An Estimation of the Rebound Effect in the Halifax Regional Municipality

Sustainability Honours Project

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1. Introduction

In the daily lives of North Americans, energy usage can vary widely depending on many factors, such as the heating degree days (HDD), or the average income of the region. Therefore, if one were to try to provide an average usage of energy for “North Americans” the findings would be unusable aside from general estimations of total energy consumption (Azevedo, 2014). Like any other subject worth studying, energy usage is broken into many smaller, more specific parts, like residential heating, ventilation, and air conditioning (HVAC).

Energy efficiency, is one such variable of note. As the cost of energy increases, the desire to reduce ones energy consumption grows. The ways that energy efficiency, and therefore energy consumption can be reduced are numerous, such as introducing conservation practices like smart home monitoring (Bird, 2014). However, the most widely researched and implemented method used to reduce energy consumption is through energy efficiency improvements (Bird, 2014). Improvements such as fuel efficiency are happening with increasing frequency in recent years, as more time and effort are devoted to solving the inherent problems relating to energy consumption (Ehrhardt-Martinez, 2012).

One major issue when energy efficiency improvements are implemented is the increased usage of newly improved items, products or services. This issue was originally documented in a classic economic concept known as “Jevon’s Paradox”. This concept was developed by William Stanley Jevon in England at the beginning of the industrial revolution. Jevon observed that with the invention of greatly improved coal based steam engines, the consumption of coal greatly increased because of the reduced cost of operation (Alcott, 2005). He then developed his paradox, which stated that when technological progress increases the efficiency of processes directly related to a resource, the total consumption of the resource increases because of reduced cost to operate those systems (Alcott, 2005). The modern interpretation was named the Khazoom-Brookes Postulate by Harry Saunders, after two economists from the 1980's who independently defined the issue of increased usage due to energy efficiency improvements (Sorrell, Dimitropoulos, & Sommerville, 2009). These two were Leonard Brookes and Daniel Khazzoom. Daniel Khazzoom created a method of measuring this in residential properties (Khazoom, 1980). Brookes Suggested the concept of a rebound effect at a macroeconomic scale. After significant debate amongst proponents of the concept, the final given name for it was the rebound effect.

The rebound effect is specifically defined as the reduction in expected energy gains from technologies that improve the energy efficiency of a product, system or service, caused by changes in total energy usage (Grubb, 1990). For example, if someone changed their personal transportation vehicle from a large truck to an electric sedan, their total consumption of fuel would decrease; however, since it is now so much less expensive to travel, they would likely use their vehicle more often. The most direct method of measuring this effect can be determined by comparing the difference between calculated energy savings, and measured energy savings. However, this requires direct measurements, and is not feasible for large scale studies or projects, because of the cost of scale. There is already a large body of literature (primarily in the USA) that covers and expands upon the rebound effect, including methods of measurement at larger scales by using econometric formulas (Sorrell, Dimitropoulos, & Sommerville, 2009) The review of literature by Sorrell, Dimitropoulos and Sommerville covers the rebound effect, how it can be measured, and its impact on energy consumption, and if it can more accurately be tracked. There are some who refute the importance of the rebound effect, however these are often claims of the unimportance of this effect (Gillginham et al; 2013).

Currently, there is very little accurate or recent data on the rebound effect in Canada, and data on the rebound effect in Halifax or Nova Scotia is non-existent. Just like any complex issue, in order to be able to understand the problem of changing energy consumption, specific information on the residential rebound effect is necessary. In order to accurately expand on this issue, and to clarify the scope of this project, it is important to further define the rebound effect. There are two main distinctions concerning the rebound effect (Sorrell, 2009). These are econometric distinctions, and temporal distinctions.

There are three main econometric categories of rebound effects: direct, indirect, and economy wide. Direct rebound effects are the specific differences between calculated and real energy savings for the product, appliance or service itself. Direct effects are the most easily tracked and recorded, because of the simplicity of recording its indicators, such as residential energy consumption before and after energy efficiency improvements (Freire-Gonzalez, 2011). Indirect rebound and economy wide effects however, are much more difficult to track and quantify, because of how many potential output variables there are (Freire-Gonzalez, 2011). Indirect rebound effects refer to the spending habits outside of the original product, appliance or service after energy savings are achieved. Since these impacts are difficult to accurately track and encapsulate, they are often left unreported. Money can be spent in many different ways, and the amount of energy consumed per dollar spent has too many variables to be considered an accurate measurement (Sorrell, Dimitropoulos, & Sommerville, 2009). Economy wide effects are the changes that occur throughout the effected energy sector (i.e. total reduced energy consumed because of regional efficiency improvements). Although they are difficult to empirically measure, estimations of indirect and economy wide rebound effects are often included in econometric studies, because they are able to be estimated using proxy variables. One such proxy econometric measurement of the rebound effect is the elasticity of demand for energy services with respect to energy efficiency, which will be further elaborated upon in the methods section.

The second distinction that is important to define, concerning the rebound, effect is the time period boundaries, which are separated as short term and long term rebound effects. Research has shown that, in the short term, rebounds are lessened due to the adherence of impacted individuals to former consumption habits and patterns (Geller, 2005). Long term rebound effects are loosely defined as the new consumption patterns once “business-as-usual” is achieved. These long term effects have been shown to be capable of eliminating as much as 50% of energy efficiency improvements, while short term effects have been shown to be estimated at 15-25% depending on the service analyzed (Azevedo, 2014).

1.2. Purpose

Specific data concerning the rebound effect, as mentioned in the introduction, is scarce in Canada, and non-existent in Halifax and Nova Scotia. The geographical scope of this study will be the Halifax Regional Municipality, which will be further explained in the methods section. The purpose of this project will be to attempt to create an accurate and reproducible body of information on the rebound effect in Halifax, Nova Scotia, by using the econometric models from several studies outlined in *Empirical estimates of the direct rebound effect: A review* by Sorrell, Dimitropoulos and Sommerville. Additionally, in order to maintain a manageable project size, the focus of the study will be based upon residential energy usage data, which have been documented as having the largest rebound effect (Azevedo, 2014).

The most recent literature-states that the most efficient measure of the rebound effect at a regional or municipal scale is through the econometric modeling of values deemed to be representative of a rebound effect (energy consumption, median disposable income, heating degree days, and energy price)(Freire-Gonzalez, 2011). By analyzing the rebound effect at this scale, and by using econometric modeling, this project can provide useful data to show the relevance and accuracy of these econometric methods within Halifax, Nova Scotia, and Canada. The focus of this project will be upon the direct and indirect rebound effects that are considered *Empirical estimates of the direct rebound effect: A review*; At the end of the study, if the results of the measurements mirror what is suggested in current literature, the econometric model can be considered accurate, and further documentation of the rebound effect can begin in Atlantic Canada, based on these methods.

