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The Impact of a Packaging Tax on the Eco-Efficiency of Industrial Packaging

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Mémoire présenté en vue de l'obtention du diplôme de *Maîtrise ès sciences appliquées*
Génie industriel

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Ce mémoire intitulé :

The Impact of a Packaging Tax on the Eco-Efficiency of Industrial Packaging

présenté par **David BONIN**
en vue de l'obtention du diplôme de *Maîtrise ès sciences appliquées*
a été dûment accepté par le jury d'examen constitué de :

Mario BOURGAULT, président
Sophie BERNARD, membre et directrice de recherche
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Nathalie DE MARCELLIS-WARIN, membre

DEDICATION

Merci aux gens qui m'ont accompagné le long de cette route cahoteuse.

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RÉSUMÉ

L'objectif de ce mémoire est d'évaluer l'impact de la tarification sur les emballages gérée par l'organisme Éco Entreprises Québec (ÉEQ) depuis 2005 au Québec. Plus précisément, il est question de l'impact de ce tarif sur l'éco-efficience de l'utilisation des emballages par les entreprises à travers 20 secteurs industriels au Québec. À l'aide de données sur l'utilisation de matériaux d'emballages par les entreprises entre 2005 et 2017 (fournies par ÉEQ), ainsi que des statistiques sur les ventes annuelles par secteur industriel, un indicateur d'éco-efficience est construit en terme de dollars ($) par kg de matériaux d'emballages utilisés. Cet indicateur permet d'observer l'évolution de l'éco-efficience de l'utilisation des emballages par les secteurs industriels au Québec entre 2005 et 2017. De manière globale, il est difficile d'établir une tendance claire au Québec durant cette période, puisque certains secteurs ont enregistré une grande amélioration alors que pour d'autre l'éco-efficience a chuté de manière vertigineuse. Cependant, avec cet indicateur d'éco-efficience, et un format des données dites longitudinales, il est possible de spécifier une modélisation économétrique qui puisse estimer l'impact du tarif sur l'éco-efficience, en prenant en compte l'hétérogéneité de chacun des secteurs industriels. Les résultats de ce modèle revèlent un effet positif du tarif sur l'éco-efficience pour deux type de matériaux d'emballages: les bouteilles de PET (Polyethylene Terephtalate) ainsi que le carton ondulé. Cependant l'impact du tarif sur l'acier sur l'éco-efficience s'avère négatif. La méthodologie ainsi que l'indicateur d'éco-efficience développé dans ce travail peuvent servir d'outil d'aide à la décision afin d'aider à améliorer les politiques de tarifications sur les emballages.

ABSTRACT

In this paper the main objective was to evaluate the impact of the packaging tax on the eco-efficiency of the packaging practices of 20 industrial sectors in the province of Quebec, Canada. To this end, an eco-efficiency indicator is constructed from data on industrial sales and packaging material use. This indicator can offer one perspective on the evolution of packaging eco-efficiency across industrial sectors from 2005-2017. Overall, many sectors improved their eco-efficiency over time, but several stagnated and others regressed. With this new indicator, and the panel data structure across industrial sector, a Least Square Dummy Variable (LSDV) model was estimated in order to quantify the impact of the packaging tax on the eco-efficiency. Using an interaction term between the quantities, taxes and also prices, while also controlling for unobserved heterogeneity and sector sales, a statistically significant, positive effect was established for the packaging tax on corrugated cardboard and PET bottles. However, a negative effect was found for the packaging tax on steel, which is somewhat contrary to what would be expected. These results, along with the eco-efficiency indicator, can provide a framework to help to improve the policy instruments designed to tackle issues related to packaging practices.

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LIST OF SYMBOLS AND ACRONYMS

EEQ	Eco Entreprises Quebec
EEI	Eco-Efficiency Indicator
PET	Polyethylene Terephthalate
PPI	Producer Price Index
PVC	Polyvinyl Chloride
LSDV	Least Square Dummy Variable
GMM	Generalized Method of Moments
FRED	Federal Reserve Economic Data
NAICS	North American Industry Classification System
EPR	Extended Producer Responsability
PLA	Polylactic Acid
HDPE	High Density Polyethylene
LDPE	Low Density Polyethylene
SD	System Dynamics

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CHAPTER 1 INTRODUCTION

1.1 Background

Packaging is omnipresent. It serves the key purpose of preserving consumer goods and allowing their transport and distribution. Food, in particular, is packaged in order to prevent spoilage and extend its shelf life. Similarly, nearly all consumer products also come in packages, be it toothbrushes, cellphones or microwaves. Long gone are the days when consumers could go out and buy new products without any packaging. The globalization of the modern economy has made it so that packaging is necessary for products to withstand the long supply chain and arrive at their destination without being damaged. [1]

Not all packaging is made of the same materials. Some are made of various plastics, others of fibers (cardboard, paper, etc.). There is also glass and various metals. Most commonly however, packages are often made with a combination of these materials. [1] In the context of food products, for example, there is great variety, from the milk cartons to the soup cans, to the lettuce bags or ice cream containers. A typical juice container, is usually made up of several layers of materials, including aluminum and cardboard. (see figure 1) The role of packaging for food products in particular is highly important because food products are typically spoiled if packaging isn't adequate. And food losses are a big problem, considering the environmental resources which go into food production. [2]

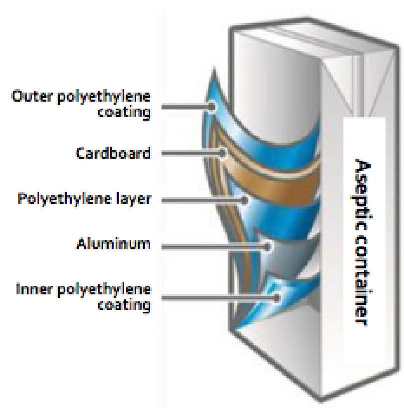

Figure 1.1 Aseptic containers, multilayered packaging (source: EEQ)

[1]Although with the advent of zero-waste shops and grocery stores, this is definitely an evolving situation

Despite many ambitious policies objectives over the past few decades, waste production is still increasing throughout most of the world, including Québec. [3] Organic waste is a significant part of this problem, but most of it is recovered as animal feed or compost. [2] It is packaging which constitutes the most significant policy concern. After end-use by the consumer, the leftover packages are either discarded or recycled. The discarded materials end up in landfills or as litter. The scale of the modern production of consumer goods has made the management of packaging waste an acute policy concern.

Several policy measures have been enacted over the past decade in Canada and throughout the world, to deal with this problem. Many such policies notably revolve around the concept of Extended Producer Responsibility (EPR), aiming among other objectives to transfer the costs of waste management and ecodesign to the producers. [4] The impact of these policies has not always been very impactful, as was the case in China in the late 2000s. [5] However, the entire world is changing rapidly, and there is a much greater awareness of these issues now than there was even five years ago, which in turn is affecting the effectiveness of EPR-related policies.

