Exploring the Relationship between Research and Development (R&D) Expenditure and Economic Growth.*

: An Investigation of GNI and GDP Growth with R&D Expenditure in Canadian Data from 2001 to 2023

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This paper investigates the relationship between Canada's economic growth and R&D expenditure from 2001 to 2023, utilizing data from Statistics Canada. The results of the study indicated that the relationship between Canada's annual R&D expenditure and GDP/GNI growth, as determined through linear regression analysis, was statistically insignificant. Additionally, it was concluded that there exists a negative correlation between nominal share and GDP growth. These insignificant results and negative correlation were explained due to a possible lag effects and issues with R&D budgeting. Additionally, these findings were further justified by referencing the common research results of Kadir, Emir, and Hakan.

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*Code and data are available at: https://github.com/KyungrokP/Research_budget_and_GNI_relation.

1 Introduction

Since the beginning of the 21st century, various technological revolutions have occurred in diverse industries worldwide. This has underscored the importance of investment in scientific technology, leading not only OECD countries but also nations globally to prioritize scientific technological investment. A significant aspect of scientific technological investment is the distribution of expenditure. Among these, annual R&D budgets signify a country's dedication to scientific technological investment of each year. Despite the OECD's average R&D expenditure as a percentage of total GDP showing a slightly lower percentage of 2.718% in 2022 compared to 2.741% in 2021 (OECD, 2023), it has exhibited a steady upward trend since 2000. This indicates that OECD countries are increasingly recognizing the importance of R&D and steadily increasing their investment.

This study aims to investigate the relationship between R&D expenditure and GDP or GNI from 2000 to 2022 using Canadian data. It seeks to answer whether annual R&D spending drives annual GDP, GNI growth, or implies the country's economic growth for that year in another sense. The estimand is whether annual R&D expenditure is related to annual GDP or GNI growth. The data is sourced from Statistics Canada, specifically quarterly GDP and GNI data for Canada, along with yearly R&D expenditure information.

While many studies have examined the connection between R&D spending and economic growth, this paper aims to revisit this correlation, with a specific focus on distinguishing between GDP and GNI. Furthermore, it will clearly define the specificity of Canada as a country and examine the relationship between R&D expenditure and economic growth within the context of Canada.

This paper consists of four main sections: Data, Model, Results, and Discussion. In the Data section, we examine the source of the data,how it was cleaned and utilized, as well as identifying any limitations inherent in the given dataset. The Method section outlines the statistical methods, particularly linear regression, utilized to understand the relationship between annual R&D expenditure and GDP, GNI growth. It also elucidates the significance and key points of these statistical methods. The Results section examines the findings regarding the relationship between Canada's annual R&D expenditure and GDP, GNI growth, using the statistical

methods described in the Model section. Finally, the Discussion Section critically evaluates the weaknesses of the analysis employed in this research. Furthermore, it re-evaluates the results of this study based on the relationship between R&D expenditure and Economic Growth elucidated in other papers, aiming to confirm the findings and identify commonalities.

2 Data

As mentioned earlier, both GNI and GDP, along with annual R&D expenditure, are sourced from Statistics Canada. The reason for distinguishing between GNI and GDP lies in their definitions.

$$\text{GDP (Expenditure Approach)} = C + I + G + (X - M) \tag{1}$$

$$\text{GNI} = \text{GDP} + \text{Income from abroad} \tag{2}$$

The Expenditure Approach used to calculate GDP, as depicted in the equation above, sums up a country's total Consumption (C), Investment (I),Government Spending (G), and Net Exports (X-M). Additionally, GNI includes income from abroad, added to domestic income, resulting in GDP + Income from abroad. Therefore, while GDP growth signifies domestic growth, GNI growth reflects the overall growth and well-being of the nation. Thus, the relationship between R&D expenditure and GDP growth will reveal the connection between R&D expenditure and domestic economic growth, while the relationship between R&D expenditure and GNI growth will illustrate the broader implications for overall country development and well-being.

