(0.01)	(0.01)	(0.01)
Industry $\times$ time			
2-digit	Y		
3-digit		Y	
4-digit			Y
N	242744	242744	242744
R^2	0.69	0.7	0.7

Note: All specifications include plant FE and provincial GDP as a control. Standard errors clustered by province $\times$ industry are in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Interpretation

	(3)
EI x CTax	-0.0073*
	(0.0038)
$\mathbb{1}(\text{TI}_i > 0)$ x (1-CIT)	0.075***
	(0.01)
N	242744
R^2	0.7

The revenue-neutral carbon tax has:

Negative direct effect

Positive indirect effect

Based on the coefficients from column (3), on average the carbon tax reduced productivity by 0.39%.

Interpretation (cont.)

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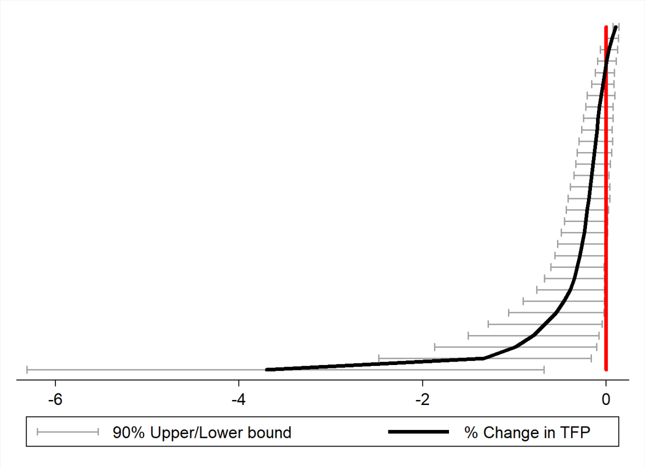

Almost all plants experience the decline in productivity. Although the reduction of CIT has a potential to alleviate the negative direct effect, the reduction rate might be too small to actually offset the negative effect.

Interpretation (cont.)

Since the annual mean of plant-level gross output (GO) during the sample period in BC is about \$11.3 million,

0.39% $\downarrow$ **in TFP** $\Rightarrow$ **GO** $\downarrow$ **by \$44,700**.

Without the CIT reduction, TFP would have declined by 0.46%, which would have reduced GO by \$52,900.

$\Rightarrow$ CIT reduction helps save plants \$8,200 worth of gross output.

Interpretation (cont.)

At provincial-level,

BC's manufacturing output declined by $230 million while CIT reduction has saved $27 million output.

With total manufacturing GDP of $14 billion in BC, $27 million output is only about 0.19%.

Entry & Exit Analysis

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Entry-exit equation

$$\begin{matrix} ENTRY_{jpt} \\ EXIT_{jpt} \end{matrix} = \beta_1(EI_{jp} \times CTax_{pt}) + \beta_2(TI_{jp} \times (1 - CIT_{pt})) + \Gamma + \epsilon_{jpt}$$

$$\begin{aligned}
\text{Entry}_{jpt} &= \#\text{ of entering plants in industry } j \text{ in province } p \\
\text{Exit}_{jpt} &= \#\text{ of exiting plants in industry } j \text{ in province } p \\
EI_{jp} &= \sum_{i \in j} ENERGY_{ijp} / \sum_{i \in j} Y_{ijp} \\
CTax_{pt} &= \text{Carbon tax variable, i.e., 0 if } t < 2007\text{, 10 if } t = 2008\text{, ...} \\
TI_{jp} &= \sum_{i \in j} TI_{ijp} \\
CIT_{pt} &= \text{provincial corporate income tax}
\end{aligned}$$

I estimate the above equation with negative binomial FEs (NB). I also combine NB FE with PSW.

Results – Dynamics

	Exit	Entry
	(1)	(2)
EI x CTax	-0.13	-0.25**
	(0.09)	(0.11)
TI x (1-CIT)	9.95	14.34**
	(7.62)	(6.83)
N	1638	1640
P-value	0.29	0.03

Note: Standard errors clustered by province $\times$ industry are in parentheses. All specifications include industry $\times$ time FEs. All also include provincial GDP to control for provincial trends. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

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On average, entry is reduced by 0.7% relative to the average entry for BC.

The direct effect reduces entry while the indirect effect increases entry. Given the insignificant results for exit, **the carbon tax imposes a larger cost to entrants than exits.**

Interpretation (cont.)