One of the most common policy instruments usually involves some type of tax on packaging. In Québec, under the Environmental Quality Act, a packaging tax system has been managed by Éco Entreprises Québec (ÉEQ), a non-profit organization, since 2005. In concert with businesses in the retail, manufacturing, service and institutional sectors, a modulating packaging tax has been applied to the packaging materials utilized for consumer goods, in an effort to incentivize eco-responsible packaging, and also to finance the cost of municipal recycling, which has been 100% compensated by the packaging tax revenues since 2013. Similar organizations and packaging tax systems exist throughout the world, for instance, Sociedade Ponto Verde in Portugal. [6] The businesses and organizations targeted by the packaging tax have an estimated aggregated economic output of around 100 B$ per year in Québec.[2] The majority of those businesses are the retailers, distributors and first-importers of packaged products, imported or otherwise. [7]

Since the introduction of the packaging tax, there has been several observable changes in packaging practices, notably the phasing out of PLA (Polylactic Acid) by 2010. In light of high treatment costs, and various difficulties associated with PLA as a packaging material, ÉEQ tripled its tax rate for PLA between 2009 and 2010, after which PLA virtually disappeared from usage as a packaging material. Across organizations and business sectors,

[2] In comparison, Québec's GDP was around 365 B$ in 2018

there is great variety in the ways to define "eco-responsible packaging" or ecodesign as a practice, but for the purposes of this study, it makes sense to use ÉEQ's definition. ÉEQ defines eco-responsible packaging according to the following three characteristics [8]: (1) Made from recycled materials, (2) Recyclable and (3) Designed to use fewer materials. Most common packaging materials are technically recyclable, but certain types like glass [9] and polystyrene [10] have been complicated to manage in Québec, because of high recycling costs and lack of appropriate equipment and facilities. All three aspects are important to consider, but because of the lack of available data to distinguish between virgin and recycled materials, this work is focused on the third aspect, in other words the eco-efficiency of packaging (using less packaging materials).

1.2 Research objectives

There are two main objectives for this study:

1. **The primary objective of this study is to evaluate the impact of the packaging tax on the eco-efficiency of packaging usage across industrial sectors for the years 2005 to 2017.**

2. **A secondary aim is to quantify and characterize the differences in packaging eco-efficiency across the different industrial sectors in Quebec.**

Because eco-efficiency can be a vague concept, it is important to use a precise metric to define it. To estimate the eco-efficiency, a rather rudimentary Eco-Efficiency Indicator (EEI) is computed for each industrial sector in the study. The approach chosen here is inspired by the basic equation of eco-efficiency presented in Figge et al. (2017). [11]

$$EE = V/r \tag{1.1}$$

This equation stipulates that eco-efficiency is a function of value created (V) and resource use (r), highlighting the fact that there are two fundamental pathways for increasing eco-efficiency. Either reducing resource use or increasing the value created, keeping resource use constant. For this article, this equation will be approximated with available data on industrial sales (economic output as a proxy for V) and quantities of packaging material generated (r) by each industrial sector. Using these elements, it is possible construct an EEI[3] expressed in terms of $/kg per sector for each year. This indicator gives us an objective, measurable value from which to observe the evolution of eco-efficiency of packaging use for each sector.

Whether a sector substitutes lighter packaging materials in the place of heavier ones, implements ecodesign practices, or uses less total packaging for a given level of economic output, this is all reflected in the variations of the EEI. Obviously this is very useful for policy analysis, and provides an empirical variable against which we can estimate the quantitative impact of the packaging tax. Moreover, constructing this indicator provides an empirical basis for analyzing an otherwise cloudy concept. Eco-efficiency is typically considered within a wider class of environmental concerns, for which there is often a little available data.

Accordingly, the precise research question this study aims to answer is the following: ***What is the impact of the packaging tax on the eco-efficiency of packaging usage at the industrial level?***

1.3 Choice of methodology

The choice of the analytical tool remains largely dependent upon the research question, and the type of effects we're focusing on. Whether it's technical, environmental, economic or even social impacts, there are different methodologies suitable for each type. Input-output modelling has been used by Ferrão et al. (2014) to estimate economic impacts of a similar packaging tax policy in Portugal [12]. To evaluate the environmental impacts of food packaging with regards to food losses, Williams and Wikström (2011) employed a life cycle approach. [13] Typically, concerns over packaging fit within a broader policy context and need to take into account a wide spectrum of impacts.

[3] Refer to the List of Symbols and Acronyms on page xi for abbreviations

For instance, system dynamic (SD) modelling provides a framework to analyze many potential impacts of a policy. A packaging tax is merely one example of a policy instrument. Its core objective is typically to incentivize ecodesign in a way that fits within the broader public policy context. However, as demonstrated by Bernard (2016), firms who react to tax policies can alter their production practices in a way which is not coherent with the overarching policy goals. [14] For instance, Dace et al. (2014) analyze the impacts of a packaging tax on the entire waste management system in Latvia, using SD modelling. They identify a "rebound" effect wherein the packaging tax causes an increased share of cheaper recycled materials in the market which in turns leads to increased total use of packaging material, obviously clashing with the policy objectives. [15]

In the present case, for example, a decline in packaging eco-efficiency induced by the packaging tax would certainly not be in harmony with policy goals. Based on the understanding of the data and through prior discussions with ÉEQ, it would not be surprising for the packaging tax to have relatively little influence over packaging practices. As a decision variable, it is probably a comparatively unimportant factor for businesses when it comes to choosing the type/quantity of packaging. Several managerial concerns are bound to be much more relevant, like marketing, durability, cost etc.

Nonetheless, there is value in identifying whether or not the packaging tax has any statistically significant impact on the packaging practices of the different industrial sectors. A common technique used to answer similar questions is econometric modelling. In particular, this modelling technique aims to establish (or disprove) the presence of causality between empirical variables, which makes it a suitable tool to answer the research question. In other words: *Can the change in eco-efficiency be explained, at least partly, by variations in the packaging tax rates over the period from 2005 to 2017 ?*

The following work is built on three major methodological steps, which are closely linked to one another. These steps are necessary to answer the research question. Firstly, the construction of a working database from different sources of data (1). This is an important contribution because it builds a framework from which to do further analysis on this topic, and the entire concept was developed from scratch. With this database, the eco-efficiency indicator can be computed (2), and then used as an input within an econometric model (3).

The model specification focuses in particular on the interaction between the packaging tax and the packaging material quantities. In other words, the packaging tax affects the packaging eco-efficiency through its impact on the quantities of packaging material used, for a given level of economic output. The model then returns precise estimates for the impact of the packaging tax on the eco-efficiency. It is important to underline the fact that without an eco-efficiency indicator, this approach would not be useful, because it wouldn't be possible to answer the aforementioned question empirically, and therefore other methodological tools like system dynamics (SD) modelling would need to be employed. Taken together, the three methodological steps (1-3) discussed above represent the core contribution of this research.

1.4 Thesis outline

Aside from this introduction, this research article contains four separate sections (or chapters) and a conclusion. In section (2), the different sources of data are covered, with description and detail on the process of aggregating the different sources together into one database. In section (3), the EEI (Eco-Efficiency Indicator) is presented, along with the steps of its computation and a discussion of the evolution of eco-efficiency across industrial sectors between 2005 and 2017. Sections (4) and (5) cover the specification of the econometric model and a discussion of the results. The conclusion provides a review, a discussion on the shortcomings of the work, along with policy implications and other considerations.

