Do environmental regulations reduce greenhouse gas emissions? A study on Canadian industries

Sedigh, Golnaz

university of Ottawa (this paper was presented by the author in CEA 2008)

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A Study on Canadian Industries

Golnaz Sedigh

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Abstract

This paper uses the Canadian industrial macro-level data from CANSIM to investigate the effect of formal and informal regulations on pollution intensity. Proxies for formal and informal regulation variables are defined as in Cole et al., 2005. The econometrics model is a panel with 23 manufacturing industries over 10 years, from 1994 to 2003. Manufacturing industries are chosen because they are the most pollutant industries. It is found that formal and informal regulations have significant effects on decreasing the direct and indirect greenhouse gas emissions in Canadian industries. Provinces with younger populations have stricter informal regulation on pollution density, because younger populations care more about the future quality of the environment. Also, provinces with a higher rate of unemployment have less formal regulation on pollution density; for those provinces, providing employment for citizens is more important than providing a healthy environment. Wealthier provinces with a low employment rate face less pressure from society and can spend more money on the environment; therefore, they have lower pollution density. Furthermore, industries with large average firm size can decrease emissions more than other industries. The cost of controlling the emissions decreases with firm size because of economies of scale.

JEL classification: O13; L60; Q21; Q25; Q28

Keywords: Canadian manufacturing industries; Air pollution; Environmental regulations

Introduction

These days, people think about pollution more than many years ago. There are numerous incentives to decrease the pollution on earth; people need cleaner environment to live more and better. Environmental regulation is one way that is chosen by government to intervene in the market to decrease the amount of pollution. Some governments use pollution tax and some other use emission fees, or tradable permits system. After performing the regulation another question may arise. Which regulation's instrument decrease more pollution? What is the effect of the regulation?

Sometimes, environmental regulation does not achieve its target. For example, Schlottmann (1976) looked at the "national coal and sulfur emissions policies" in US and found out that regulation did not have any effect on pollution induction. Thus, it is important to insure the efficiency of environmental policies and regulation to decrease the possibility of failure to achieving our goals. To answer these questions, there is a need of an evaluation method. The evaluation method can be a survey, which can be asked from polluters or people who are affected by the regulation. Then, researcher can work on survey's statistics and measure the impact of regulation on pollution.

However, this kind of survey usually has bias and is affected by incentives of respondents. An econometric model can help to find better estimation of the impact of regulation on pollution. What are needed in an econometric model? First, a good model should include all variables which can affect pollution. Second, correct proxies for regulation should be used. Different regulation in different countries can have a special proxy. Third, an econometric model needs enough data. Maybe it is easy to choose a good proxy for regulation; however, there may not be enough data for that, or data may exist but they are not accessible. Especially for regulation variables these problems are bigger; because, regulation can change year by year. This can make impossible to run a time-series or panel model. Fourth, a good model should be able to measure short term and long term effect of regulation.

This paper starts with a literature review about the impact of regulation on pollution and some other variables, and the proxies which are chosen for regulation. In the second section, the econometric model and its Data are explained. In the third section, the results from the model are interpreted and compared with the literature review. In the last section, conclusion is presented and some suggestions are proposed to extend this research.

Literature review

Nowadays, environmental sustainability is a critic issue for the world, and governments have been working on this issue. In economics, many economists have tried to find the effect of governments and their regulations on environment to see how the governments can help protect the environment and provide a good and healthy environment for their citizens. The author is inspired by Cole et al (2005) to start this paper. They looked at UK and found out the effect of regulations' proxies on pollution. This work is a good try to run the same model to check the effect of government on decreasing air-pollution in Canada. Before and after Cole et al (2005), many people have worked on the effect of regulation on pollution. In this part the literature is reviewed.

Hettige et al (1996) check effect of informal regulation on pollution intensity in South and Southeast Asia. They use "community pressure" as a measure of "informal regulation" and use “income and education” as the proxies for “community pressure”. In their econometric model, they include some other explanatory variables like: new technology, productivity, and public and foreign ownership of firms. Their source of econometric model was Pargal and Wheeler (1995).