The data is directly downloaded from Statistics Canada portal, and three data sets, GDP Growth Data, GNI Growth Data and R&D Expenditure data, are utilized. The detailed information of dataset is described below, and the raw data can be seen by following the url in reference section Data, cleaning and analysis was processed through software R program (R core team, 2023), tidyverse(Wickham et al. 2019), ggplot2(Wickham, 2016), janitor(Sam Firke, 2023), tibble(Müller and Wickham, 2023), readr(Wickham et al. 2024) and here(Kirill Müller, 2020). Especially, the linear regression analysis was done by utilizing rstanarm(Ben et al. 2024) package, and the coversion of csv files for raw data to parquet files was processed through using arrow(Neal et al. 2024) package.

2.1 GDP Growth Data

The GDP data, sourced from Statistics Canada, records quarterly total expenditure. Through the data cleaning process, quarterly total expenditures were aggregated into annual totals, enabling the calculation of GDP growth rates. Table 1 presents the annual GDP total expenditure and GDP growth rates from 2001 to 2005

Table 1: GDP Expenditure and Growth rate of Canada from 2001 to 2005

Year	Total Expenditure (million CA $)	Change in Total Expenditure (million CA $)	Change rate in total expenditure (%)
2000	814516	NA	NA
2001	853863	39347	4.830722
2002	904699	50836	5.953648
2003	948231	43532	4.811766
2004	990250	42019	4.431304
2005	1043178	52928	5.344913

Figure 1 illustrates Canada's GDP growth from 2001 to 2023. Since 2001, excluding the year 2009 and 2020, Canada's GDP growth has maintained above 2.8 percent. The year 2020, marked by the severe impact of the COVID-19 pandemic, recorded a negative growth rate of approximately -2.67 percent. This stands in stark contrast to the GDP growth rate of 1.68 percent observed in 2009, following the 2007-2008 financial crisis. Additionally, there was a significant jump in GDP growth after 2020, and currently, it appears to maintain a growth rate similar to pre-pandemic levels.

2.2 GNI Growth Data

The GNI data, like GDP data, also originates from Statistics Canada. A crucial aspect here is the method of recording GNI, where Statistics Canada measured GNI for different years relative to 2017. Specifically, they set the average GNI for the fourth quarter of 2017 as 100 and recorded GNI for other years based on this index.

Table 2 below presents GNI data from 2001 to 2005. To measure GNI growth, quarterly GNIs were aggregated by year and compared to the total GNI of the following year.

Table 2: GNI Growth rate of Canada from 2001 to 2005 based on year 2017 volume

Year	Total GNI (volume index 2017 = 100)	Change in Total GNI (volume index 2017 = 100)	Change rate in total GNI (%)
2000	276.3	NA	NA

Table 2: GNI Growth rate of Canada from 2001 to 2005 based on year 2017 volume

Year	Total GNI (volume index 2017 = 100)	Change in Total GNI (volume index 2017 = 100)	Change rate in total GNI (%)
2001	279.5	3.2	1.158161
2002	285.8	6.3	2.254025
2003	296.3	10.5	3.673898
2004	310.9	14.6	4.927438
2005	324.9	14.0	4.503056

Figure 2 depicts Canada's GNI growth from 2001 to 2023. Compared to Figure 1, it's noticeable that the volatility of GNI growth is higher than that of GDP. Particularly, the impact of the 2008-2009 financial crisis is evident in the negative GNI growth of -6.2% in 2009, as well as the influence of the COVID-19 pandemic reflected in the -5.56% GNI growth in 2020, showing similar negative growth rates. This stark contrast with other years' GNI growth rates underscores the significant impact of these crises. Additionally, there has been substantial growth in GNI since 2020, indicating concerted efforts to overcome the negative growth experienced in that year.

2.3 R&D Expenditure Data

Finally, the annual total R&D expenditure data for Canada is sourced from Statistics Canada. Table 3 presents the total R&D expenditure and change rate from 2001 to 2005, irrespective of the type of investor.