CHAPTER 2 DATA

Econometric models require a neatly arranged and complete database (i.e. spreadsheet). To construct the database for this analysis, four sets of data are needed: (1) A confidential dataset from Éco-Entreprises Québec (ÉEQ) comprising of data detailing packaging material use from firms belonging to 36 industrial sectors. (2) The packaging tax rates for 17 different types of packaging materials (also from ÉEQ). (3) Sector sales data from Statistics Canada (4) Prices for materials from the Federal Reserve Economic Data (FRED) website. [16]

Table 2.1 Data sources

Data	Source	Description
1	ÉEQ	Packaging materials generated by sector (kg)
2	ÉEQ	Packaging tax rates per type of material ($/kg)
3	Statistics Canada	Sales per industrial sector ($)
4	FRED	Producer price indexes for raw materials (unitless)

Dataset **(1)** is the core data for this analysis. It contains the quantities (kg) and types of packaging materials declared/used by each industrial sector for every year between 2005-2017. The full dataset was originally down to the firm level, but in an effort to comply with confidentiality agreements, and also to suit the purposes of this study, the data was aggregated into industrial sectors. Of the 36 sectors available in the original dataset, all weren't usable from an analytical perspective. Notably, several sectors had no obvious corresponding economic sector sales data from Statistics Canada. Without economic output data, it is impossible to compute the eco-efficiency indicator. Therefore, this number was reduced to 20 sectors for which sufficient data was available. This enabled the computation of 20 sets of eco-efficiency indicators, one for each sector. The packaging tax rates are **(2)** are self-explanatory and can be found in Appendix A. The industrial sales data **(3)** from Statistics Canada follows the NAICS (*North American Industry Classification System*) Classification. Two tables (**1610004801** [17] and **2010000801**) [18] were used, one for retail sectors and another for manufacturing sectors. This data will be used as a proxy for the value created numerator in the eco-efficiency equation, as a measure of economic output for a given year. To control for global trends in raw material prices, producer price indexes (PPI) **(4)** from the FRED (Federal Reserve Economic Data) were selected and matched according to the broad classes of material, as presented in Appendix C.

Overall, 8 specific time series were used: Steel [19], Aluminum [20], Corrugated cardboard [21], Unbleached Kraft and Paperboard [22], Laminated paper [23], Plastics [24], Polystyrene [25] and Glass [26]. As an overview, Figure 2.1 outlines the general price trends for the individual times series from 2005 to 2017. As can be observed, aside from the value of steel, which has stagnated, and that of aluminum, which has even regressed over the years, most of the other materials have a positive upward trend. Including this information in the analysis allows to isolate the effect of the packaging tax itself, distinct from the overall trends in material prices.

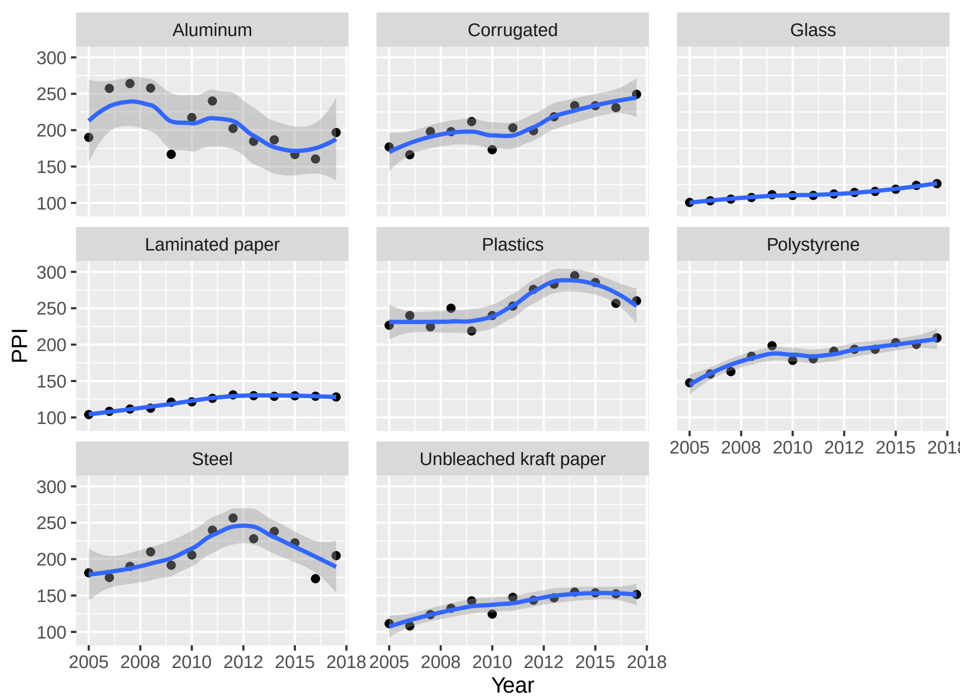

Figure 2.1 PPI for the raw materials (source: Federal Reserve Economic Data)

The various data sources aren't exactly compatible, and therefore an effort of aggregation is necessary in other to create a usable database for modelling purposes. This implies matching the ÉEQ materials to the broader FRED classification. For instance the packaging tax rates for clear and colored glass are both linked to the same FRED price index category: **Glass and Glass Product Manufacturing**. The tables in appendices B and C illustrate this process of aggregation for both the ÉEQ sectors and NAICS (from Statistics Canada) sectors, and the ÉEQ-FRED categories.

Some of the sales data needed to compute the EEI was missing in particular years, and for certain sectors. This is probably because of confidentiality measures by Statistics Canada. Since the missing data points were few and predictable, they were filled using basic interpolation techniques in Excel. This was deemed suitable because the missing data points were clearly not missing at random, there was a visible trend, and removing the entire rows/columns would have made the estimation procedure impossible. [27] Similarly, ”missing” amounts for the tax rates and quantities of material generated were set to 0, because that is in effect what they are. The absence of a tax means that it cannot have an impact on quantities, and therefore its effect is null (zero). Additionally, the original dataset had "missing" quantities, but in effect it simply meant that was none of the specific packaging material was generated for the specific sector during that particular year. In the original dataset, there were a lot more missing observations for individual firms/businesses, but thankfully, aggregating to the sector level alleviated these concerns.

sector	year	qty	sales	eei	q1	q2	...
1	2005	16.68223337	15.66748955	0.309317757	11.62499443	11.374594	...
1	2006	16.87514574	15.79997155	0.293593275	11.82451936	11.65825449	...
1	2007	17.03928325	15.93374087	0.285954026	12.29788125	11.66980955	...
1	2008	17.03949686	15.9570534	0.291748833	12.29788125	11.66980955	...
1	2009	17.18331009	16.01052202	0.269647522	12.19667361	11.50795312	...
...	...	...	...	...	...	...	...

Figure 2.2 Final database

This database (see figure 2.2 above) constitutes was is called a (micro) panel data set, where the same cross-sections (in this case industrial sectors, comprised of the same firms), are followed through time. In this case, it’s 20 industrial sectors (N) over 13 years (T), with no missing years, and therefore a balanced panel, meaning we have the same number of observations and years for each unit of observation (i.e. the industrial sectors) The final database is in the long format, with a row for every observation of each industrial sector for every year. After being transformed from the initial spreadsheet format, according to tidy data principles, each variable becomes a column, each observation is a row. [28] The sector-dependent observations are the Eco-Efficiency Indicator (EEI) and the individual quantities of material generated for each year. The other variables, the packaging tax and materials price, are cross-section independent, and only vary with time. Therefore they need to be repeated (i.e. literally copy-pasted) for every cross-section in the database.