Jorgenson et al (1990) investigate effect of environmental regulation on economic growth of US, and Regens et al (1997) look at effect of environmental regulation on “the demand for pollution control equipment”. Tannenwald (1997) surveys different effect of environmental regulations. In his paper, he explains some measures of “regulatory stringency”. According to him, Bartik (1988) use “governmental spending on water quality control as a fraction of manufacturing employment, average for 1972–78” and “government spending on air quality control as a fraction of manufacturing employment, average for 1972–78” as measures of regulation to find the effect of regulation on “New plant location”. Also, According to Tannenwald (1997), Duffy-Deno (1992) use “[m]anufacturers’ air pollution abatement costs as a fraction of manufacturing value added” and “[m]anufacturers’ total pollution abatement costs as a fraction of manufacturing value added” as other measures of regulation to find the effect of regulation on “Manufacturing employment and earnings per capita.” Moreover, according to Tannenwald (1997), Friedman, Gerlowski, and Silberman (1992) use “State pollution abatement capital expenditures as a fraction of gross state product originating in manufacturing” as a measure to calculate effect of regulation on “Location of foreign branch plants, by state.”

Hettige et al (2000) say, “. . . credible indices of environmental regulation are difficult to find.” In an interesting research they found that “environmental Kuznets curve(EKC) hypothesis” is true for “industrial water pollution” in US and some other countries; in fact, pollution first rise with income and start to decrease after a point. According to Hettige et al

(2000): Hettige et al (1996), Pargal and Wheeler (1996), Wang and Wheeler (1996), Hartman et al (1997a,b), and McConnell (1997), also, use "per capita income" as a proxy for formal and informal regulation. Moreover, Berman et al (2001) use US data to measure the effect of environmental regulation on employment in South Coast Air Basin. One of the proxies for regulation, in this paper, is "budgets" that government spent on regulation.

Antweiler et al (2001) work on relation between trade liberalization and "sulfur dioxide concentrations" for 43 countries. They mention that income per capita can be a measure of regulation; then, Cole et al (2003) start with a model for OECD countries to check the result of Antweiler et al (2001). Cole et al (2003) use "sulfur dioxide emission" instead of concentrations. They used income per capita as a proxy for environmental regulation. They also apply "country's relative capital–labor ratio" and "the ratio of imports plus exports to GDP" in their model to check the effect of these variables on emission and check the effect of "interaction" of these variables with regulation on pollution.

Cole et al (2005) use different macro-level data for UK industries. Also, they use regional data for employment, ratio of dirty industries output to total output, total population, population under 44 years old, and income per capita as proxies for formal and informal regulation. Merlevede et al (2006) check the "environmental Kuznets curve hypothesis" for 45 countries. They add "average firm size" for each country to their model to check the effect of size on pollution. They find that "large firm countries" has more pollution; also, they find that if these countries are developed, then they have this privilege to accept regulation easier; therefore, development may decrease the pollution of "large firm countries." Kathuria (2007) find an interesting proxy for informal regulation in Gujarat, one of the India's states. He finds out that "No. of articles/decisions against the industry pertaining to water pollution" in some newspapers in this state can work as a regulation instruments. Also, he finds a significant negative effect of this variable on water pollution for most cases. Moreover, Cole et al (2007) run the same model as Cole et al (2005) for China, and they find that increase in energy use and human capital intensity increases industrial air pollution, and increase in industrial research and development and productivity decreases the pollution. They check the effect of formal and informal regulation on emissions in China and find that regulation almost does not have significant effect on pollution. In this paper, author use the Cole et al (2005)'s model and check the effect of regulation on industrial pollution in Canada. The econometric model is presented in next section.