One possible interpretation ...

Carbon tax may act as an entry barrier

$\Rightarrow$ Once they enter, perhaps plants in the market are strong enough to deal with the extra cost imposed by the carbon tax, leading to fewer plants to exit.

At the same time, given that the magnitude is small, the positive indirect effect for entry might have lowered this entry barrier.

Summing up

Q: How did British Columbia's imposition of a carbon tax affect the plant-level manufacturing productivity?

- Carbon tax had negative but small effect on productivity of manufacturing plants (within-plant responses)
- The reduction of CIT does alleviate the direct negative effect of the carbon tax, but it was not enough. The CIT rate may need to be reduced more
- Carbon tax may act as an entry barrier

  $\Rightarrow$ Positive indirect effect has much larger impact on entry decisions than decisions on manufacturing activities

Takeaway: Recycling the tax revenue through the CIT reduction was important for alleviating the negative impact

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Thank you

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More related studies

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More US CAA studies in manufacturing:

Gollop & Roberts (1983) – 43% $\downarrow$ in utility ($1.35 million)
Gray (1987) – 0.17% point $\downarrow$ in manufacturing
Gray & Shadbegian (2003) – 4.8% $\downarrow$ in pulp and paper
Greenstone et al (2012) – 5% $\downarrow$ in manufacturing ($21 billion)

Non-US studies in manufacturing:

Alpay et al (2002) – $\uparrow$ in PACE increases TFP in Mexican food
Hamamoto (2006) – $\uparrow$ in PACE increases TFP in Japan
Yang et al (2012) – $\uparrow$ in PACE increases TFP in Taiwan
Tanaka et al (2014) – Chinese regulation $\uparrow$ TFP

More Literature Review

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Different TFP measures:

Three methods used in this literature

- Index number approach
  Berman & Bui (2001) – divisia index
  Greenstone et al (2012) – growth accounting
- Production function approach
  Martin et al (2014)
  Tanaka et al (2014)
- Semi-parametric (OP/LP) estimation approach
  Commins et al (2011) – OP
  Yang et al (2012) – LP
  Lutz (2016) – ACF

More Literature Review

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Direct vs. Indirect Approach

- Direct approach: Compares regulated and unregulated units directly

  Berman & Bui (2001), Commins et al (2011), Greenstone et al (2012), Martin et al (2014), Tanaka et al (2014), Lutz (2016)
- Indirect approach: Use a proxy to measure stringency of the policy, such as PACE

  Gray (1989), Alpay et al (2002), Gray & Shadbegian (2003), Hamamoto (2006), Yang et al (2012)

More Literature Review

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Weakness

Commins et al (2011):

- ddd

Martin et al (2014):

- TFP measure suffers from inputs endogeneity issue
- Control plants are affected by CCL and EU-ETS

Lutz (2016):

- EU-ETS is applied only to large firms, i.e., large firms vs. small firms
- Potential aggregation bias from using firm-level data
- Capital is constructed by PIM

ASM-GIFI Linked Data

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Annual Survey of Manufactures (ASM)

- Plant-level data on performance variables
  - Total shipments of goods of own manufacture (Output)
  - Total employment
  - Intermediate input expenditures (e.g., materials and energy)

General Index of Financial Information

- Firm-level administrative data (e.g., financial statement)
  - Capital (book value total tangible assets) – No PIM
  - Taxable income

Linking process

1. Using firm ID, they are linked at firm-level (enterprise-level)
2. Using the output share of each plant within a firm, allocate firm-level data to plant-level

Revised Levinsohn and Petrin approach

back

Goal: $\text{TFP}_{it} \equiv \widehat{\omega}_{it} = y_{it} - \widehat{\beta}_0 - \widehat{\beta}_l l_{it} - \widehat{\beta}_k k_{it} - \widehat{\beta}_m m_{it}$

Issue: Inputs are endogenously determined (e.g., $E(l_{it}, \omega_{it}) \geq 0$)

2-step method to estimate a production function

$$y_{it} = \beta_l l_{it} + \beta_k k_{it} + \beta_m m_{it} + \omega_{it} + \eta_{it}$$