A primary driver of rebound effects is the financial losses or gains incurred from energy usage (Bird, 2014), so it is possible that the results of this study could be used to examine usage patterns, which would have an impact on residential energy consumption before and after utility improvements (Bird, 2014). The primary data procurement method that will be used will be the obtainment of energy consumption data from Stats Canada CANSIM database. Following the analysis of this data, and the included statistics of energy prices, median disposable income, and weather patterns, an analysis of the rebound effect can be produced. Most studies that have used the suggested formulas use community data from municipalities including energy usage statistics from the utility companies, and the median incomes of involved communities. However, there are other variables that are sometimes included, such as specific energy resource prices, specific energy service data, and national census data.

Beginning with an analysis of previous methods of measuring the rebound effect, a literature review will be used to clarify several aspects of the problem, and why the final model that will be used was selected. A methods and results section will follow, which will include and compare the primary data to existing data sets, and comparisons of their relevant values will be presented. The implications and significance of the primary data findings will follow in a discussion section. Finally, the project will be concluded with statements of potential further research, and the significance of this data.

2. Literature Review

The rebound effect has been extensively researched in many different fashions, from national modeling which focuses on factors that affect every variable, to regional and local case studies which have been used to show specific differences (Sorrell, Dimitropoulos, & Sommerville, 2009). However, the concept of the rebound effect is relatively unknown to people, but when explained is easily grasped (Ehrhardt-Martinez, 2012) As stated in the introduction, the rebound effect is the reduction of expected energy savings after energy efficiency improvements to appliances, vehicles or utilities, which results from increased usage patterns (Sorrell, Dimitropoulos, & Sommerville, 2009). The rebound effect has been fully documented in many different places around the world over the past 40 years (Sorrell, Dimitropoulos, & Sommerville, 2009), and at many different levels, from macroeconomic models, such as those developed by Freire (2010), or Howells (2010); or with individuals and single residence like Khazoom's original model from the 1980's. This literature review will focus on the different econometric models used, and the variables that have led to the thesis of this study.

2.1. Key Terms in the Literature

Appliances; Backfire; Elasticity of demand for energy; Energy efficiency improvements; Energy efficiency; Electricity consumption; Energy savings; Halifax, Nova Scotia; Heating, ventilating and air-conditioning (HVAC); Khazoom-Brookes Postulate; Rebound effect; Residential; Utilities; Econometrics

2.1.1. Rebound Effect: History & Definition

The rebound effect, which was first independently defined by Daniel Khazzoom and Leonard Brookes in the 1980s, was created because they had both postulated that increased energy efficiency often leads to increased energy consumption. The idea has its roots in classical economics as “Jevon’s Paradox”. Because of the observations of Daniel Khazzoom and Leonard Brookes, interest in energy consumption patterns increased (Grubb, 1990). It was found that with energy consumption (especially in residential properties) when energy efficiency improvements were installed, there was a varied (based on study), but noticeable increase in consumption (Grubb, 1990). The varied changes are a result of the numerous studies that have been done since the 1980s, which have had many different methods of measuring the effect. Some conclude that the rebound effect is so severe, that the new consumption is greater than it was originally (known as backfire), while others have stated that the rebound effect is so minimal, that it is statistically insignificant (Gillingham, 2013). However, the current consensus is that in North America, the short-term rebound effect is about 25%, and the long-term effect is 49% (Sorrell, Dimitropoulos, & Sommerville, 2009). The definition of the rebound effect has since expanded to include economy and society wide rebound effects, which are a result of the financial savings gained from improved products, appliances and services (Sorrell, Dimitropoulos, & Sommerville, 2009). It is widely accepted that the direct rebound effect is important enough to warrant inclusion in energy consumption estimates, however its impact varies on a case by case basis. The rebound effect has been analyzed from many different viewpoints, and at many different levels, and a large sampling of studies from around the world were collected in the works of Sorrell and Dimitropoulos. Therefore this paper will not spend any time trying to further prove the significance or the existence of the rebound effect, instead it will show the size of the rebound effect on the Halifax Peninsula, and its impacts upon energy savings in the province.

One of the most complete and accurate studies that has been completed recently was created by Jaume Freire-Gonzalez, starting in 2011. By analyzing the collected research of Sorrell and Dimitropoulos, he was able to create a more effective econometric model of the rebound effect at the municipal-residential level. Starting in Catalonia, Spain, he was able to develop his theoretical model, and has since applied it in other regions. This is the model that this study will attempt to apply to the energy consumption data of the Halifax Peninsula. This model compares the suggested variables (price of energy, average disposable income, and heating degree days) to the dependant variable, total energy consumption. By weighting each variable, based on its impact on total energy consumption, a value representative of the rebound effect can be created. This will be expanded upon in later sections.

2.1.2. Energy Savings and Energy Efficiency

The core purpose of recording the rebound effect is to analyze the correlation between energy efficiency and energy savings. In residential properties, this is most significant in heating, ventilation and air-conditioning. In HVAC systems, direct rebound effects have been found to be as high as 50% on average in the long term (Sorrell, Dimitropoulos, & Sommerville, 2009). Consequently, there has been several attempts at reducing the impact of the rebound effect in residential properties, through education programs (Ehrhardt-Martinez, 2010; Azvedo, 2014) or incentive programs (Bird, 2012; Laquatra, 2009). Conclusions drawn from these papers show that the rebound effect can be reduced through the implementation of education and awareness programs. With the data on energy consumption and the rebound effect, a similar program could be implemented on the Halifax Peninsula through our energy efficiency utility “Efficiency Nova

Scotia" (ENSC), which is mandated to help improve the energy efficiency of Nova Scotia (ENSC, 2015) The rebound effect has also been analyzed through governmental channels, such as Thomas DiNapoli's (a previous New York State Comptroller) *"Green Best Practices Briefing for the State of New York"* (n.d), or Bruce Tonn's "*State-Level Benefits of Energy Efficiency*" (2007). These government reports stress the importance of reducing consumption in order to improve energy savings, and they offer several possibilities for implementation, prominently among them being awareness and education programs. Secondly, funding for energy efficiency improvements and programs wherever possible are highly suggested options.

At the end of this study, as suggested by many different papers, the results concerning the rebound effect in Halifax should be applied in awareness and education programs, such as those offered by ENSC.