The econometric model and Data

This paper uses the same model as Cole et al (2005). According to them, demand and supply of pollution produce a model which shows the effect of socio-economic variables on pollution. In their model, pollution is a function of energy use, physical capital intensity, human capital intensity, average size of firms, productivity, capital expenditure, and R&D expenditure. Also, it includes some proxies for formal and informal regulations which use regional variables like: unemployment, population density, population under 44 years old, production of dirty industries, and income per capita. Cole et al (2005) state:

> " . . . [W]e can summarize pollution demand and supply by defining an industry's pollution demand as:
>
> $$e_{it} = f(p_{it}, n_{it}, pci_{it}, hci_{it}, s_{it}, tfp_{it}, mod_{it}, innov_{it}) \quad (1)$$
>
> where, subscripts i and t denote industry and year, e denotes air emissions, p denotes the expected price of pollution as a result of environmental regulations, n denotes energy use, pci is physical capital intensity, hci is human capital intensity, s is the size of the average firm in the industry, tfp is the total factor productivity of the industry, mod is a measure of the vintage of production processes and, finally, innov represents innovation. . . .

The industry's pollution supply schedule identifies the expected price that it will pay for pollution. This, in turn, is a function of the quantity of pollution and the stringency of formal and informal environmental regulations.

$$p_{it} = f(e_{it}, FRegs_{it}, IRegs_{it}) \qquad (2)$$

where p and e are as already defined, FRegs refers to formal environmental regulations, whilst IRegs refers to informal regulations.
In equilibrium, pollution can therefore be defined as:

$$e_{it} = f(n_{it}, pci_{it}, hci_{it}, s_{it}, tfp_{it}, mod_{it}, innov_{it}, FRegs_{it}, IRegs_{it}) \qquad (3)"$$

First the method of Cole et al (2005) for making formal and informal variables is explained; then, the variables in this paper and their sources presented. The same as Cole et al (2005), we use this equation below to calculated the informal and formal regulation variables.

$$\mathrm{REG}_{\mathrm{X\ it}} = \sum_{r} (\mathrm{S}_{\mathrm{irt}} \times \mathrm{X}_{\mathrm{rt}})$$

Where x(it) is the proxy variable for regulation for industry i in time t

Sirt is the ratio of GDP of industry i in province r to total national GDP of industry i. [1]

X(rt) is the proxy variables for province r in time t

In CANSIM, the data for provincial GDP was not available for 1999-2003. The data is imputed, because without those years' information, Sirt=0 for those years and make regulation variables data for those years equal to 'zero'. The robustness is checked before and after imputation. Also, because of missing value for regional GDP of Northwest Territories and Nunavut, those provinces are dropped from data.

Cole et al (2005) usethis formula for "pollution prosecutions scaled by manufacturing output", "regional unemployment rate" , "population density", "population under the age of 44",

[1] Cole et al (2005) use output instead of GDP. Here, I could not find the information for output. Therefore, I use GDP in the model.

"the concentration of UK dirty industries within a region.", and "regional per capita income". The data for "pollution prosecutions scaled by manufacturing output" is not available.

According to Cole et al (2005) regions that have higher unemployment rates may have lower regulations; because, they have more social problems that they should consider before thinking about environment. Also, in the area with lower unemployment rate, people ask more for better environment; because, they are richer and they like to live in clean area. They considered unemployment as proxy for both formal and informal regulation. Cole et al (2005) claim that regions with larger population densities ask for more regulation. Populated regions need more regulation because the lives of more people are in danger. Also, they say that "a pollution intensive plant may be less 'visible' in a densely populated, urban area and hence may escape the attentions of the local population." Therefore, we may see the positive relation between population density and pollution, in this way. This variable is a proxy for informal regulation.

Population under 44 years old, according to Cole et al (2005) can have power to ask better environment, they are young and may have more energy to follow their request, Therefore, it is seen that regions with relatively younger population has more regulation to keep the air clean. This variable is a proxy for informal regulation. Share of dirty industries in the region is one of the Cole et al (2005)'s formal regulation variables. Cole et al (2005) first use "pollution prosecutions scaled by manufacturing output" as proxy of formal regulation, and in their sensitive analysis, they replace this variable with the share of dirty industries in the region.

As the data for the pollution prosecution is not available, share of dirty industries is used in this work. This variable shows that the more dirty industries in the region, the more regulation is in an area. For finding making share of dirty industries in the region, the same as Cole et al

(2005), the average Greenhouse Gas emission (tonnes per thousand current dollars of production) during 1994-2003 for each industry are taken and then found the most 5 pollutant industries in Canada. (Table 1) Chemical manufacturing, food manufacturing, non-metallic mineral product manufacturing, transportation equipment manufacturing, and petroleum and coal products manufacturing are the most pollutant industries in Canada.