Table 3: Total R&D expenditure and change rate from 2001 to 2005

Year	Total R&D expenditure (million CA $)	Change in total R&D expenditure (million CA $)	Change rate in total R&D expenditure (%)
2000	20555	NA	NA
2001	23132	2577	12.537096
2002	23534	402	1.737852
2003	24693	1159	4.924790
2004	26680	1987	8.046815
2005	28022	1342	5.029985

Figure 3 illustrates the change rate in Canada's R&D expenditure from 2001 to 2023. Comparing 2001 to subsequent years, there is a declining trend in the R&D expenditure change rate between 2002 and 2009. However, since 2009, aside from a few spikes, there has been a steady increase in R&D expenditure.

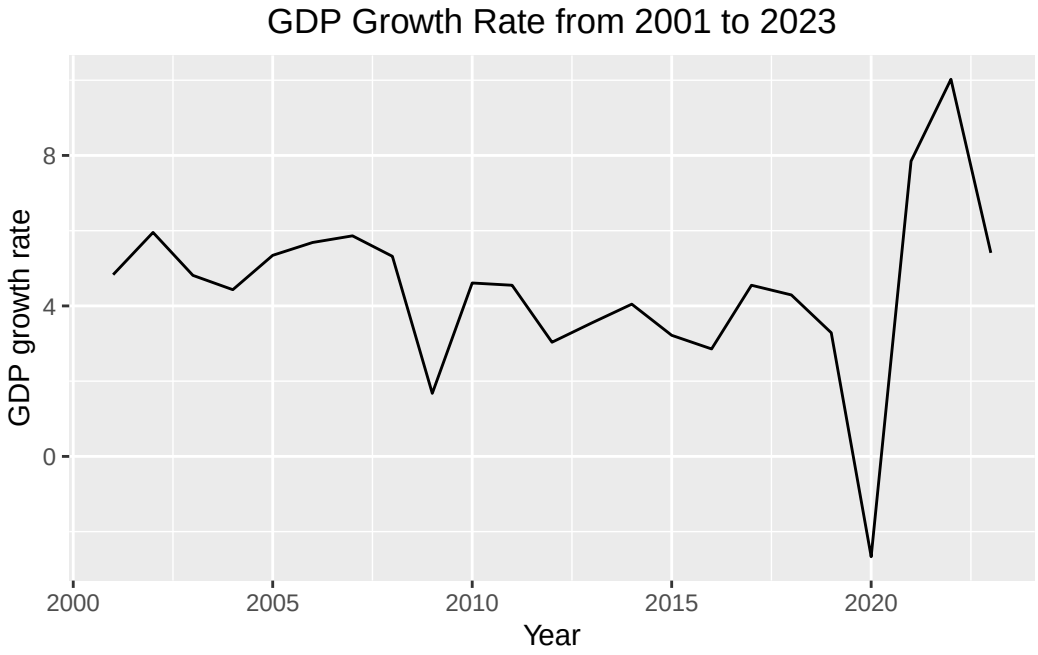

Figure 1: Canada's GDP growth Growth rate from 2001 to 2023

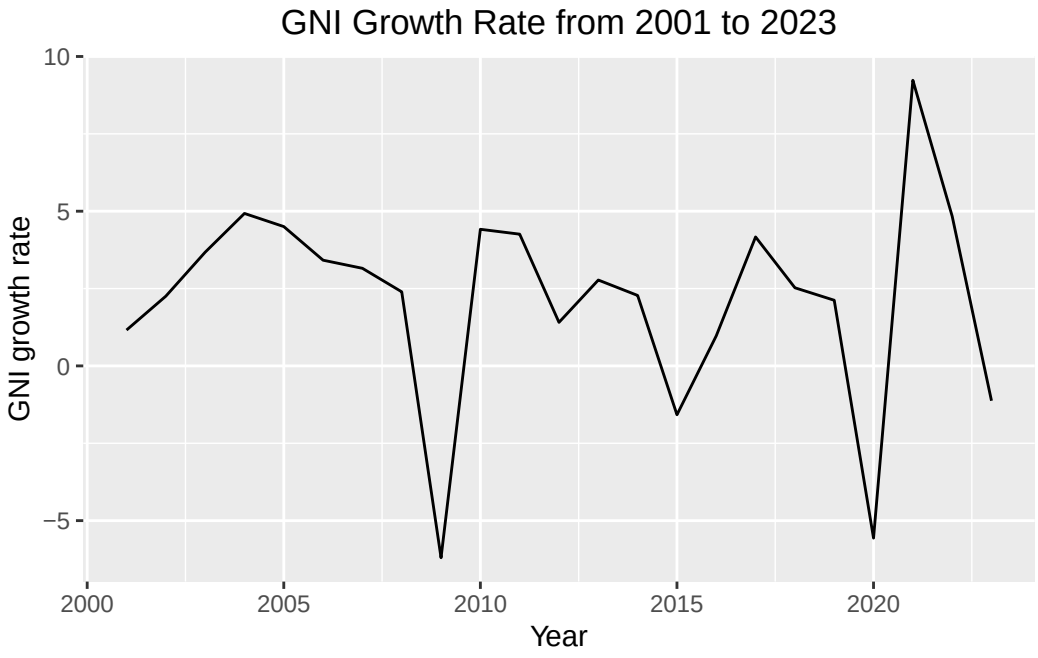