2.1.3. Geographic Scope: Halifax, Nova Scotia

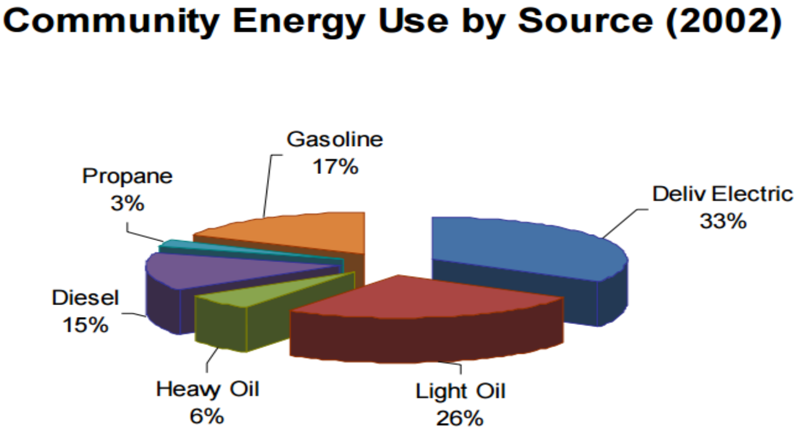
Currently, there hasn't been any research done into the rebound effect, and it has not been measured, based on publically available information in Halifax or Nova Scotia. The lack of any data set in Halifax or Nova Scotia is a primary driver of this study. The vast majority of studies were done in the United States, and the two rebound effects that have been most extensively studied were personal automotive transportation, and residential space heating, both of which have been shown to be statistically significant in regards to total energy consumption (Sorrell, Dimitropoulos, & Sommerville, 2009). The similarity of Halifax's climate to other geographic data sets that are currently available, such as those in New York (Tonn, 2007), means that formulas of estimation will remain statistically relevant. Similarly, recommendations for reducing the rebound effect, like in Erhardt-Martinez's paper are able to remain statistically relevant as well, such as reducing winter time heating in residential properties. Nova Scotia and

Halifax have already made commitments to increasing energy savings and providing energy efficiency savings for the province (Nova Scotia Department of Energy, 2009; Halifax Regional Municipality, 2015). Any findings from this study will therefore have relevant applications when finished, and can be applied through programs such as those offered by ENS, like their environmental management systems applications (ENS, 2015)

The primary data that will be required for the econometric model that will be used for this study will be derived from several sources. Energy consumption and energy pricing data from Statistics Canada's CANSIM database will be compared with the energy consumption data available through the census data on the Statistics Canada's website. Income statistics will be taken from the most recent Halifax Vital Signs report (2011), and similarly compared to available census data. Finally, the historical data of heating degree days in Halifax will be taken from Environment Canada.

The formulas suggested to estimate the rebound effect (which will be explained in section 2.1.4.) require information on breakdown of energy usage by source within the area being measured. Within Halifax, the breakdown of energy use by source is as follows:

Figure 1. HRM energy usage breakdown by source. (Whitford, 2007)



2.1.4. Estimating the Rebound Effect

One of the primary ways that the rebound effect has been recorded is through estimations by energy usage statistics, energy efficiency equations, and median incomes. In 1980, Daniel Khazzoom created several formulas for estimating the rebound effect at the residential level. Within the writings of Sorrell and Dimitriopoulos (2009), many preliminary studies that they analyzed utilized a very simple formula in order to record the rebound effect. They defined this as the “Quasi-Experimental” approach, which was first suggested by Khazoom (Sorrell, Dimitropoulos, and Sommerville 2009). It was called “quasi-experimental” because of its ignorance to several variables, such as behaviour change and temperature differences. The first equation that will be used, can be calculated by the following formula:

$$\boldsymbol{RE = \frac{(Calculated\ Savings - Real\ Savings)}{Calculated\ Savings}}$$

Figure 2. Simple calculation of direct rebound effects (Sorrell, Dimitropoulos, and Sommerville 2009)

The values that are required to utilize this equation are total energy usage before energy efficiency improvements (TEB), calculated total energy usage after energy efficiency improvements (CTEA), and measured total energy usage after energy efficiency improvements (MTEA). This equation allows the interpretation of two main values: (a) the difference between TEB and CTEA, and (b) the difference between TEB and MTEA. With these values, the severity of the rebound can be determined. It is important to note that although this formula is effective at providing a simple measurement of the rebound effect, it makes several large assumptions. These assumptions are that (a) all differences between calculated and measured energy usage are a rebound effect and (b) both direct and indirect rebound effects are included in the total measured difference. This formula is also unable to differentiate between individual energy services, such as heating or lighting. The literature that has analyzed the different potential methods of measuring the rebound effect categorize this method as only being effective at providing a rough estimate.

In the literature analysis of Sorrell and Dimitropoulos, it was also suggested that because of how prohibitively expensive it is to directly measure the rebound effect at a large scale, that depending upon data availability, direct rebound effects can be estimated from one of two proxy energy efficiency elasticities (Sorrell, Dimitropoulos, & Sommerville, 2009). Elasticities refers to the percentage change in one variable following changes in another, holding all other measured variables constant (Sorrell, Dimitropoulos, & Sommerville, 2009). The two suggested elasticities are as follows:

> $\boldsymbol{\eta_\varepsilon(E)}$: the elasticity of demand for energy (E) with respect to energy efficiency (ε)
>
> $\boldsymbol{\eta_\varepsilon(S)}$: the elasticity of demand for energy services (S) with respect to energy efficiency (where $S=\varepsilon E$)
>
> (Sorrell, Dimitropoulos, & Sommerville, 2009)

For the sake of clarity, each part of these formulas will be outlined.

η = Elasticity curve: a measure used to show the responsiveness to the quantity demanded of a good or service resulting from changes in price. In the case of energy services in Canada, usage is fairly inelastic, which means that attempts to record it are fairly accurate.

ε = Energy Efficiency of Energy Systems (such as heating, lighting or refrigeration)

S = Energy Consumed * Price of Energy ($S = \varepsilon E$)

E = Energy inputs (the total energy used by a system)

While these two elasticities are accurate measurements of the rebound effect, the data required to create them is often difficult and time consuming to obtain at larger scales. As a result of this difficulty in obtaining the needed data, alternate proxy values have been suggested for measuring the rebound effect, which do not require information on energy efficiency (which, as previously stated, is difficult to obtain) but instead use price elasticities. These suggested alternatives are as follows:

> **ηPS(S)**: the elasticity of demand for energy services with respect to the energy cost of energy services (PS)
>
> **ηPE(S)**: the elasticity of demand for energy services with respect to the price of energy (PE), or
>
> **ηPE(E)**: the elasticity of demand for energy with respect to the price of energy.
>
> (Sorrell, Dimitropoulos, & Sommerville, 2009)

Again, for the sake of clarity, any terms that were not previously outlined are shown and described below. Elasticity curves are again used as estimations of the rebound effect.