Table 1: Average Greenhouse Gas emission during 1994-2003

(tonnes per thousand current dollars of production)

industry	Average Greenhouse Gas emission (tonnes per thousand current dollars of production) During 1994-2003
Chemical manufacturing	11.29222
Food manufacturing	9.657778
Non-metallic mineral product manufacturing	5.212222
Transportation equipment manufacturing	3.807778
Petroleum and coal products manufacturing	3.167778
Beverage and tobacco product manufacturing	3.132222
Paper manufacturing	2.114444
Plastics and rubber products manufacturing	1.695556
Primary metal manufacturing	1.692222
Electrical equipment appliance and component manufacturing	1.306667
Textile mills	0.88
Fabricated metal product manufacturing	0.7655556
Computer and electronic product manufacturing	0.6777778
Wood product manufacturing	0.6433333
Miscellaneous manufacturing	0.6044444
Leather and allied product manufacturing	0.5888889
Printing and related support activities	0.5611111
Machinery manufacturing	0.5188889
Furniture and related product manufacturing	0.4877778
Clothing manufacturing	0.4855556

Income per capita is another variable that they use in their paper as a proxy for informal regulation. Richer people ask for more regulation to keep their area clean. The data for income per capita is not available for some years, therefore, the effect of this variable does not check in this paper.

Energy use, physical capital intensity, human capital intensity, average size of firms, productivity, capital expenditure, and R&D expenditure are the other variables that are used in this paper. According to Cole et al (2005), more use of energy means more pollution. More physical capital means more machinery which means more pollution that those industries whose input is just labour. Industries with higher human capital can increase pollution; because, they can form industries with high technology that usually use pollution-intensive machinery. From other side, educated people may use better the technology and produce less pollution. More "output" means more pollution, therefore, industries with higher average size, predicted to have more pollution; also, because of economy of scale "we may expect this relationship to be diminishing at the margin."

More productive industries and more innovative industries expect to pollute less; because, productive in one way means to have less waste and therefore less pollution, and the new technologies try to be more environmental friendly. Also, more capital expenditure means more new technology and means more environmental friendly technology too. Table 2 includes the variables[2] which is used in this work and the variables which Cole et al (2005) use.

[2] Source of these variables can be found in Appendix 1. Also Appendix 2 presents a summary statistics.

Table 2: definitions of variables and their equivalent in Cole et al (2005)

variables	comments	equivalence in Cole et al (2005)
E_{it}	Direct and indirect greenhouse gas emissions - I aggregated them into 2-digit NAICS (tonnes per thousand current dollars of production)	" Emissions divided by gross value added "
N_{it}	fossil_fuel use /manufacturing value added (gigajoules/ $ 1000)	" Energy use divided by gross value added "
PCI_{it}	manufacturing value added / number of total employees ($/ person)	"Physical capital intensity: Non-wage value added per worker ((VA-payroll)/employees)"
$HCI_{manf\ it}$	• average industrial wage/average manufacturing wage ($ 1000/ $ 1000) • average industrial wage = total wages/total employees for each industry ($1000 / person) • average manufacturing wage = total wages/total employees for whole manufacturing industries ($1000 / person)	" An industry's wage rate relative to the average manufacturing sector's wage "
$SIZE_{it}$	manufacturing value added / number of establishments ($ 1000 / unit)	" Value added per firm "
TFP_{it}	the same as its source (index, 2002=100 unless otherwise noted)	" Total factor productivity "
CAP_{it}	Capital expenditure / manufacturing value added ($ 1000 000 current prices / $ 1000 000)	" Capital expenditure divided by value added "
RD_{it}	business R&D/manufacturing value added ($/$)	" Research and development expenditure divided by value added "
S_{irt}	sirt= Regional GDP / industrial GDP ($ 1000 000 / $ 1000 000) (this data is imputed for 1999-2003)	"s is the output of industry i in region r as a share of total national output of industry i"
$REG_{\ dirtmanf\ it}$	$\sum_r (S_{irt} \times \text{province's share of Canadian dirty production})$ • province's share of Canadian dirty production = sum of productions of 5 pollutant industries in each province / sum of productions of 5 pollutant industries in Canada ($ 1000 000 / $ 1000 000)	$\sum_r (S_{irt} \times \text{a region's share of UK dirty production})$ "a region's share of UK dirty production, where dirty production is classed as the production from five of the most pollution intensive industries "
$REG_{Pd\ it}$	$\sum_r (S_{irt} \times \text{provincial population density})$ • provincial population density =population/area (person/ km^2)	$\sum_r (S_{irt} \times \text{regional population density})$
$REG_{unemp\ it}$	$\sum_r (S_{irt} \times \text{provincial unemployment rate(\%)})$	$\sum_r (S_{irt} \times \text{ regional unemployment rate})$
$REG_{agepop\ it}$	$\sum_r (S_{irt} \times \text{provincial share of population under the age of 44})$	$\sum_r (S_{irt} \times \text{regional share of population under 44})$
$REG_{PCY\ it}$	$\sum_r (S_{irt} \times \text{provincial per capita income (\$)})$	$\sum_r (S_{irt} \times \text{regional per capita income})$