Figure 2: Canada's GNI Growth rate from 2001 to 2023

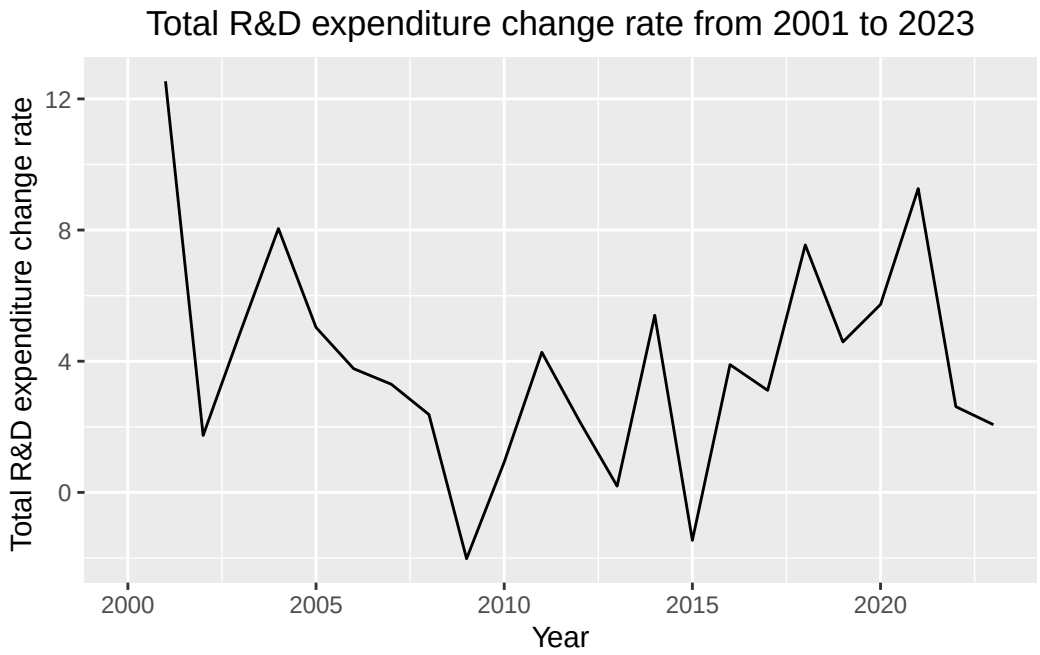

Figure 3: Canada's Total R&D expenditure change rate from 2001 to 2023

2.4 Nominal Share

In addition to the three mentioned data sets above, this study also introduced the nominal share by year. The nominal share refers to the proportion of R&D expenditure relative to the total GDP of the country. If there are years with higher nominal shares, it indicates a greater proportion or contribution to R&D expenditure of the country in that year. Table 4 presents the nominal share of Canada from 2000 to 2005. Through these nominal shares, a more precise understanding of Canada's annual contribution to R&D can be obtained, and this will be utilized to assess its correlation with economic growth.