P_E = Price of energy inputs (such as total electricity consumed by a heating system)

P_S = Cost of energy services. ($P_S = P_E / \varepsilon$)

P_G = Overall cost of providing an energy service, $P_G = P_S + P_A + P_M + P_{TC}$

P_A = Annualized capital cost

P_M = Maintenance

P_{TC} = Time Cost

Several other important factors must be considered when attempting to estimate the rebound effect. The estimated size of the rebound effect will vary widely, based on how the energy service (and therefore the energy efficiency of that service) is defined. Secondly, the magnitude of the rebound effect is proportional to the share of each energy service in the overall cost of the energy, and it can be measured by using a weighted average of all energy sources used, based on each individual price, and the change in energy inputs (Sorrell, Dimitropoulos, & Sommerville, 2009). In order to decide which of the three price elasticity measures will be most effective, the available data needs to be collected. In most situations, data on energy services (S) and energy efficiency (ε) is less common, and less accurate, than data on energy prices (E) and consumption patterns. As the most easily accessible, this study will use first the elasticity of demand for energy, with respect to the price of energy, which is considered to be most effective in estimations of household rebound effects (Sorrell, Dimitropoulos, & Sommerville, 2009). In the work of Jaume Freire-Gonzalez, using $\eta P_E(E)$ resulted in a short term (5 years) elasticity of 35%, and a long term rebound effect of 49%. This means, for every improvement made to energy services, and the price of energy, the savings that could be made will be reduced by nearly half (Freire-Gonzalez, 2011).

2.1.5. Conclusions of Literature

The rebound effect within individual households, can be accurately and easily measured. However, as the scale of measurements increase, the time required, and the cost to measure become prohibitive. As a result, proxy measurements of energy consumption have been used around the world, and the most recent collection of these methods, by Sorrell and Dimitropoulos in 2009, have shown which are most effective for each level of aggregation, and each type of rebound effect. Their analysis of the available literature has also shown where and how the rebound effect has been studied, with the majority being in the United States, which mostly focus on residential heating and personal automotive transport. Most studies that have been done have shown the effectiveness of different proxy values in proving the existence of the rebound effect.

3. Methods

3.1. Justification

Energy usage statistics at both the macroeconomic and microeconomic scale are abundantly available within Canada. Energy services, such as heating, have easily accessible data from which to base further research into consumption patterns (Sorrell, Dimitropoulos, & Sommerville, 2009). Although there have been quasi-experimental studies done in Canada on the rebound effect, their methods have had too much variation between each study to be considered a cohesive body of data (Sorrell, Dimitropoulos, & Sommerville, 2009). As stated during the literature review, there is a lack of data in Canada, and there isn't any data in Nova Scotia. Fortunately, the data required to utilize the price elasticity model stated in section 2.1.4., is quite easily accessible. Usually, there are several reasons for the difficulty in collecting data on the rebound effect. First, the difficulty in recording the rebound effect stems from the lack of easily accessible data required to use direct measurements. Direct rebound effects, although quite straightforward, are unfeasible to measure individually on a large scale. As a result proxy values are used in place of direct measurements. Proxy values are based on variables such as energy consumption, prices of energy services, weather patterns and disposable income, and are all required for the suggested price elasticity model. Most of this data is available through Statistics Canada's database, CANSIM. As stated in the literature review, the econometric model which is most accurate for measuring the residential energy consumption rebound effect, and that will be implemented in this study is the elasticity of demand for energy, with respect to the price of energy. Notably, the data that is required for this price elasticity is not directly comparable between each value. The variables will be converted to monetary values in order to solve this, and will be further explained in section 3.2. Since the cost of scale for measuring the rebound effect directly is quite prohibitive, both temporally and financially, the study will not attempt to compare the accuracy of the proxy measurements to direct measurements. It will accept the assumptions made in Sorrell, Dimitropoulos and Sommerville as accurate. This study will provide a foundational data set for the rebound effect in Halifax, based on price elasticity models previously outlined

3.2. Data Procurement

The price elasticity model that was first suggested to be used was further refined by Jaume Freire-Gonzalez, and his expanded price elasticity model will be used for the basis of this study. In his 2010 paper, "*Empirical evidence of direct rebound effect in Catalonia"* he breaks down his formula into each individual variable, of which there are 4. These are: energy consumption, price of energy, average disposable income, and heating degree days. For the purpose of this study, in order to determine the short-term and long term rebound effects, cross-sectional data will be used from 1991 to 2015, with data for all four variables coming primarily from Statistics Canada, but also the HRM Community Energy Plan and Environment Canada.

3.2.1. Residential Energy Consumption

The energy consumption statistics came from the CANSIM Database from Statistics Canada. The CANSIM Database is a collection of all socioeconomic data acquired by Statistics Canada. The CANSIM database breaks energy consumption in Canada through several methods. One method is by region, and the other is by sector. Based on these two groups of information, the total residential energy consumption for Nova Scotia, and the Halifax Regional Municipality was able to be produced. The following table shows this, as well as the energy usage data used to obtain each value.