Cole et al (2005) use the model A:

$$E_{it} = \alpha_i + \delta_t + \beta_1 N_{it} + \beta_2 PCI_{it} + \beta_3 HCI_{it} + \beta_4 SIZE_{it}$$
$$+\beta_5 TFP_{it} + \beta_6 CAP_{it} + \beta_7 RD_{it} + \lambda' REG + \varepsilon_{it} \quad (A)$$

This model is simple panel model and can be used when there is no 'unit root' problem. However, the variables have unit roots. Moreover, after 'cointegration test', it is found that there is cointegration; therefore, 'Vector Error Correction Model' (VECM) can be used. VECM show the short run and long run effects of variables. The main econometric model is model B:

$$\Delta E_{it} = \beta_0 E_{it-1} + \alpha_i + \delta_t + \beta_1 N_{it} + \beta_2 PCI_{it} + \beta_3 HCI_{it} + \beta_4 SIZE_{it} + \beta_5 TFP_{it} + \beta_6 CAP_{it} + \beta_7 RD_{it} + \lambda' REG + \beta_8 \Delta N_{it} + \beta_9 \Delta PCI_{it} + \beta_{10} \Delta HCI_{it} + \beta_{11} \Delta SIZE_{it} + \beta_{12} \Delta TFP_{it} + \beta_{13} \Delta CAP_{it} + \beta_{14} \Delta RD_{it} + \gamma' \Delta REG + \varepsilon_{it} \quad (B)$$

$where\ \Delta X_{it} = X_{it} - X_{it-1}$.[3]

The model is a Random effect model; because 'Breusch-pagan test' shows that the model is a panel instead of pool. Also, 'Hausman test' shows that random effect model should be used instead of fixed effect model. Next section is discussed the results.

Result

Long run elasticity for variables calculated the same as Acharya & Coulumbe (2006). For variable X, They 'divide the estimated coefficient for *X* by the opposite of estimated coefficient for lagged dependent variable to find the long run elasticity of variable X'. Most of the variables of this study have significant effect on pollution in Canada. Table 3 show the econometric results. First the long run effects of variables are interpreted; then, the short run effects are explained.

The result of regression 1, with and without imputation, is in table 3. The sign of variables in two regressions are almost the same, however, more data is available with imputation; therefore, the coefficients are more significant.

[3] The coefficient behind the ΔX_{it} explains the short run effect of change in variables X on pollution.