CHAPTER 3 ECO-EFFICIENCY INDICATOR

For this study, 17 distinct types of packaging materials are considered (see Appendix A for the names corresponding to the IDs and packaging tax rates). There were more in the original dataset, but several types had become redundant and overlapping, mostly because of changes in labels and classification between 2005 and 2017. Therefore, in order to streamline the modelling process, the material types were aggregated in the most sensible way possible. For example, this meant regrouping PVC, PLA together into a broader class of materials: **PVC, polylactic acid (PLA) and other degradable plastics.**

Figure 3.1 Variation in eco-efficiency of packaging from 2005 to 2017, according to sectors (sectors 9 and 15 omitted for scaling purposes)

Of the 20 sectors considered, some use a lot more packaging material than others, notably the food production and retail sectors. However, simply looking at aggregate quantities does little to illuminate the matter of eco-efficiency. With this information, we're able to compute an EEI for each sector and every year. At this point, the obvious interest is to figure out which sectors have actually become more eco-efficient over the years 2005 to 2017. Graphically, it is possible to get a general idea of the evolution. Most sectors seem to have improved their packaging eco-efficiency, according to the EEI's definiton. It is also clear that it is not a linear process, as in many cases eco-efficiency dropped for several years and then increased back up again. Sector 10 (Computer and electronic product manufacturing) and sector 13 (Furniture and related product manufacturing) have such characteristics. Sector 20 (Clothing manufacturing) somehow experienced precipitous decrease in eco-efficiency. There are limits however to this visual analysis. To better ascertain the change in eco-efficiency across time and sectors, it makes sense to numerically compare the relative change between 2005 and 2017 for each sector. To this end, equation (2) gives the overall relative change in eco-efficiency (in %) for each industrial sector, defined as $\Delta EEI\%$.

$$\Delta EEI\% = \left(\frac{EEI_{2017} - EEI_{2005}}{EEI_{2005}}\right) * 100 \tag{3.1}$$

ID	Sector	% change in Eco-efficiency over 2005-2017
15	Transportation equipment manufacturing	90.9
2	General merchandise stores	75.5
1	Health and personal care stores	50.6
17	Beverage and tobacco product manufacturing	39.7
12	Hardware manufacturing	37.6
10	Computer and electronic product manufacturing	30.7
16	Food manufacturing	28.7
4	Clothing and clothing accessories stores	26.9
13	Furniture and related product manufacturing	26.6
6	Building material and garden equipment and supplies dealers	19.4
5	Sporting goods, hobby, book and music stores	15.7
9	Motor vehicles and parts dealers	-1.5
7	Electronics and appliance stores	-2.0
11	Electrical equipment appliance and component manufacturing	-18.2
18	Chemical manufacturing	-33.0
8	Furniture and home furnishings stores	-39.7
3	Food stores	-47.6
19	Pharmaceutical and medecine manufacturing	-58.0
14	Sporting and athletic goods manufacturing	-60.4
20	Clothing manufacturing	-78.9

Figure 3.2 Variation in % of eco-efficiency between 2005 to 2017, sorted from best to worse

Applying this formula for every sector yields the relative change in packaging eco-efficiency between 2005 and 2017, sorted from best to worse, seen in Figure 3.2 above. Focusing specifically on food products, it can be seen that for Food manufacturing (16), there has been a clear improvement of 28.7% against the value of 2005. Interestingly, the same cannot be said of food retailers (3), where a nearly 50% decline in packaging eco-efficiency can be observed. This surprising result suggests that the packaging practices of groceries and other food stores may not be as exemplary as that of the food manufacturers. It may be that the repackaging of wholesale food products for final sale leads to excessive total packaging, and that this particular aspect has gotten worse over the years. The improvement in the eco-efficiency of food manufacturing can potentially be explained, at least partly, by the replacement of glass containers with PET (Polyethylene Terephtalate) containers, a trend which has been observed across the food manufacturing industry in recent years. [29]

Since glass is much heavier, replacing it with lighter materials would significantly improve eco-efficiency according to the definition of the current indicator. The computer and electronic product manufacturing sector has also seen a great increase in efficiency, which may be evidenced by more efficient, more compact packaging for personal electronic products. Another impressive result is the 75.5 % gain for General merchandise stores (2), implying significant reduction of excess packaging for common consumer goods. This might simply reflect a general trend of structural change and greater environmental awareness over the years, resulting in a better packaging-to-product ratio for many common consumer products. [30]

This indicator is simple in the way that it compares a certain level of economic activity against the total weight of packaging material. This is a useful definition for the purpose of this research, given the focus on the sole criteria of eco-efficiency. There would be a number of ways to improve the versatility of this indicator, for instance by taking into account the different characteristics of the materials; for example their unit weight, life-cycle impact, cost of recovery, transportation etc. These were all factors considered in this analysis, but required significantly more data than was available. A different indicator may paint a different picture to the outlook presented in Figure 3.2. For instance, choosing a different indicator formula or using other metrics instead of industrial sales, like a specific number for value added, the likes of which can be found in provincial input-output tables, or weighting the different types of packaging materials differently according to their respective life-cycle environmental impacts.

CHAPTER 4 REGRESSION MODELLING

Armed with this EEI, it is now possible to answer the research question. Again, the goal is to try to quantify the impact of the packaging tax on variations in eco-efficiency. In order to do this, the most appropriate approach in the present case is a regression model tailored for the need of a panel data structure. In this scenario, the data is comprised of observations on the same industrial sectors for 13 consecutive years, which represents a panel or "longitudinal" data set. The benefit of this data format is the possibility of controlling for the unobserved heterogeneity of the individual industrial sectors, with their specific production characteristics, which represent a unique feature of panel data models [31]. Keeping in mind the research objective, it makes sense to consider the following model specification:

$$EEI_{it} = \beta_0 + \beta_1 t_{jt} * q_{it} + \beta_2 f_{jt} * q_{it} + sales_j + \alpha_i + \mu_{it} \tag{4.1}$$

This is a model where the Eco-Efficiency Indicator (EEI) is regressed against the interaction term of packaging tax (t_{ij}) and quantity (q_{it}), for all taxes and respective quantities. (see Appendix D). A second interaction term captures the effects of the global price trends for the raw materials. Controlling for the sales per sector is necessary, because varying sales is one of the pathways which can affect the EEI, according to the established definition. The subscripts i, j, t define respectively, the material type, the sector and the year. The α_i and μ_{it} are the individual (cross-section) and idiosyncratic (time-dependent) errors, respectively.

Table 4.1 Model variables

Variable	Description
EEI_{it}	Eco-efficiency indicator for sector i at year t
t_{jt}	Packaging tax for packaging material j at year t
f_{jt}	Price index for packaging material j at year t
q_{it}	Quantity of packaging material i at year t
$t_{jt} * q_{it}$	Interaction term
$f_{jt} * q_{it}$	Interaction term
$sales_j$	Sales for sector j
α_i	Unobserved effects
μ_{it}	Idiosyncratic errors

The interaction terms $t_{jt} * q_{it}$ and $f_{jt} * q_{it}$ reflect the effect of the packaging tax (t_{ij}) and price indexes (f_{ij}) on the quantities of packaging materials .[1] This is the meaningful effect to evaluate because the effect of the packaging tax (or the price indexes) is not relevant in of itself. Taken on its own, the singular effect of the tax on eco-efficiency implicitly assumes that the quantities of material stays constant, which is not interesting, because the packaging tax affects eco-efficiency through its effect on the quantities on packaging material used. Moreover, the cross-sections vary only in quantities of material generated, not according to the taxes and prices.