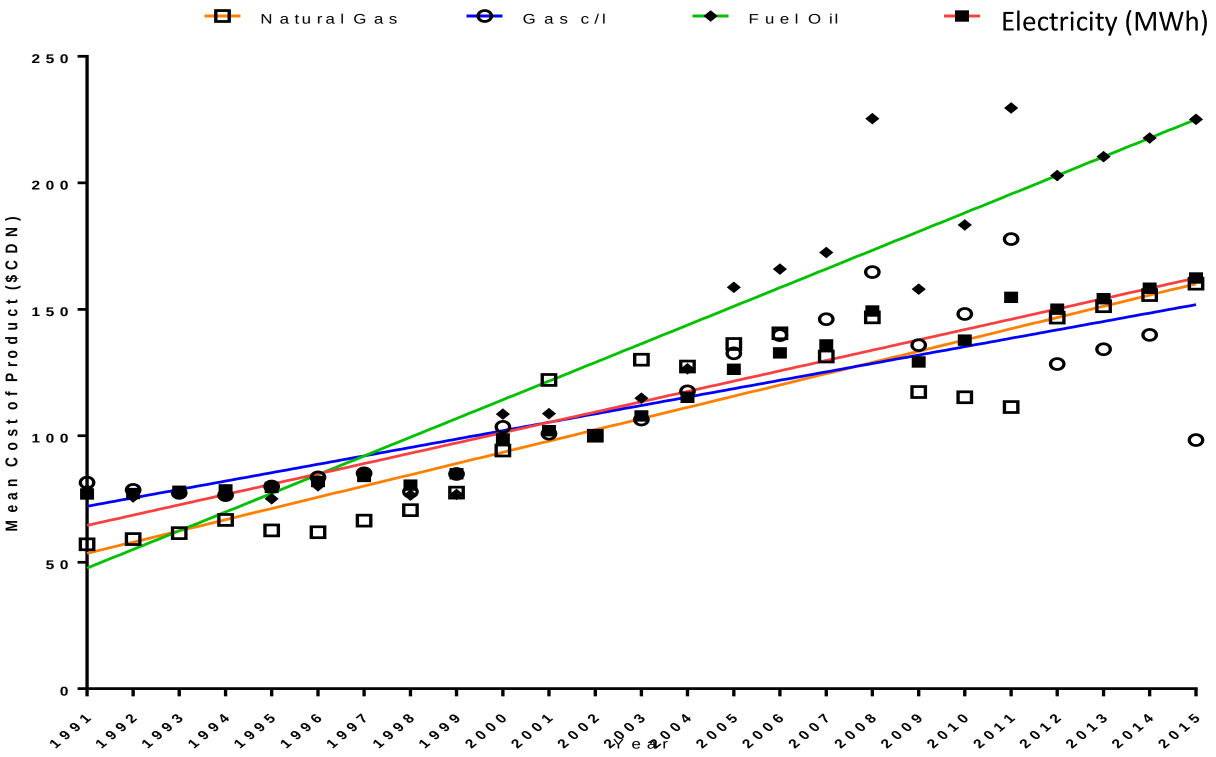
Table 1. CANSIM Energy Usage Statistics, 1991 – 2015

Year	Total Energy Canada (TJ)	Total Residential Energy Canada (TJ)	Total Atlantic Canada Energy (TJ)	Total Atlantic Canada Residential Energy (TJ)	Total Nova Scotia Residential Energy (TJ)	Total HRM Residential Energy (TJ)
1991	6737517	1234012	486634	85505	33851	14173
1992	6795765	1239882	486575	85494	33847	14172
1993	6854013	1245752	486516	85484	33843	14170
1994	6912261	1251623	486457	85473	33839	14168
1995	6839016	1256272	465112	81723	32354	13546
1996	7034084	1336257	470274	82630	32713	13697
1997	7147159	1291859	486562	85492	33846	14171
1998	6987420	1179009	474825	83430	33030	13829
1999	7165645	1229096	484754	85174	33720	14118
2000	7384644	1290743	499132	87700	34721	14537
2001	7222600	1245859	497613	87434	34615	14493
2002	7440893	1300949	500595	87958	34822	14580
2003	7609639	1358370	516182	90696	35907	15034
2004	7587824	1341655	507925	89245	35332	14793
2005	7640606	1329738	499289	87728	34732	14542
2006	7512842	1280358	467463	82136	32518	13615
2007	7915388	1398512	498739	87631	34693	14526
2008	7885612	1399817	482920	84852	33593	14065
2009	7490198	1320954	454719	79897	31631	13244
2010	7654343	1264877	469146	82432	32635	13664
2011	7902478	1351418	485450	85296	33769	14139
2012	7960726	1357288	485391	85286	33765	14137
2013	8018974	1363159	485331	85276	33761	14135
2014	8077222	1369029	485272	85265	33756	14134
2015	8135470	1374899	485213	85255	33752	14132

3.2.2. Price of Energy

The price of energy in Halifax has been recorded as being one of the highest in Canada. There have been many attempts at dealing with the impact that the price of energy has on consumers, such as programs to reduce consumption, like those offered by ENS. The price of energy is a large driver for individuals to reduce their consumption, and in Halifax, the consumption of energy has remained relatively inelastic since 1991. The price of energy for the HRM is a weighted average of energy consumed by source, shown in section 2.1.3., The overall price of energy has also been steadily increasing. One of the largest variables in the price of energy for Halifax is the price of heating oil which has been increasing at a steady rate, along with the price of electricity, the individual prices used are as follows:

Table 2. CANSIM Price of Energy by source, 1991 – 2015



3.2.3. Average Income

Although Halifax has high energy prices, it also has one of the highest average disposable incomes of any Canadian city (Community Foundation of Nova Scotia, 2012). The average income of Halifax residents was $74,800 in 2012, and after adjusted for cost of living, the disposable income of Halifax residents was $26,230. According to Vital Signs Canada, based on census data, the average income of Halifax residents increased by 3.9% yearly (CFNS, 2012; Stats Canada, 2015). Based on this yearly change, Halifax's average income in 2015 was $86,123, meaning that the average disposable income in 2015 was $36,172.