Table 3: Econometric results

variables	(1)		(2)	(3)
Dependent variable: D1.emission	VEC	Long Run elasticity	GLS	VEC Without imputation for regional GDP
L1.emission	-0.70 (0.06)		-0.70 (0.00)	-0.95 (0.04)
energy	-0.03 (0.88)	insignificant	-0.03 (0.65)	-0.15 (0.61)
PCI	0.72 (0.03)	1.03	0.72 (0.00)	0.27 (0.49)
HCImanf	1.40 (0.03)	2.01	1.40 (0.00)	0.63 (0.69)
SIZE	-0.61 (0.04)	-0.87	-0.61 (0.00)	-0.61 (0.24)
MFP	0.39 (0.24)	insignificant	0.39 (0.00)	0.09 (0.84)
CAP	0.01 (0.95)	insignificant	-0.00 (0.859)	-0.20 (0.44)
R&D	-0.07 (0.55)	insignificant	-0.07 0.070	-0.073 (0.67)
REGpd	2.50 (0.00)	3.57	2.50 (0.00)	1.03 (0.47)
REGunemp	1.45 (0.07)	2.06	1.48 (0.00)	0.62 (0.42)
REGagepop	-3.62 (0.00)	-5.16	-3.62 (0.00)	-1.41 (0.26)
REGdirtmanf	-0.76 (0.05)	-1.08	-0.76 (0.00)	-0.40 (0.59)
D1.energy	0.36 (0.03)	Short run effect +	0.36 (0.00)	0.016 (0.96)
D1.PCI	-0.28 (0.30)	insignificant	-0.28 (0.002)	-0.55 (0.20)
D1.HCImanf	-1.76 (0.00)	Short run effect –	-1.76 (0.00)	-1.52 (0.12)
D1.SIZE	0.56 (0.18)	insignificant	0.56 (0.00)	0.67 (0.36)
D1.MFP	-0.65 (0.08)	Short run effect –	-0.65 (0.00)	-0.28 (0.61)
D1.CAP	-0.02 (0.84)	insignificant	-0.02 (0.55)	0.03 (0.88)
D1.R&D	-0.08 (0.34)	insignificant	-0.076 (0.004)	0.06 (0.623)
D1.REGpd	-1.59 (0.00)	Short run effect –	-1.59 (0.00)	-0.73 (0.24)
D1.REGunemp	-0.79 (0.16)	insignificant	-0.79 (0.00)	-0.39 (0.44)
D1.REGagepop	1.99 (0.02)	Short run effect +	1.99 (0.00)	0.84 (0.24)
D1.REGdirtmanf	0.58 (0.00)	Short run effect +	0.58 (0.00)	0.31 (0.34)

The value in paranthesis are P-value.

In long run increase in physical capital intensity has a positive effect on direct and indirect greenhouse gas emissions. One percent increase in physical capital intensity increases

1.03 percent direct and indirect greenhouse gas emissions. More physical capital means more machinery which means more pollution that those industries whose input is just labour. Also, in long run, an increase in human capital increases pollution; because, they can form industries with high technology that usually use pollution-intensive machinery. One percent increase in human capital intensity increases 2.01 percent direct and indirect greenhouse gas emissions. Furthermore, increase in the average size of industries has a negative effect on pollution because of economy of scale. Bigger firms can control pollution better; therefore, one percent increase in average size of firms decrease 0.87 percent direct and indirect greenhouse gas emissions.

According to Cole et al (2005), "a pollution intensive plant may be less 'visible' in a densely populated, urban area and hence may escape the attentions of the local population." Therefore, there might be positive relation between population density and pollution. Table 3 suggests that one percent increase in informal regulation through population density increase 3.57 percent direct and indirect greenhouse gas emissions. It can be, also, said that people like to live in polluted area because there are more job in those areas. Table 3 suggests that one percent increase in formal and informal regulation through unemployment rate increase 2.06 percent direct and indirect greenhouse gas emissions.

According to Cole et al (2005) regions that have more unemployment rate may have lower regulations; because, they have more social problems that they should consider before thinking about environment. Also, in the area with lower unemployment rate, people ask more for better environment; because they are richer and they like to live in clean area. Population under 44 years old, according to Cole et al (2005) can have more power to ask better environment, they are young and may have more energy to follow their request, Therefore, it is seen that provinces with relatively younger has more regulation to keep the air clean. One percent increase in informal regulation through population under 44 years old decreases 5.16 percent direct and indirect greenhouse gas emissions.