Therefore, to leverage the panel structure in place, it's important to recognize that the impact of the packaging tax on eco-efficiency is dependent on the variation in quantity. The interaction terms capture this overall impact on eco-efficiency. In other words, the partial effect of the packaging tax on eco-efficiency, depends on the corresponding quantity of packaging material. [31] The idea is that a higher tax rate would be expected to negatively impact quantity and therefore increase eco-efficiency and vice-versa.

The problem with the previous model specification is that it does not take into account the sector heterogeneity, or the unobserved factors which could affect packaging eco-efficiency. It aggregates all of the cross-sections (sectors) together, and derives its estimates from the entire dataset. This is called a "pooled" regression. However, properly accounting for the differences between sectors is a valuable step to take, because panel data (multiple cross-sections) is much more informative than a single cross-section. One solution to this problem is to add dummy variables for each sector to control for the individual differences. This is called the Least Square Dummy Variable (LSDV) method.

$$EEI_{it} = \beta_1 t_{jt} * q_{it} + \beta_2 f_{jt} * q_{it} + sales_j + sector_j + \alpha_i + \mu_{it} \tag{4.2}$$

The main motivation in this case for using the LSDV (as opposed to say a Fixed Effects Method) is to control explicitly for individual but not time, effects. Indeed, the key explanatory variable, the packaging tax, is cross-section independent. Meaning, it varies only across time, not across sectors. Controlling for time effects (additionally to individual effects) would make the packaging tax perfectly collinear to the full set of time dummies (minus the constant), removing their effect entirely. Since the objective is precisely to capture the impact

[1] In the model the f_j values are, **f1** = steel, **f2** = aluminum, **f3** = corrugated cardboard, **f4** = unbleached kraft and paperboard, **f5** = laminated paper, **f6** = plastics, **f7** = polystyrene, **f8** = glass

of the packaging tax, it is important to control strictly for the unobserved heterogeneity by including $sector_j$, the full vector of 20 dummy variables for each sector.

All of the variables of the model are transformed with the natural log **ln(1+x)** monotonous transformation, for a couple of reasons. First and foremost, the ability to interpret the model in terms of %, but also to simplify the model and linearize the relationship between variables. The choice of adding the constant 1 in the log term is necessary to prevent negative values, since even if all the values in the data are non-negative, some are under 1 and some are zero. Another important benefit is that taking the log of a variable often narrows its range, which can make model interpretation easier. [31] This is particularly useful in this case since the different sets of variables have varying orders of magnitude. Finally, log transformations can normalize the distribution of residuals, and often improve estimation. [27]

Another model, which is not explored in this work, is still interesting to discuss. Much of the change in packaging eco-efficiency may be also explained not be individual sector characteristics, or the packaging tax, or material price trends, but also by endogenous structural change within society. In general, there is greater and greater awareness of this issues, and innovation in terms of ecodesign are probably a general trend across the economy. Specifying a dynamic relationship by including a lagged value of the EEI in the model might be useful if we want to capture this change, or rather the convergence of packaging eco-efficiency across the industrial sectors over the years. A model is said to be dynamic when the lagged value of the dependent variable is included as one of the explanatory variables [32]

$$EEI_{it} = \theta EEI_{i,t-1} + \beta_1 t_{jt} * q_{it} + \beta_2 f_{jt} * q_{it} + sales_j + sector_j + \alpha_i + \mu_{it} \tag{4.3}$$

The difference with equation (4.2) is the inclusion of the term $\theta EEI_{i,t-1}$. The parameter θ reflects the stochastic or unpredictable nature of the relationship, and can include unobservable factors discussed above like innovation, awareness etc. It captures an accumulation effect, where the level of eco-efficiency is expected to rise over time. These factors, along with the previous level of eco-efficiency, help explain the current level of eco-efficiency at year t. However, introducing the lagged variable creates an endogeneity problem and makes the LSDV estimator biased. [27] The Arellano-Bond (1991) estimator corrects this problem, and could be applied to the current data using the methods in Croissant & Millo (2019), chapter 7. [32]

CHAPTER 5 RESULTS

Before getting to the results, it is appropriate to reflect on the expected output of the model, because otherwise it's too easy to rationalize results after the fact. As stated earlier, from internal discussions with ÉEQ, and understanding of the topic, it wasn't expected that this model would reveal a strong impact of the packaging tax on eco-efficiency outcomes, but rather that if there was any effect it would be subtle. The main reason for this, as stated earlier, is clearly that the packaging tax is not the major factor in determining packaging material choice for most firms/sectors, and several other aspects, including economic variables and packaging design concerns, are more susceptible of influencing the quantity of packaging material used by firms. For every sector, and every firm in that sector really, there are numerous unmeasured explanatory variables which can affect the behavior of the units (sectors) being analyzed. Not including these variables normally leads to what is commonly referred to as OVB (Omitted Variable Bias). That being said, panel data methods can compensate for this problem by controlling for the unobserved heterogeneity of each industrial sector. [27]

Model (3) is estimated first with regular OLS (pooled cross-sections), and returns no significant effect for the interaction terms. The coefficient for q_{11} is significant, but the interaction term is not, and its interpretation would imply that $t_{11} = 0$, which is obviously not relevant to this analysis (a null tax can't have any effect). Turning to model (4)[1], it turns out that several of the sector dummy variables are highly statistically significant, indicating strong unobserved effects, particularly for sectors (5), (7), (9), (12) and (15). Controlling for this unobserved heterogeneity produces to the regression results displayed in Figure 5.2.

The model estimates are robust to heteroskedasticity and autocorrelation via clustered standard errors, as suggested by the residual diagnostics D.1 in Appendix D.1 Clustered errors and are a type of standard error which are so-called *Heteroskedasticity and Autocorrelation Consistent* (HAC) standard errors, and not including them can otherwise lead to distorted values for the estimators. Clustered errors allow for both hetereoskedasticity and autocorrelation within an entity (sector), but treat the errors as uncorrelated across entities. [33]

None of the singular (non-interaction) effects (t_j & q_j) are significant, which is to be expected, but a few interaction terms are. $t1 * q1$, $t3 * q3$ and $t12 * q12$ have respectively negative,

[1] see Appendix D.1 for the R code

positive and positive impacts on eco-efficiency. These correspond to Steel (1); Corrugated cardboard (3) and PET Bottles (12). In order to evaluate the impact of the packaging tax rates t1, t3 and t12, specific values of q1, q3 and q12 need to be inserted into the interaction term, to obtain the direct impact of t. [31] A sensible approach is to compute the quantity means across all sectors and all years for q1, q3 and q12. Accordingly, $\bar{q}_1 = 10.08$, $\bar{q}_3 = 13.78$, $\bar{q}_{12} = 7.33$. Inserting these values into the interaction terms, and multiplying with the corresponding estimate value returns the following:

$$\frac{\Delta EEI}{\Delta t_3} = \hat{\beta} * \bar{q}_3 = (0.23004)(13.78) \simeq 3.17$$

Figure 5.1 Interaction term: impact of t_3 on EEI

Because of the natural log transformation, this value can be interpreted in %. Therefore, on average, a 1% increase of the packaging tax rate on Corrugated cardboard (t_3) leads to about 3.17 % improvement in overall packaging eco-efficiency. This is a strong effect, indicating that the quantity of corrugated cardboard is very responsive to its corresponding packaging tax. Similarly, for q_{12} (PET Bottles) the impact of a 1% increase in t_{12} leads to less than proportional, but still positive effect of around $\approx 0.68\%$ increase in eco-efficiency, on average.