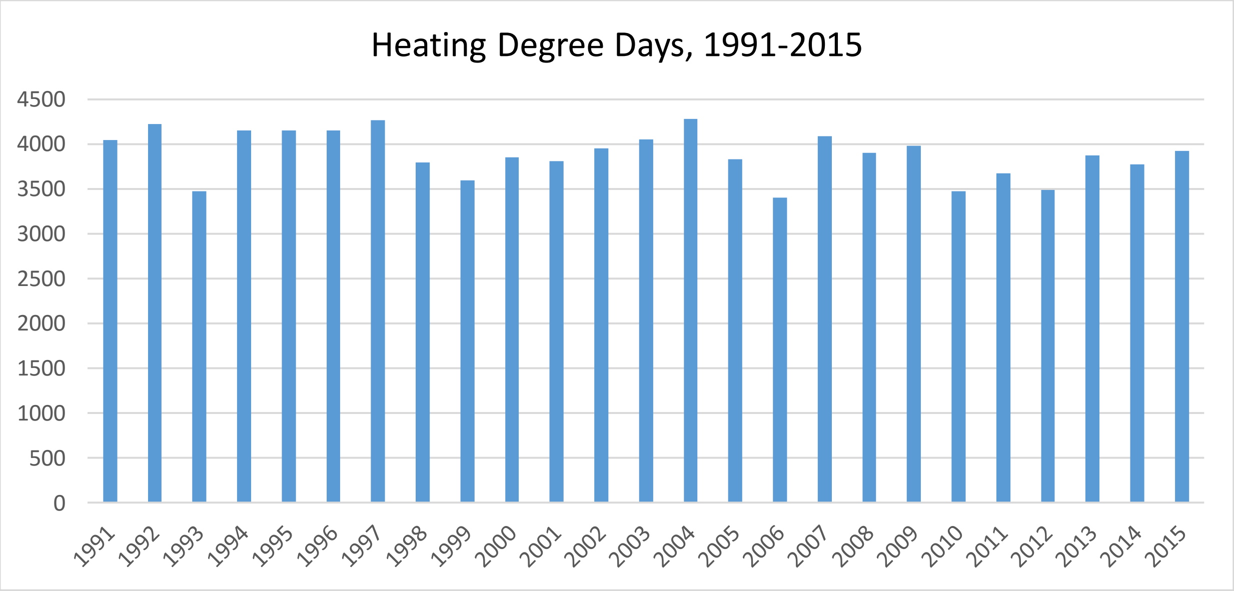
Year	Median Income ($)	Median Income After Tax ($)	Rate of Inflation
1991	42306	17768	3.75%
1992	44589	18727	2.17%
1993	45571	19140	1.65%
1994	45955	19301	0.23%
1995	47587	19987	1.74%
1996	48780	20488	2.16%
1997	49973	20989	0.78%
1998	50334	21140	1.00%
1999	52700	22134	2.63%
2000	53500	22470	3.20%
2001	56000	23520	0.72%
2002	58000	24360	3.80%
2003	59200	24864	2.08%
2004	61400	25788	2.13%
2005	64700	27174	2.09%
2006	67600	28392	1.67%
2007	70610	29656	2.38%
2008	74040	31097	1.16%
2009	75050	31521	1.32%
2010	76500	32130	2.35%
2011	78690	33050	2.30%
2012	80490	33806	0.83%
2013	82510	34654	1.24%
2014	84808	35619	1.47%
2015	86123	36172	1.61%

Table 3. CANSIM Average Income (Census results) 1991 - 2015

3.2.4. Heating Degree Days

Heating Degree Days are the number of degrees that a year's average temperature is below 18^{o} Celsius. This is considered the average temperature that a home begins to need heating. Consequently, many of the HDD's come from the winter months, when the temperature is constantly below the average. Environment Canada keeps a daily record of HDD, and there weren't any changes needed to the data for it to work with the model.

Table 4. Environment Canada. Heating Degree Days, Halifax Penninsula. 1991 – 2015



3.2.5. Econometric Approach

Now that all potential variables in the econometric model have been explained, the final model from Jaume Freire-Gonzalez's paper can be shown. The purpose of the formula is to expand upon the suggested price elasticity of demand for energy, $\eta P_E(E)$. This price elasticity is found by the following equation:

$$\eta P_E(E) = (\delta C_{it} / \delta PE_{it}) \text{ x } (PE_{it} / C_{it}).$$

The reason that the price elasticity needs to be further expanded is because it does not take into account several other factors that impact the representative variable (price elasticity) of the rebound effect, namely disposable income and heating degree days. This is where the expanded model, shown below, is applied.

$$\ln C_{it} = \mu_i + \beta_1 \ln PE_{it} + \beta_2 \ln Y_{it} + \beta_4 \ln HDD_{it} + u_{it}$$

The purpose of this equation is to provide an estimation of the direct rebound effect for all energy services in Halifax households, both short and long term. The data that will be used is previously listed, but in this equation, it is displayed in natural logarithmic values (ln). This is done in order to remove heteroskedacity, which limits the spread of each variable (Haas, 2000). The involved variables each provide some impact to the final value, however, as will be explained, the income and HDD variables have a minimal, but not insignificant impact. In order to clarify the equation, each individual variable is defined as follows:

μ = population mean (average total energy consumption)

β = Beta (the individual weighting of each variable in relation to Energy Consumption)

C_{it} = Energy consumption in period t

P_{Et} = Price of energy in period t

Y_t = Disposable income in period t

HDD_t = Heating Degree days in period t

U = Residual (difference between observed TEC and predicted (average) TEC)

3.3. Application of data

The expected result of the formula will be an estimated rebound effect for the municipality of Halifax. According to literature, it will be a direct rebound effect of 49% (Freire-Gonzalez, 2011). This formula will be based upon the data shown in section 3.2. of this paper, shown in natural logarithmic values. Once the rebound effect has been recorded, it will be compared with the estimations made in literature to ensure that the chosen method of estimation is accurate. If there is significant variance between what is estimated, and what is suggested in recorded studies from Sorrell, Dimitropoulos and Sommerville (2009), then one of the other price elasticity proxy value measurements will be attempted. If all proxy value measurements are found to be inaccurate, a reassessment will take place at that time.

3.4. Limitations of the Study

The data that will be used will be obtained from Statistics Canda, NSPI, and ENSC. Since the study will be dealing with estimations of the rebound effect (the price elasticity of energy consumption patterns of Halifax residents), all conclusions must be considered a preliminary attempt at recording the rebound effect. Secondly, there are inherently some biases and inaccuracies to the planned methods:

3.4.1. The methods that will be used are based on the collected price elasticity measurements outlined in the papers ***Empirical estimates of the direct rebound effect,*** and ***Methods to empirically estimate direct and indirect rebound effect of energy-saving technological changes in households***

3.4.2. The measurements that will be taken as estimations of the rebound effect may have additional factors that affect the total difference between calculated and measured energy usage. For example, the savings created from efficiency improvements, that are spent elsewhere. However, these variables will not be explicitly outlined, and are instead included in the general estimation.

3.4.3. Accepting that the elasticities models are accurate is based on the assumption that the methods from ***Empirical estimates of the direct rebound effect***, and ***Methods to empirically estimate direct and indirect rebound effect of energy-saving***

technological changes in households for determining rebound effects are accurate.

3.4.4. Whatever final values that may be found will only be rough estimates, and in order to move forward with further research, direct measurements of the rebound effect must be recorded in the HRM, in order to prove the accuracy of the estimates.

3.5. Summary of Methods

As stated in the review of the rebound effect by Sorrell, Dimitropoulos and Sommerville, "The accurate estimation of direct rebound effects is far from straightforward." The required data on energy consumption, energy services and energy efficiency which will be collected and synthesized can provide estimations, but they can still have inaccuracies, based on the variability of the used data. The purpose of using multiple methods (the simple and complex econometric models) will be to determine whether more simple methods of measuring the rebound effect can be considered accurate. They will then be compared to existing estimations from literature, which will have total consumption before and after energy efficiency improvements, as well as suggested price elasticities. By analyzing the specific price elasticities, and the changes that the rebound effect can create in total energy consumption, the intention is to draw attention to the importance of addressing the rebound effect in Halifax. Several potential comparisons could be made with the reports on future supply and demand of energy in Nova Scotia (ICF International, 2014), as well as the impact that energy efficiency programs such as those from ENSC can have when the rebound effect is included (ICF International, 2014). Afterwards, the potential impact of other impactful programs, such as consumer education will be considered.