Assumption: l_{it}, m_{it} are variable inputs, but k_{it} is fixed factor

Key: Express ω_{it} as a function of observables

Proxy: $m_{it} = m_{it}(\omega_{it}, k_{it}, \boldsymbol{z_{it}}) \Rightarrow \boxed{\omega_{it} = \phi_t(k_{it}, m_{it}, \boldsymbol{z_{it}})}$

where z_{it} is the vector of the energy-saving activities

1st step: recover β_l by estimating the below with OLS

$y_{it} = \beta_l l_{it} + \phi_t(k_{it}, m_{it}, \boldsymbol{z_{it}}) + \eta_{it}$

$\beta_l : E(\eta_{it}, l_{it}) = 0$

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Revised Levinsohn and Petrin approach

back

2nd step: recover β_k & β_m

Assumption: 1st order Markov, $\omega_{it} = g(\omega_{it-1}, \mathbf{z_{it-1}}) + \xi_{it}$

$$\hat{y}_{it} - \hat{\beta}_l l_{it} = \beta_k k_{it} + \beta_m m_{it} + g(\omega_{it-1}, \mathbf{z_{it-1}}) + \xi_{it} + \eta_{it}$$

From 1st step: $\phi_{it-1} = \beta_k k_{it-1} + \beta_m m_{it-1} + \omega_{it-1}$

$$\hat{y}_{it} - \hat{\beta}_l l_{it} = \beta_k k_{it} + \beta_m m_{it} + g(\hat{\phi}_{it-1} - \beta_k k_{it-1} - \beta_m m_{it-1}, \mathbf{z_{it-1}}) + \xi_{it} + \eta_{it}$$

Estimate the above with NLLS to recover β_k & β_m

$\beta_k : E(\xi_{it} + \eta_{it}, k_{it}) = 0$ because capital is determined at $t-1$

$\beta_m : E(\xi_{it} + \eta_{it}, m_{it}) \neq 0 \Rightarrow$ instrument by m_{it-1}

Predicted residual is TFP

Insights from Conceptual Framework

back

Plant-level responses to the policy

Energy tax (direct effect):

$\rightarrow$ Introducing distortion in energy market ($\downarrow$ E)

- Scale down the operation ($\downarrow$ Y)
- Factor substitution ($\uparrow$ K or L)

$\rightarrow$ Exacerbating distortions in labor & capital market ($\downarrow$ L & K)

CIT rate reduction (indirect effect):

$\rightarrow$ Improving distortion in capital market ($\uparrow$ K)

- Invest more, e.g., energy-saving technology

$\rightarrow$ Improving distortion in labor market ($\uparrow$ L)

ΔTFP depends on the size of these countervailing forces driven by distortions in input markets

Conceptual Framework

back

Building on Copeland & Taylor (2003), I assume:
Net-output: $x = A(1-\theta)L$
Emission: $z = \varphi(\theta)L$
θ is a fraction of inputs allocated to abatement.

$$\text{TFP} = A(1-\theta) \tag{1}$$

Borrowing from Forslid et al (2015), I assume:
$\varphi(\theta) = (1-\theta)^{1/\alpha}/\Omega(I_A)$

Then, I can express the net-output as:

$$x = A(\Omega(I_A)z)^{\alpha}L^{1-\alpha} \tag{2}$$

Conceptual Framework

back

Solving a following cost minimization problem:

$$c^x(\omega, \tau) = \min_{(z,L)} \{ \tau z + \omega L + T + I_A : A\big(\Omega(I_A) z\big)^{\alpha} L^{1-\alpha} = 1 \}$$

where $T = t_c(p - \tau z - \lambda \omega L)$ is the amount of CIT paid.
This yields:

$$z = \frac{(1+\gamma)^{1-\alpha}}{A\Omega(I_A)^{\alpha}} \left(\frac{\alpha}{1-\alpha} \frac{\omega}{\tau} \right)^{1-\alpha} \tag{3}$$

where $(1+\gamma) \equiv (1 - \lambda t_c)/(1 - t_c)$ is the marginal effective tax rate (METR) on capital.
Finally, using $e = \Omega(I_A) z / x$ in Eq.(2), and then plugging Eq.(3) yields:

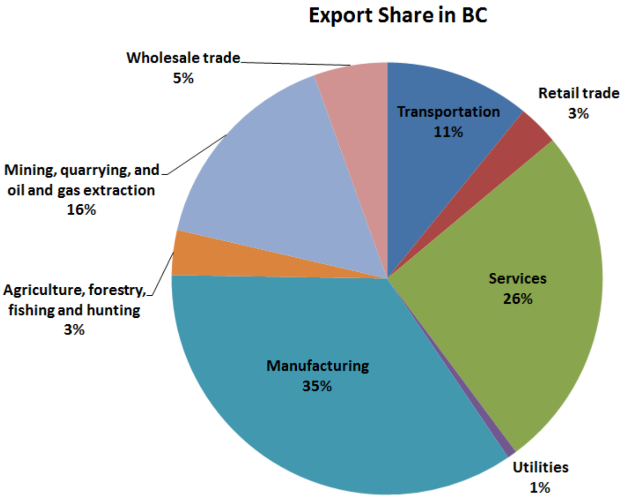
$$\text{TFP} = A \underbrace{\left(\frac{\alpha}{1-\alpha} \right)^{\alpha} \left(\frac{\Omega(I_A)}{\tau} \right)^{\alpha} (1+\gamma)^{\alpha}}_{(1-\theta)} \tag{4}$$

Why manufacturing sector?

Emission-intensive AND trade-exposed sector

- Higher emission intensity, higher compliance costs
- Trade-exposed sectors
  - Unable to raise a price ⇒ Must to bear the entire costs
  - Competitors are not subject to the same policy

Why manufacturing sector?



Source: Statistics Canada, CANSIM Table 386-0003

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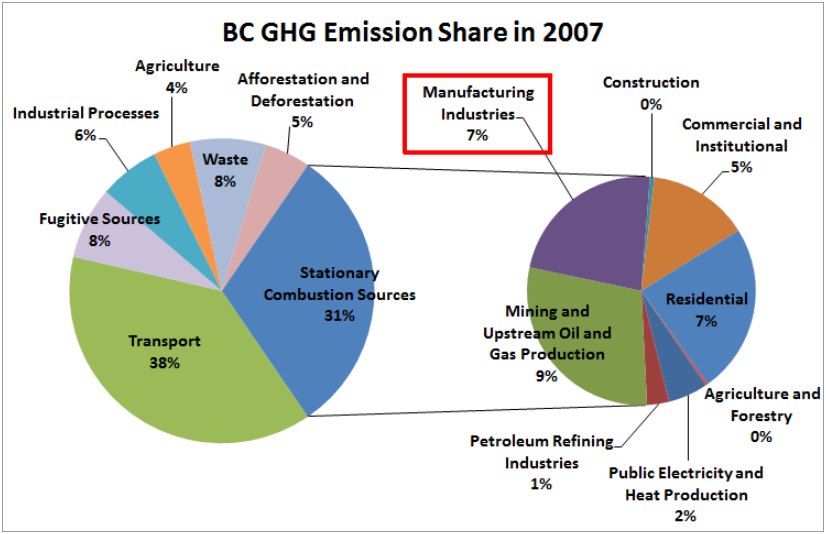

Source: Ministry of Environment, British Columbia Greenhouse Gas Inventory

Comparison to UK Carbon Tax

back

UK CCL vs. BC Carbon Tax

	UK (2001)	BC (2008)
Level	National	Provincial
Implementation	2 years	5 months
Coverage	Only industrial	All
Rates (t/CO_2)	Electricity (£8.45)	All fossil fuel ($30)
	Coal (£4.36)	
	Natual gas (£8.17)	
	LPG (£5.99)	
Revenue	Neutral	Neutral
	National Insurance Contribution	Personal & corporate income tax
Exepmtion	CCA	None

Energy intensity ranking in BC

Top 5	NAICS	Industry
1	322	Paper
2	327	Non-metallic mineral product
3	321	Wood
4	313	Textile mills
5	331	Primary metal

Bottom 5	NAICS	Industry
1	334	Computer and electronic product
2	315	Clothing
3	335	Electrical equipment
4	323	Printing
5	339	Miscellaneous

Results – Dynamics

	Exit		Entry	
	(1)	(2)	(3)	(4)
	HHG	NB	HHG	NB
EI x CTax	-0.16	-0.13	-0.22***	-0.25**
	(0.21)	(0.09)	(0.07)	(0.11)
TI x (1-CIT)	8.9	9.95	3.28	14.34**
	(7.41)	(7.62)	(6.41)	(6.83)
N	1638	1638	1640	1640
R^2	0.001		0.86	
P-value	0.33	0.29	0.01	0.03

Note: Standard errors clustered by province $\times$ industry are in parentheses. All specifications include industry $\times$ time FEs. All also include provincial GDP to control for provincial trends. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$