Table 4: Nominal share of Canada between 2000 to 2005

Year	Total GDP (million CA $)	Total R&D expenditure (million CA $)	nominal share (%)
2000	814516	20555	2.523585
2001	853863	23132	2.709100
2002	904699	23534	2.601307
2003	948231	24693	2.604112
2004	990250	26680	2.694269
2005	1043178	28022	2.686215

3 Model

A statistical method used in this study is linear regression. As shown in the data section, a total of four variables were utilized: GNI growth, GDP growth, Research budget change rate, and nominal share. In this study, three linear regression models have been defined to analyze the relationship between R&D expenditure and economic growth

First model: Y_i (*dependent variable*) = GNI growth rate (in year i), X_i (*independent variable*)= Research budget change rate (in year i)

Second model: Y_i (*dependent variable*) = GDP growth rate (in year i), X_i (*independent variable*)= Research budget change rate (in year i)

Third model: Y_i (*dependent variable*) = GNI growth rate (in year i), X_i (*independent variable*)= Nominal share change rate (in year i)

$$Y_i = \beta_0 + \beta_1 X_i + \varepsilon_i \tag{3}$$

- Y_i represents GDP/GNI growth rate in year i
- X_i represents Research budget/Nominal change rate in year i
- β_0 represents the intercept (constant term), the expected value of GDP/GNI growth when the independent variables (Research Budget rate/Nominal share) is zero.
- β_i represents the coefficient for the R&D expenditure change rate and nominal share in year i. It indicates the rate of change in GDP/GNI growth rate depending on the change rate in R&D expenditure/nominal share
- $\varepsilon_i$represents the error terms, the discrepancy between the actual GDP/GNI growth rate observed and the GDP/GNI growth rate predicted by the linear regression model based on the research budget/nominal share change rate

Table 5: Summary table of 3 different linear regression models

	GNI growth	GDP growth	GDP growth
(Intercept)	0.662	4.112	4.292
	(p = 0.527)	(p = <0.001)	(p = <0.001)
change_rate_in_research_budget	0.386	0.088	
	(p = 0.070)	(p = 0.563)	
change_in_nominal_share			−12.776
			(p = 0.018)
Num.Obs.	23	23	23
R2	0.148	0.016	0.239
R2 Adj.	0.108	−0.031	0.203
AIC	122.1	108.5	102.6
BIC	125.5	111.9	106.0
Log.Lik.	−58.071	−51.249	−48.298
RMSE	3.02	2.25	1.98

4 Results

Table 5 shows the summary of 3 linear regression models. The first model displays the coefficient of 0.386, which illustrates as R&D expenditure change rate increases 1%, the GNI growth rate by 0.386 %. The second model shows the coefficient of 0.088, which also illustrates as R&D expenditure change rate increases 1%, the GDP growth rate increases by 0.088 %. However, both model shows p-value > 0.05 which is a generally accepted value for significance level. Thus, it concludes that the linear regression result for GNI/GDP growth and R&D expenditure budget is not significant in this research.

On the other hand, the third model shows coefficient of -12.776 which shows the negative relationship between GDP growth rate and R&D expenditure change rate (as nominal share change rate increases by 1 %, GDP growth rate decreases by -12.776%). The model also shows the p-value of 0.018 (<0.05), which suggests the result is significant. However, this result seems very counter-intuitive since the purpose of R&D investment is to stimulate the economic growth. Several factors could influence these results, such as the duration of the data used (insufficient sample size), lag effects, the background of Canada as a country, and the purpose and specifics of the R&D investments. Detailed explanations are provided in the following section, the Discussion section.