4. Results of Econometric Modeling

The results of the two econometric models, both the simple price elasticity ($\eta P_E(E)$) and the more complex model developed by Freire-Gonzalez show similar values for the rebound effect to those found in literature. The results of the equation $\eta P_E(E) = (\delta C_{it} / \delta PE_{it}) \text{ x } (PE_{it} / C_{it})$ show a price elasticity value of -0.52. This value means that for every 10 MWH saved as a result of energy efficiency programs, only 4.8 MWH of total energy consumption is reduced in the HRM. The variables that were used (change in energy consumed, change in price of energy, price of energy, and energy consumption) can be found in Appendix A. The price elasticity of demand is the representative number of the changes in energy consumption in the HRM from 1991 to 2015. As stated in literature, this price elasticity is an all-encompassing estimate, taking into account direct, indirect and economy wide effects. It makes the several large assumptions. First, that any changes in consumption are a part of the rebound and secondly, that all other variables will remain constant. The values range quite significantly in literature, however with the average being -0.49 for the price elasticity of demand (Sorrell, Dimitropoulos, & Sommerville, 2009), the HRM value is quite similar. The value of the income elasticity is found through $(\delta C_{it} / \delta Y_{it}) \text{ x } (Y_{it} / C_{it})$, which equates to 0.42, suggesting a lower impact upon energy consumption than price of energy. Finally, the elasticity of heating degree days to energy consumption equates to a value of 0.075. The last two values are lower than the price of energy elasticity, however, they still seem to have an impact on energy consumption and one another, which is why a multivariate analysis is required. This is where the formula by Jaume Friere-Gonzalez becomes necessary.

The expanded formula, $\ln C_{it} = \mu_i + \beta_1 \ln PE_{it} + \beta_2 \ln Y_{it} + \beta_4 \ln HDD_{it} + u_{it}$, is a semi-logarithmic weighted formula which provides a more accurate estimation of the price elasticity of energy demand. By running a weighted multivariate regression (one dependent variable compared with

3 or more independant variables) the relationship between the independant variables price of energy ($\beta_1 \ln PE_{it}$), income ($\beta_2 \ln Y_{it}$), heating degree days ($\beta_4 \ln HDD_{it}$), population mean (μ_{it}) and the explanatory variable, total residential energy consumption in the HRM ($\ln C_{it}$). The regression has been found to be accurate, and the coefficients can be used to show the difference in total residential energy consumption before and after the rebound effect in the Halifax Regional Municipality. The results of regression are shown in **table 5.**

Variable	*Coefficients*	*Standard Error*	*t Stat*	*Probability*
Intercept	8.198539	1.567102	5.231655	0.000004
Population Mean	1.021624	0.037567	27.19473	0.000000
Ln(Price of Energy)	-0.511340	0.102629	-9.21823	0.000000
Ln(Income)	0.401642	0.14095	3.154044	0.004993
Ln(HDD)	0.075865	0.108425	-1.96372	0.063617

Regression Statistics	
Multiple R	0.988813
R Square	0.977752
Adjusted R Square	0.973302
Standard Error	0.033168
Observations	25

Table 5. Fixed Effects Model. Total Residential Energy Usage HRM. Primary Data in Appendix A

The resulting coefficients, which are all statistically significant at 95% confidence interval, except for heating degree days, which can be considered accurate at a 90% confidence interval show the magnitude of the rebound effect in Halifax. As shown in **table 5.**, there is similarity between the coefficients created with the simple price elasticities, the multivariate regression, and the values suggested in literature. What this means is that the model can be considered accurate for representing the relationship between explanatory (or dependent) variable, energy consumption and the response (or independent) variables, PE, Y, and HDD. By reconverting the variables from their natural logarithmic form to their real values, the actual impact of the rebound effect can be recorded.

5. Discussion

The demand for energy is relatively inelastic, meaning that even with significant changes to the independent variables, there isn’t a significant change in the explanatory variable. From 1991 to 2015, the average overall price of energy was changed from $51.20/MWH, to $114.93/MWH; meanwhile, the total residential energy consumption in the HRM remained relatively stable, at a yearly average of 3,931,260 MWH. There are several reasons for this:

1. 44% of total residential energy consumption in the HRM is from home heating. Homeowners heat their homes to an overall average to reach maximum comfort, despite the price of energy, and final cost to the consumer. (Ehrhardt-Martinez, 2015).
2. Efficiency measures are constantly being implemented, which lowers the cost to consumers. Even with the rebound effect and the increased cost of energy, they can keep their total energy consumption the same, despite over a doubling in price from 1991 to 2015 (Ehrhardt-Martinez, 2015).
3. Increases in the price of energy spur innovation, but energy efficiency savings are not lost when the price of energy is lower than average. This means that the average increase in energy efficiency matches the increase in price of energy, in order to keep consumption the same. (Sorrell, Dimitropoulos, and Sommerville, 2009)

The average total energy consumption of the HRM, when the rebound effect is removed, lowers by approximately 19,000 MWh. One of the most recent reports on the supply and demand for energy from NSPI states that the current ENSC programs save 21,000MWH of total energy consumption in Nova Scotia. With the rebound effect coming close to completely negating the ENSC savings, it is evident that the rebound effect must be addressed. In order to place this impact in a more applicable context, the average price of energy cost in 2015 was $114/MWh, while total consumption was 3,925,510MWh; the rebound effect had a cost of $2,166,000. This is money that could be put towards new efficiency programs, or helpfully, consumer education on the rebound effect (Laquarta, 2009). Conceivably, with the rebound effect almost negating the efficiency programs from ENSC in the residential sector of the HRM, there might be a lack of public support for increasing funding to efficiency programs. This lack of support would be based on the perceived lack of impact of said programs (Bird, 2012). However, the impact of the rebound effect cannot keep pace with efficiency programs, as its impact is around 50%. The overall impact will lessen the closer all residents are in the HRM to energy consumption saturation (Comstock & Jarzomski, 2012). Simply explained, this means that once lower income residents are closer to reaching an optimal energy consumption level, even with their lower income, they will stop spending as much on their comfort. In a zero-sum game scenario like the energy efficiency program / rebound effect comparison, the cost is nearly equal to the losses incurred by the rebound effect. Therefore, the ideal scenario, as suggested by Comstock & Jarzomski, is to continue improving the energy efficiency in residential energy consumption, in order to eventually reach energy consumption saturation. Ignoring this potential scenario, even if the rebound effect eliminates the financial savings suggested in ENSC reports, energy efficiency programs should still be pursued. The focus would instead be upon the reduced total energy consumption for the HRM and the environmental benefits resulting from reduced energy use. The NSPI estimate for the savings generated from efficiency programs is expected to increase dramatically in the coming years (ICF International, 2014). Although the rebound effect eliminates the savings generated currently, if the forecasted savings from energy efficiency programs increases to 255000MWH per year, as suggested in NSPI's Supply and Demand report (ICF International, 2014), the overall rebound effect would be lessened.