Variable	Estimate	SE	t	p-value
t1:q1	-0.31416	0.09390	-3.35	0.0010 **
t2:q2	0.04004	0.05519	0.73	0.4690
t3:q3	0.23004	0.07830	2.94	0.0037 **
t4:q4	-0.14779	0.29469	-0.50	0.6166
t5:q5	0.03374	0.02742	1.23	0.2202
t6:q6	0.01303	0.04049	0.32	0.7480
t7:q7	-0.10299	0.06868	-1.50	0.1355
t8:q8	-0.06098	0.09348	-0.65	0.5150
t9:q9	0.02978	0.02283	1.30	0.1938
t10:q10	0.08632	0.12548	0.69	0.4924
t11:q11	0.06778	0.06735	1.01	0.3156
t12:q12	0.09270	0.04105	2.26	0.0251 *
t13:q13	-0.04541	0.07493	-0.61	0.5453
t14:q14	-0.15971	0.12685	-1.26	0.2097
t15:q15	0.04970	0.04836	1.03	0.3054
t16:q16	0.09559	0.08514	1.12	0.2630
t17:q17	-0.17632	0.11081	-1.59	0.1133

Figure 5.2 LSDV regression results on the packaging tax interaction terms

The model results are shown in 5.2. The first column represents the interaction terms of each of the tax rates (t) and corresponding quantities (q). The second column lists the values for the parameter estimates (β) of the effect of the interaction term on the EEI. Columns 3-5 show the standard errors, t statistics and p-values, respectively. At the same time, the partial effect of t_1 (Steel) is seemingly negative. Computing the interaction term as before, gives a roughly -3.17% average effect on eco-efficiency. (coincidence with Δt_3).

This negative effect is contrary to expectations, and should serve as a caution when interpreting this results. What these estimates suggest is that the packaging tax doesn't have a clear, predictable impact across all types of material, and that the current results are at best weak evidence of a tangible effect. The R^2 for LSDV regressions is typically not useful information, being artificially high and driven by the inclusion of many dummy variables, and of course the sector sales, capturing the individual sector effects and explaining most of the variation of the explained variable (in this case the eco-efficiency indicator).

Overall, the lack of discernible statistical evidence of an impact of the packaging tax for most materials can be seen as disappointing, but in light of expectations, the results here at least suggest that for some packaging materials (Corrugated cardboard and PET Bottles), the packaging tax has a quantifiable and statistically significant impact on packaging eco-efficiency. These results should be seen as the first step or as a preliminary analysis which confirms that the packaging tax is associated with positive effects on packaging eco-efficiency, at least for two materials.

On the other hand, this does not mean that the packaging tax has not impacted other types of packaging materials, but rather that it wasn't possible to find statistical evidence of it doing so based on the available data. Indeed, it is conceivable that the present results could be altered in a major way if data on packaging material use from recent years (2018-2020) was included in the dataset. The reasoning behind this idea is that the global effect of the packaging tax seems to be getting more significant as the years go by, as the firms get more and more used to it, and through greater awareness of the value of ecodesign. This is obviously an hypothesis which would need to be tested empirically.

CHAPTER 6 CONCLUSION

6.1 Review

The objective of this research was to understand the impacts of ÉEQ's packaging tax on the eco-efficiency of packaging use for 20 industrial sectors in Québec. Although it may not be immediately obvious, the vast majority of the work involved a very lengthy period of time spent on ”data cleaning” tasks, towards creating the final database used for the econometric model. This can be a very boring part of the research process, but it laid the ground work which made the rest of the analysis possible. By combining these different data sources together, it was possible to create an Eco-Efficiency Indicator (EEI). This indicator revealed significant, but heterogeneous changes in eco-efficiency across industries. While certain industrial sectors improved tremendously, others got significantly worse, so it's difficult to speak of widespread improvements across the economy. The econometric model (LSDV) produced results which revealed a positive impact of the packaging tax on eco-efficiency, for two specific types of packaging materials, PET bottles and Corrugated cardboard. However, the packaging tax on steel had a negative impact on packaging eco-efficiency, which runs contrary to expectations.

6.2 Shortcomings & Future research

This research focused on one criteria, eco-efficiency. There are many other considerations related to packaging, namely recyclability, environmental empacts, cost concerns etc. More importantly, there are interactions between all of these components, as was shown by Dace et al.(2014) in their system dynamics (SD) model. System dynamic modelling relies on differential equations to model variables for which data is deficient. The theoretical framework on which SD is built allows to create models where the dynamic relationships between many variables are considered simultaneously. [34] These interactions cannot be captured when focused on one isolated aspect, and indirect impacts which could potentially alter the overall results are therefore ignored. Moreover, the process required to create a working database involved a lot of ad hoc steps which can cause measurement bias. This was partly caused by the somewhat convoluted aggregation procedure needed to sort the data and then compute an eco-efficiency indicator. Aggregation of data is a common occurrence in empirical work, but it could be avoided with more harmonious data collection ”in the field”. The eco-efficiency indicator itself is straightforward, while being fully adequate, but still cannot distinguish between different types of packaging materials according to weight, transportation costs, CO_2 emissions and life-cycle impact. Incorporating each of these characteristics into a new definition for the eco-efficiency indicator would increase its explanatory power and make the results derived from it more robust. It is of course difficult to get the required data to estimate each of these concerns, but it would be a productive way to extend this research.

Econometric analysis is a very popular and time-tested technique to test empirical relationships, but in particular when data on a particular policy interest in insufficient, system dynamics (SD) modelling can bridge the gap by allowing to model aspects for which the information is lacking, and modelling their interaction with the rest of the ”system” relevant to the policy studied. [35] In this way econometrics and SD are complementary, and should be used together to analyze the broader implications of packaging concerns. Moreover, estimates of economic and environmental impacts can be included in this analytical process, via the use of input-output modelling and life-cycle analysis, respectively.

6.3 Policy implications

The eco-efficiency indicator developed here, while rudimentary in terms of its definition, is still useful for summing up a lot of information in a single, compact metric. To quote Franklin-Johnson et al.(2016), “Indicators typically represent phenomena which are difficult to quantify, or for which units of measurement do not exist.“ [36] It can be difficult for policy makers to evaluate the consequences of policy instruments, outside of the conventional setting of macro-economic considerations (interest rate, GDP etc.), for which there is an abundance of data. Environmental and social impacts have long being included more within the realm of qualitative, rather than quantitative, considerations, and have thus been difficult to measure with any kind of precision.