5 Discussion

5.1 Lag effects

R&D expenditure is known to have a positive relationship with a country's Total Factor Productivity (TFP) (Zhou&Xia, 2010). However, it is understood that the increase in TFP takes considerable time, leading to long-term growth in a country's GDP/GNI due to the lag effect of TFP. Since this study analyzed the relationship between R&D expenditure and economic growth for each year, it is not immune to the influence of such lag effects. In this research, the results of Models 1 and 2 have already indicated that the relationship between R&D expenditure and GNI/GDP growth is not significant. In addition,the negative relationship between nominal share and GDP growth is identified. the results of these three models collectively prove that there is no positive year-by-year relationship between R&D expenditure and economic growth, possibly due to lag effects. Moreover, Canada ranks 6th in the OECD, indicating a high convergence rate. This further underscores that while R&D investment may have a positive effect on economic growth, it requires a considerable amount of time to manifest, likely due to lag effects.

5.2 Possible problems in Resource allocations

The negative relationship between R&D and economic growth revealed in Model 3 of this study may imply issues with the allocation of R&D investment in Canada, beyond just the influence of lag effects. R&D investment involves not only government but also various companies and enterprises. Moreover, the diversity of investor types leads to the allocation of R&D investment across various industries. However, despite this diversity in investment portfolios, changes in R&D allocation may occur annually or quarterly, and concentration in certain industries may negatively impact economic growth. Conversely, the diversity of investment portfolios may also have a negative impact on economic growth. Canada's productivity declined in 2023, with 10 out of 12 quarters experiencing a decrease (Canadian Chamber of Commerce, 2024). This decline in productivity, coupled with the negative relationship between R&D and economic growth, suggests issues with the allocation of R&D investment in Canada. Potential solutions include investigating the R&D expenditure and investment levels in each sector to focus investment on industries that can drive the country's growth, or adjusting the annual or quarterly R&D investment portfolio with investment diversity if needed. To achieve this, proactive intervention in government R&D allocation and advocacy for investment in industries requiring diverse investments may be necessary.

5.3 Relevant Literature

The research, "The Relationship Between Research & Development Expenditures and Economic Growth: The Case of Turkey" (Kadir, Emir & Hakan, 2015), investigated the relation-

ship between R&D expenditure and economic growth using data from Turkey spanning from 1990 to 2013. In detail, Unit root tests, cointegration tests, and Granger's causality tests were conducted, and the results indicated no significant relationship between R&D expenditure and economic growth. Furthermore, the causality tests revealed no causal relationship betweem them. In the study by Kadir, Emir & Hakan, the lack of relationship was attributed to the characteristics of Turkey as a country and the lag effect of R&D, which is consistent with the conclusions of this study. So, what does this study imply? The answer can be found in the conclusions mentioned in the previous study. Kadir, Emir & Hakan emphasized the importance of considering both short-term and long-term outcomes of R&D investments. Therefore, R&D investment should be approached with consideration for both quantitative and qualitative standards, and this may necessitate changes in national policies.

5.4 Weaknesses and Next Steps

As mentioned earlier, a weakness of this study lies in exploring the relationship between annual growth and R&D expenditure. Typically, scientific research and development unfold over long periods, making it challenging to predict the accurate timing of the result. For this reason, the relationship between annual growth and scientific investment may not exist, or it might indicate unforeseen directions. Moreover, the realm of R&D investment is vast, encompassing industries not only in general health or labor but also spanning a wide array of scientific fields. However, our study did not differentiate the industries where R&D expenditure was invested but instead aggregated them all to explore their relationship with national growth. In future research, I would like to delve into segmenting the areas where R&D expenditure is allocated to investigate whether R&D investment in each industry sector contributes to its growth. Furthermore, it is desirable to measure the time it takes for R&D investment to benefit specific industries' growth. This would involve measuring the pace of industrial growth attributable to R&D investment in each sector.

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