The second suggestion is to increase the use of consumer education programs, in order to improve the consumption habits of end users. (Laquarta, 2009). Examples of these can be found in other regions of North America, as well as with ENSC. Numerous studies have shown that by providing consumer education on energy consumption, the overall energy consumption in the area can be lessened, suggesting a reduced rebound effect (Laquarta, 2009). Some examples of programs that could impact the consumption habits of HRM residents could focus on concepts such as:

1. Awareness of the impact of small lifestyle changes on energy consumption
2. The consumption habits of homes with similar household uses and size, specifically those with the lowest total energy consumption
3. The economic benefits of reducing energy consumption.

Additionally, programs focusing specifically on the rebound effect, as suggested by Azevedo, would be able to lessen the impact of long term rebound effects, by modifying consumer behaviour and consumption habits (Azevedo, 2014). If a consumer were to have direct, useable information about their total energy consumption, before and after energy efficiency improvements, and the most commonly followed courses of action after improvements, they would be much more likely to reduce the impact of short term and long term rebound effects (Azevedo, 2014). The rebound effect in the HRM is quite large; with 44% of the Nova Scotian population in the HRM, it is important to address it from a municipal level. By showing residents the size of the total rebound effect, and their implicit connection to it, the importance of energy efficiency programs can be shown to still be effective. Even if the efficiency programs are currently negated, by showing HRM residents the overall impact, support for more programs could be achieved (Bird, 2012).

6. Conclusions and Further Research

The objective of this paper was to provide an estimation of the rebound effect in the Halifax Regional Municipality of Nova Scotia, Canada for all residential energy consumption. The rebound effect is present in the HRM residential sector, at a magnitude of approximately -0.51. This was found through the use of a price elasticity of demand for energy, $\eta P_E(E) = (\delta C_{it} / \delta PE_{it}) \times (PE_{it} / C_{it})$, and a weighted multivariate regression. The results of the regression were accurate with $r = 0.98$, and with each variable having a p-value less than 0.005. The results, all together, were found to be similar to those found within literature, including the studies collected by Sorrell, Dimitropoulos and Sommerville. When the regression predictions are compared to the recorded total energy consumption for the HRM, the rebound effect is a size of approximately ~19,000MWh per year. It is important to note again, that this is just a preliminary estimation of the rebound effect, using socioeconomic data. The results are based on the assumption that energy efficiency improvements will always remain despite changes in energy prices, and that consumers will react similarly to price of energy decreases as to energy efficiency improvements. The financial impact of a rebound efffect of ~19,000MWh in 2015 is approximately $2,100,000. The possibility for financial improvements to the HRM economy (such as further energy efficiency programs) without the rebound effect is evident.

Moving forward, it is recommended that further analysis of the rebound effect is done, with primary data being collected from HRM home owners, to determine whether the suggested magnitude of this study is accurate. As mentioned in the literature review, the rebound effect can be directly measured by comparing the energy usage of residential properties before and after energy efficiency improvements. If once the primary data is found to be similar to that of the econometric results, analysis of other Atlantic Canadian provinces can begin, and a more complete picture can be developed.

In conclusion, having an estimation of the rebound effect is only the first step. Merely having knowledge of the magnitude of the rebound effect is not enough, programs aimed at improving the consumption habits of consumers, and programs aimed at improving the energy efficiency of the HRM are still incredibly important.

7. APPENDIX A

Year	Energy Consumed	Population Mean	Ln(Price of Energy)	Ln(Income)	Ln(HDD)	Predicted Energy Consumed with RE (MWH)	Recorded Energy Consumed (MWH)
1991	15.18308	7.917647	3.935791	9.785175	8.305682	3781420	3925784
1992	15.17476	7.912644	3.923407	9.837733	8.347851	3861637	3893273
1993	15.1877	7.89573	3.910377	9.859533	8.152659	4044626	3943968
1994	15.18457	7.897259	3.903829	9.867908	8.331803	3938209	3931659
1995	15.23371	7.889362	3.91333	9.902822	8.331321	3932574	4129696
1996	15.22592	7.921848	3.956428	9.927581	8.331755	3945690	4097633
1997	15.17081	7.970753	4.018289	9.951742	8.358526	3931826	3877924
1998	15.21305	7.921264	3.956992	9.958936	8.241782	4073857	4045249
1999	15.21646	7.961001	4.011164	10.00487	8.186409	4162629	4059058
2000	15.16136	8.104557	4.22538	10.01994	8.255828	3904244	3841433
2001	15.158	8.123217	4.256881	10.06561	8.245621	3950343	3828559
2002	15.1682	8.110201	4.225514	10.1007	8.282104	4047149	3867812
2003	15.13531	8.185266	4.331407	10.12118	8.30704	3968203	3742662
2004	15.15152	8.230169	4.410714	10.15766	8.361264	3872247	3803833
2005	15.15971	8.291264	4.534802	10.21002	8.250254	3841126	3835115
2006	15.22917	8.301377	4.588276	10.25386	8.132148	3857995	4110990
2007	15.17222	8.328717	4.586632	10.29743	8.314734	3896679	3883392
2008	15.16665	8.393629	4.719526	10.34486	8.269834	3786202	3861818
2009	15.25611	8.243217	4.500337	10.35841	8.28969	4002260	4223246
2010	15.23751	8.30316	4.588241	10.37755	8.152227	4066211	4145390
2011	15.18433	8.404865	4.731594	10.40577	8.2089	3941172	3930720
2012	15.18948	8.407725	4.739868	10.42839	8.157714	4004921	3951018
2013	15.19022	8.4172	4.747027	10.45317	8.261242	3972549	3953929
2014	15.18078	8.447654	4.798555	10.48065	8.234592	3973551	3916796
2015	14.18514	7.416716	4.744361	10.49603	8.275224	3925510	3792038

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