Indicators, even though they simplify reality, are a solution to this problem, being quantitative in nature. To be able to analyze all types of environmental policies, and EPR-focused instruments in particular, it is important to have precise policy objectives. [37] Policy assessment is a much more objective endeavour when it relies, at least partly, on precise quantitative measurements. From a managerial perspective, indicators can shape understanding and implementation, and enable empirically-based decision-making. They become a tool of constant feedback, and this is perhaps why the concept of ”data-driven” companies and organizations is becoming more and more popular with each passing year. By accumulating more data and using indicators and modelling, the interactions between different policy concerns can be observed in real time, and serve as a continual tool for assessment and adjustments of policy.

Whereas a decade ago or more, wider considerations of social responsibility and environmental awareness did not really factor in to the inner management of businesses, in today's world, firms are in a constant process of learning and adapting to new realities. [38] Beyond its responsibilities in managing the packaging tax system, ÉEQ has also being active in teaching and helping businesses adapt and adjust their packaging practices. In this way, it is an important intermediary between the public policy objectives and the individual economic actors in the industrial sectors. Within the perspective of the circular economy, conventional business models need to evolve along with the wider societal changes. [39] Policy instruments are a useful tool to influence and steer this process, but efforts to improve knowledge and facilitate awareness are just as important. There needs to be a collaborative relationship between the regulatory agencies and the individual economic actors, and this can foster an integrative approach to packaging and a grounding in empirical data can help drive this process.

This study was based strictly around the idea of reducing the amount of packaging per unit of economic value. However, just as there are hazards to overpackaging, there are significant risks with underpackaging. [8] Research by Williams & Wikström (2011) showed that increased packaging per product ratio can reduce the total environmental impact associated with a product, in particular if it can prevent food or material losses. [13] There are complex interactions at play and therefore it bears reminding that making more with less (or eco-efficiency) is only one of the characteristics of eco-responsible packaging, and focusing on it exclusively can lead to inadequate outcomes. Most notably, there are numerous health considerations regarding the use of plastic instead of heavier packaging material like glass, which may seem less desirable based on the sole criteria of eco-efficiency. For example, endocrine disruptors in plastic can cause deleterious hormonal effects, by leaching into the food products themselves. [40] In the long run, this could lead to health consequences and costs which offset the initial benefits of switching from glass to plastic containers. Currently, health considerations regarding packaging are often ignored [41], and yet they should be as important (if not greater) a criteria as eco-efficiency.

This further reinforces the importance of an interdisciplinary perspective when evaluating policies, because the overall objective of any policy, including EPR instruments like a packaging tax, is ultimately to improve social welfare [37], and failure to embrace an holistic perspective can lead to unforeseen impacts. Historically, there has been a perceived dichotomy between environmental and economic concerns, but in reality there are many more such criteria including, technical (feasibility), social and health considerations, which are often mutually conflicting. [42] Multi-criteria decision analysis methods have a large literature and have been proven an effective tool to deal with multiple policy concerns or criteria. For example, it has been used to evaluate sustainable packaging design while conciliating economic, social and environmental considerations. [43]

To summarize the practical implications of this work: emphasizing the use of clear metrics, and using these indicators to shape and adjust policy. Constructing more indicators, and adopting a data-driven perspective should help steer results towards the broader policy objectives related to industrial packaging practices. However, the model results and approach presented here should not be misconstrued as particularly strong evidence regarding the impact of the packaging tax. What it does reveal is that there is some evidence of positive effects on eco-efficiency, but because of the presence of a negative impact for the packaging tax on steel, it would be prudent to extend this analysis by adding the recent years (2018-2020) of packaging material and tax rates information to the dataset, before drawing too many conclusions from the current results. Accordingly, this work should spur further research on the topic, with more considerations for proper data collection, while also including other important aspects in the analysis, like making a distinction between recycled and virgin packaging materials. Altogether, indicators can be helpful to decision-makers, particularly because they simplify complex realities into simple numbers. Building on this approach with further data, would only help to better understand and monitor the true impacts of EPR-related policies.

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APPENDIX A PACKAGING TAX AND MATERIAL ID

Table A.1 ÉEQ packaging tax rates and material IDs

ID	Material	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
1	Steel	0.0353	0.0359	0.0816	0.0565	0.0624	0.0962	0.1085	0.1260	0.1084	0.1149	0.1442	0.1564	0.1602
2	Aluminum	0.0112	0.0115	0.062	0.0449	0.0547	0.0852	0.0961	0.1107	0.18	0.1878	0.1275	0.1296	0.1456
3	Corrugated cardboard	0.0556	0.0565	0.0667	0.0747	0.0748	0.1492	0.1693	0.1999	0.2499	0.2647	0.1859	0.1925	0.1906
4	Boxboard and other paper packaging	0.0556	0.0565	0.0667	0.0747	0.0748	0.1189	0.1349	0.1592	0.1614	0.1694	0.1953	0.2074	0.2069
5	Gable-top containers	0.0702	0.0714	0.0896	0.1071	0.1384	0.2101	0.2385	0.283	0.1555	0.163	0.1953	0.2119	0.2092
6	Aseptic containers	0.0702	0.0714	0.0896	0.1071	0.1384	0.2101	0.2385	0.283	0.2719	0.2848	0.2287	0.237	0.2378
7	Kraft paper	0.000	0.000	0.000	0.000	0.0748	0.1492	0.1693	0.1999	0.2499	0.2647	0.1859	0.1925	0.1906
8	Laminated paper	0.0702	0.0714	0.0896	0.1071	0.1384	0.2101	0.2385	0.283	0.1735	0.182	0.245	0.2655	0.2896
9	PVC, PLA and other degradable plastics	0.000	0.000	0.000	0.000	0.1712	0.4102	0.4655	0.5497	0.6653	0.6813	0.7503	0.7898	0.7083
10	Other plastics, polymers and polyurethane	0.1191	0.1211	0.1288	0.152	0.1712	0.2222	0.2518	0.2961	0.2559	0.2664	0.3022	0.3161	0.3164
11	HDPE bottles	0.0692	0.0704	0.0831	0.1056	0.1121	0.1678	0.1900	0.2225	0.2068	0.2174	0.1597	0.1637	0.1620
12	PET bottles	0.0860	0.0875	0.1092	0.1027	0.1233	0.2079	0.2356	0.2766	0.2127	0.2203	0.2624	0.2803	0.2769
13	PET containers	0.000	0.000	0.000	0.000	0.000	0.2222	0.2518	0.2961	0.2559	0.2664	0.2624	0.2803	0.2769
14	HDPE/LDPE plastic film	0.1191	0.1211	0.1581	0.1915	0.2606	0.3436	0.3898	0.4639	0.4897	0.5178	0.4714	0.4888	0.4979
15	Polystyrene	0.1191	0.1211	0.1729	0.2710	0.3263	0.4102	0.4655	0.5497	0.6653	0.6813	0.7503	0.7898	0.7083
16	Clear glass	0.0256	0.0260	0.0373	0.0368	0.0377	0.0374	0.0424	0.0500	0.0977	0.0971	0.1457	0.1838	0.1884
17	Colored glass	0.0268	0.0273	0.0372	0.0369	0.0356	0.0332	0.0377	0.0443	0.0950	0.0944	0.1416	0.1846	0.1892