Also, one percent increase in formal regulation through provincial share of Canadian dirty production decreases 1.08 percent direct and indirect greenhouse gas emissions. This variable shows that the more dirty industries in a province, the more regulations are in for area. Therefore, it could possible to have more pollution prosecutions and firms avoid polluting because of those regulation and pollution prosecutions.

In short run, more use of energy causes more pollution. Educated people use technology efficiently and produce less pollution. Also, more productive industries and more innovative industries expect to pollute less; because, productive in one way means to have less waste and therefore less pollution, and the new technologies try to be more environmental friendly. Industries with larger population density have more informal regulation. Populated regions need more regulation because the lives of more people are in danger. In short run the effect of this informal regulation variable is negative on direct and indirect greenhouse gas emissions.

It is observed that industries in area with younger population, in short run, cause more pollution. More younger population cause more jobs and more production in those areas and it may cause increase in pollution in short run. Moreover, Provincial share of Canadian dirty production, the proxy for formal regulation, in short run increases direct and indirect greenhouse gas emissions. It can be said that dirty industries in short run increase pollution, however, in long run, formal regulation like pollution prosecution decrease their incentives to pollute. In general, the result of this model in Canada confirms the result of Hettige (1996), Cole et al (2005), and Cole et al (2007).

Conclusion

This paper studies the effect of formal and informal regulations on pollution intensity on Canadian industries. The econometrics model is a panel with 23 manufacturing industries over 10 years, from 1994 to 2003. In this study, pollution is a function of energy use, physical capital intensity, human capital intensity, average size of firms, productivity, capital expenditure, and R&D expenditure. Moreover, proxies for formal and informal regulations include unemployment, population density, population under 44 years old, and production of dirty industries.

Most of the variables of this study have significant effect on pollution in Canada. An increase in physical capital intensity has a positive effect on direct and indirect greenhouse gas emissions in long run such that one percent increase in physical capital intensity increases 1.03 percent direct and indirect greenhouse gas emissions. An increase in human capital increases pollution in the long run. One percent increase in human capital intensity increases 2.01 percent direct and indirect greenhouse gas emissions. Furthermore, increase in the average size of industries has a negative effect on pollution such that one percent increase in average size of firms decreases 0.87 percent direct and indirect greenhouse gas emissions. Moreover, one percent increase in informal regulation through population density increases 3.57 percent direct and indirect greenhouse gas emissions, one percent increase in formal and informal regulation through unemployment rate increase 2.06 percent direct and indirect greenhouse gas emissions, one percent increase in informal regulation through population under 44 years old decreases 5.16 percent direct and indirect greenhouse gas emissions, and one percent increase in formal regulation through provincial share of Canadian dirty production decreases 1.08 percent direct and indirect greenhouse gas emissions in the long run. Short-run effects of variables have been also estimated. In general, this paper suggests that formal and informal regulations have significant effects in reducing direct and indirect greenhouse gas emissions in Canada. This study confirms the result of Hettige (1996), Cole et al (2005), and Cole et al (2007). This study on Canadian industries can be improved if new data is captured for variables such as pollution prosecution and income per capita for provinces in Canada.