APPENDIX B INDUSTRIAL SECTORS

Table B.1 Industrial sectors and corresponding NAICS numbers

ID	Industrial sectors	NAICS #
	Retail	
1	Health and personal care stores	446
2	General merchandise stores	452
3	Food stores	445
4	Clothing and clothing accessories stores	448
5	Sporting goods, hobby, book and music stores	451
6	Building material and garden equipment and supplies dealers	444
7	Electronics and applicance stores	443
8	Furniture and home furnishings stores	442
9	Motor vehicles and parts dealers	441
	Manufacturing	
10	Computer and electronic product manufacturing	334
11	Electrical equipment, appliance and component manufacturing	335
12	Hardware manufacturing	3325
13	Furniture and related product manufacturing	337
14	Sporting and athletic goods manufacturing	33992
15	Transportation equipment manufacturing	336
16	Food manufacturing	311
17	Beverage and tobacco product manufacturing	312
18	Chemical manufacturing	3251
19	Pharmaceutical and medecine manufacturing	3254
20	Clothing manufacturing	315

APPENDIX C AGGREGATION TABLE

Table C.1 Aggregation between corresponding ÉEQ tax rates and FRED price indices

EEQ	FRED Series
Metals	
Aluminum containers	Global price of aluminum
Aerosol and other steel containers	Iron and Steel
Plastics	
PET bottles	Plastics material and resin manufacturing
HDPE bottles	
HDPE/LDPE Plastic film	
PET containers	
PVC, polylactic acid (PLA) and other degradable plastics	
Other plastics, polymers and polyurethane	
Polystyrene	Polystyrene
Fibers	
Corrugated cardboard	Corrugated paperboard
Kraft paper	Unbleached Kraft Packaging and Industrial Converting Paperboard
Boxboard and other paper packaging	
Gable-top containers	
Aseptic containers	
Laminated paper	Laminated paper
Glass	
Clear glass	Glass and Glass Product Manufacturing
Colored glass	

APPENDIX D R CODE AND RESIDUALS DIAGNOSTICS

This R code uses two packages, AER [44] and tidyverse. The tidyverse [45] loads a set of core packages necessary for data manipulation, including two packages used here, dplyr and readr. The AER package is required for computing clustered standard errors.

```
# load packages

library(tidyverse); # for dplyr::mutate() and read_csv()

library(AER) # for the coeftest function, sandwich errors etc.

# set working directory

setwd("~/Google Drive/Poly-EEQ")

# load data

eeq_data <- read_csv("eeq_data.csv")

# apply ln(1+x) transformation on all variable and create new dataset

log_data <- mutate_all(eeq_data[-c(1:3)], log1p)

write_csv(log_data, "log_data")

log_eeq <- read_csv("log_data.csv")
```

Once the data is loaded, both regression models are run with the standard lm() function. The sector dummy variable is specified as **as.factor(sector)** because the lm() function automatically adds dummy variable for factor variables. For the lsdv model, the - 1 indicates that no general constant is to be estimated.

The model estimates are then computed with adjustment for autocorrelation + heteroskedasticity via the coeftest() function. (see D.1 below) The HC1 weight option is specified. To interpret the interaction terms, the mean of the quantities for q_1, q_2 and q_3 across all cross sections is computed. The value of which is then used to calculate the partial effect of t_1, t_3, t_{12}.

```
# Regression ---------------------------------------------------

# Pooled model

ols <- lm(eei ~ t1*q1 + t2*q2 + t3*q3 + t4*q4 + t5*q5 +
             t6*q6 + t7*q7 + t8*q8 + t9*q9 + t10*q10 +
             t11*q11 + t12*q12 + t13*q13 + t14*q14 + t15*q15 +
             t16*q16 + t17*q17 + f1*q1 + f2*q2 +
             f3*q3 + f4*q4 + f4*q5 + f4*q6 + f5*q8 + f6*q9 +
             f6*q10 + f6*q11 + f6*q12 + f6*q13 + f6*q14  +
             f7*q15 + f8*q16 + f8*q17 + sales, data = log_eeq)



# Least square dummy variable model to control for sectors

lsdv <- lm(eei ~ t1*q1 + t2*q2 + t3*q3 + t4*q4 + t5*q5 +
             t6*q6 + t7*q7 + t8*q8 + t9*q9 + t10*q10 +
             t11*q11 + t12*q12 + t13*q13 + t14*q14 + t15*q15 +
             t16*q16 + t17*q17 + f1*q1 + f2*q2 +
             f3*q3 + f4*q4 + f4*q5 + f4*q6 + f5*q8 + f6*q9 +
             f6*q10 + f6*q11 + f6*q12 + f6*q13 + f6*q14  +
             f7*q15 + f8*q16 + f8*q17 + as.factor(sector) +
             sales - 1, data = log_eeq)

```

```
# Estimates with clustered standard errors

coeftest(ols, vcov = vcovHC, type = "HC1")

coeftest(lsdv , vcov = vcovHC, type = "HC1")


# Interaction term  ------------------------------------------

# compute mean for q3, q12 across all sectors and all years.

mean(log_eeq$q3)

mean(log_eeq$q12)
```

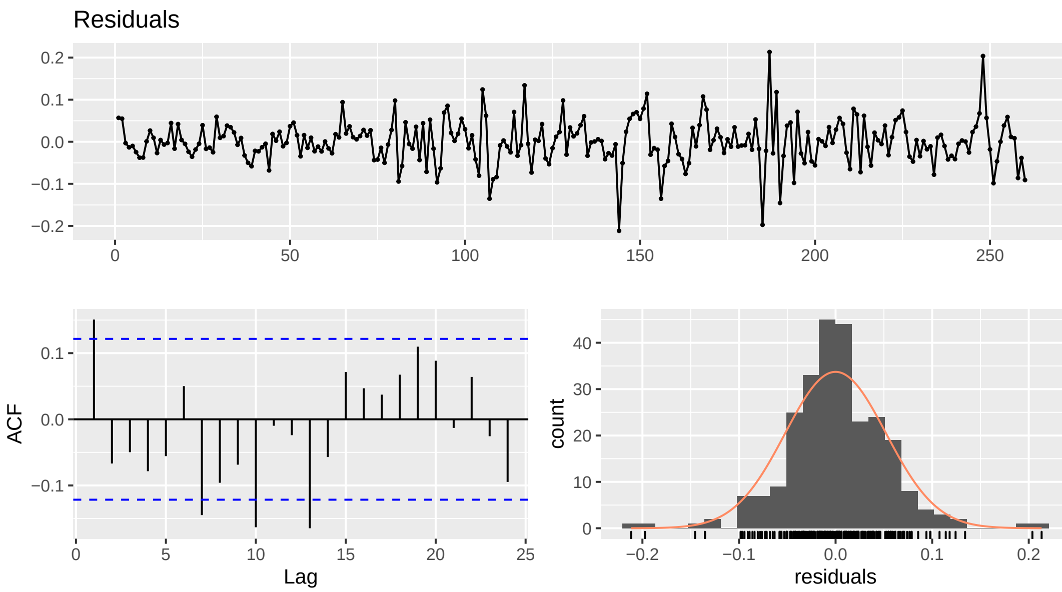

Figure D.1 Model residuals diagnostics, some heteroskedasticity but roughly normal distribution.