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Appendix 1: Source of data

variable	description	source:
emission	Direct and indirect greenhouse gas emissions	Statistics Canada's key socio-economic database (CANSIM): Table 153-0033 - Direct and indirect greenhouse gas emissions (carbon dioxide equivalents), by industry, L-level aggregation, annual (tonnes per thousand current dollars of production)
fossil_fuel	Energy fuel consumption	Statistics Canada's key socio-economic database (CANSIM): Table 128-00061 Energy fuel consumption of manufacturing industries in gigajoules, by North American Industry Classification System (NAICS), annual
manu_va_1000	Manufacturing value added	Statistics Canada's key socio-economic database (CANSIM):Table 301-0003 - Annual survey of manufactures (ASM), principal statistics by North American Industry Classification System (NAICS), incorporated businesses with employees having sales of manufactured goods greater than or equal to $30,000 (dollars unless
totalemployees	total employees	Statistics Canada's key socio-economic database (CANSIM):Table 301-0003 - Annual survey of manufactures (ASM), principal statistics by North American Industry Classification System (NAICS), incorporated businesses with employees having sales of manufactured goods greater than or equal to $30,000 (dollars unless
induwage	total salaries and wage per industry	Statistics Canada's key socio-economic database (CANSIM): Table 301-0003 - Annual survey of manufactures (ASM), principal statistics by North American Industry Classification System (NAICS), incorporated businesses with employees having sales of manufactured goods greater than or equal to $30,000 (dollars unless
manufwage	Total salaries and wages (x 1,000)	Statistics Canada's key socio-economic database (CANSIM): Table 301-0003 - Annual survey of manufactures (ASM), principal statistics by North American Industry Classification System (NAICS), incorporated businesses with employees having sales of manufactured goods greater than or equal to $30,000 (dollars unless
number_of_establishments	number of establishments	Statistics Canada's key socio-economic database (CANSIM): Table 301-0003 - Annual survey of manufactures (ASM), principal statistics by North American Industry Classification System (NAICS), incorporated businesses with employees having sales of manufactured goods greater than or equal to $30,000 (dollars unless
mfp_based_VA	Multifactor productivity based on Value added	Statistics Canada's key socio-economic database (CANSIM): Table 383-0022 - Multifactor productivity, gross output, value-added, capital, labour and intermediate inputs at a detailed industry level, by North American Industry Classification System
cap_exp_current_prices	Capital expenditure (current price)	Statistics Canada's key socio-economic database (CANSIM): Table 031-0002 - Flows and stocks of fixed non-residential capital, by North American Industry Classification System (NAICS), annual (dollars x 1,000,000)
business_rd_x_1000000	Business R&D	Statistics Canada's key socio-economic database (CANSIM): Table 358-0024 - Business enterprise research and development (BERD) characteristics, by industry group based on the North American Industry Classification System (NAICS), annual (dollars unless otherwise noted)

unemploy	unemployment rate in each province	Statistics Canada's key socio-economic database (CANSIM): Table 282-0055 - Labour force survey estimates (LFS), by provinces, territories and economic regions, annual (persons unless otherwise noted)
population	population in each province	Statistics Canada's key socio-economic database (CANSIM): Table 051-0001 - Estimates of population, by age group and sex, Canada, provinces and territories, annual (persons)
area	area for each province	source: http://en.wikipedia.org/wiki/List_of_Canadian_provinces_and_territories_by_area
age44	population by age group (0-44)	Statistics Canada's key socio-economic database (CANSIM): Table 051-0001 - Estimates of population, by age group and sex, Canada, provinces and territories, annual (persons)
regional_gdp	Provincial GDP per industry	Statistics Canada's key socio-economic database (CANSIM): Table 379-00251,25,26 Gross Domestic Product (GDP) at basic prices, by North American Industry Classification System (NAICS) and province, annual (dollars x 1 000 000)
GDP_industry	GDP for each industry in canada	Statistics Canada's key socio-economic database (CANSIM): Table 379-00251,25,26 Gross Domestic Product (GDP) at basic prices, by North American Industry Classification System (NAICS) and province, annual (dollars x 1 000 000)
income_percapita	income per capita	Statistics Canada's key socio-economic database (CANSIM): Table 111-0009 - Family characteristics, summary, annual

Appendix 2: summary statistics

variables	# of Obs.	Mean	Std. Dev.	Min	Max
emissions	180	2.46	3.04	0.34	14.91
energy	187	9.77	23.14	0.01	155.36
PCI	210	65775.69	58107.61	12614.78	415715.70
HCImanf	210	0.99	0.26	0.54	1.62
SIZE	210	7395.94	7586.65	857.37	33528.22
MFP	200	93.70	12.75	65.60	178.40
CAP	200	0.10	0.06	0.02	0.42
R&D	170	0.04	0.07	0.00	0.45
REGdirtyma~m	230	0.11	0.14	0.00	0.46
REGpop_im	230	6.74	3.92	0.00	22.84
REGunem_im	230	6.31	3.46	0.00	16.01
REGagepop_im	230	0.50	0.27	0.00	1.33