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"Machine Learning Insights into Canadian Unemployment: Analyzing the Pandemic's Impact and Predicting Future Trends (2025–2030)"

1. Introduction and Discovery

This project examines unemployment data in Canada over the past six years (2018–2023), focusing on the significant impact of the global Covid-19 pandemic on unemployment rates during 2020–2021. The analysis utilizes publicly available data from the Statics Canada, ensuring accuracy and transparency in the study. The aim is to gain a deeper understanding of the pandemic's effects on various demographic groups and to provide insights that can inform future policy development. In addition to analyzing the pandemic's impact, unemployment rates have been studied across different education levels, gender groups, and age ranges to identify which groups were most affected. Furthermore, the project attempts to predict the potential impact of a similar crisis, such as a pandemic, on unemployment rates over the next six years (2025–2030). Using machine learning models, historical data was analyzed to make these forecasts. The goal of this project is to highlight how crises impact unemployment rates across different demographics, helping the Canadian government develop proactive policies to mitigate the effects of such events in the future.

2. Data Preparation and Feature Engineering

The analysis is based on the dataset titled *"Unemployment rate, participation rate, and employment rate by educational attainment, annual,"* retrieved from Statistics Canada (Statics Canada, 2024a). Comprising 18 columns and 504 rows, the dataset captures unemployment trends in Canada from 2018 to 2023. Its metadata reveals a detailed structure, including five primary dimensions—Geography, Labour Force Characteristics, Educational Attainment, Sex, and Age Group. The dataset spans a reference period from January 1, 1990, to January 1, 2023, with annual frequency. This comprehensive dataset provides a robust foundation for analyzing unemployment trends across different demographic and socioeconomic factors in Canada.

2.1. Dataset Columns and Preprocessing

The dataset initially comprised various columns, including REF_DATE, GEO, DGUID, Labour force characteristics, Educational attainment, Sex, Age group, UOM, UOM_ID, SCALAR_FACTOR, SCALAR_ID, VECTOR, COORDINATE, VALUE, STATUS, SYMBOL, TERMINATED, and DECIMALS. To optimize the analysis, irrelevant columns such as DGUID, GEO, UOM, UOM_ID, SCALAR_FACTOR, SCALAR_ID, VECTOR, COORDINATE, STATUS, SYMBOL, TERMINATED, and DECIMALS were excluded. Additionally, certain column names were updated to enhance clarity and usability: REF_DATE was renamed to "year," VALUE to "unemployment_rate," and Educational attainment to "educational_level." These adjustments ensured a more focused and interpretable dataset for analysis.

2.2. Feature Engineering

To enhance the analysis, additional preprocessing was performed. A new feature, pandemic_impact, was created to capture the unique effects of 2020–2021, corresponding to the Covid-19 pandemic. Categorical variables such as educational_level, sex, and age group were encoded to ensure compatibility with machine learning models.This prepared and refined dataset forms the foundation for the subsequent analysis and model implementation, focusing on exploring unemployment trends across various demographics and predicting the potential impact of future crises.

3. Exploratory Data Analysis (EDA)

The dataset was analyzed to uncover key patterns and relationships between variables, providing a foundation for subsequent modeling efforts. The analysis focuses on the unemployment rate, demographic characteristics, and the impact of the Covid-19 pandemic on the labor market. The unemployment rate in the dataset shows a mean value of 8.06%, with a standard deviation of 3.99%, reflecting moderate variability across regions and time periods. The minimum observed unemployment rate is 3.4%, while the maximum reaches 25.8%, indicating significant disparities in unemployment levels. This variability is likely influenced by demographic and economic factors, which are explored further in this analysis. Educational attainment is represented by binary features for various education levels, including "0 to 8 years," "high school graduate," "postsecondary certificate or diploma," and "university degree." On average, 16.7% of the observations are associated with each educational level. This balanced distribution allows for meaningful comparisons between groups with different levels of education. Demographic variables such as gender and age groups are also evenly distributed. Gender is represented by binary variables (sex_females and sex_males), each with a mean of 0.5, reflecting an equal split between males and females. Similarly, age groups, such as age_group_15_to_24_years and age_group_25_to_44_years, have a mean value of 0.143, indicating that all age categories are proportionally represented in the dataset. The pandemic_impact variable, which captures the influence of the Covid-19 pandemic during 2020–2021, has a mean value of 0.33. This indicates that 33% of the observations correspond to the pandemic period. The inclusion of this variable enables an in-depth analysis of how the pandemic affected unemployment rates across different groups.

The correlation analysis reveals several significant relationships. Unemployment rate is positively correlated with the pandemic_impact variable (correlation coefficient of 0.41), highlighting the notable increase in unemployment during the pandemic. A positive correlation is also observed between unemployment rate and lower educational attainment, such as educational_level_0_to_8_years (0.36), while higher educational levels, such as educational_level_university_degree, exhibit a negative correlation (-0.30). This suggests that individuals with less education faced higher unemployment rates, whereas those with higher education were less affected. Age emerges as another critical factor, with unemployment rate strongly correlated with age_group_15_to_24_years (0.55). This indicates that younger individuals experienced disproportionately high unemployment levels compared to older groups.

On the other hand, youth unemployment in Canada has been a persistent concern, with recent data indicating significant challenges. In August 2024, the youth unemployment rate reached 14.5%, the highest since 2012, though it began to decline in the subsequent months. By September 2024, the rate had decreased to 13.5%, yet it remained 2.8 percentage points higher than the same period in the previous year (Statics Canada, 2024b). This trend underscores the disproportionate impact of economic fluctuations on young Canadians, particularly in the wake of the COVID-19 pandemic. The pandemic exacerbated employment challenges for youth, with sectors heavily employing young individuals, such as retail and hospitality, experiencing significant job losses (Morissette, 2021).

3.1. Univariate Analysis

The unemployment rate was examined through a histogram with a kernel density estimate (KDE) overlay and a boxplot to understand its distribution and identify key characteristics.

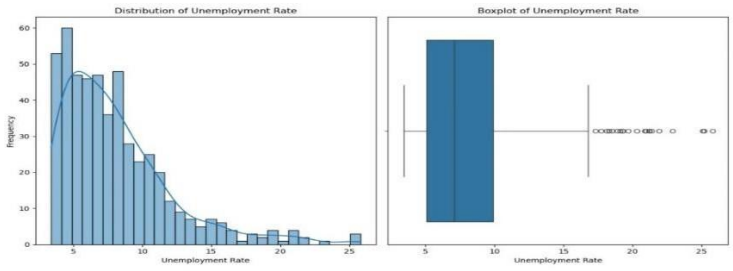

Figure 1: *The histogram displays the unemployment rate's frequency distribution.*

3.1.1. Distribution Analysis

The histogram reveals a positively skewed distribution of unemployment rates. Most observations are concentrated at the lower end of the range, between 5% and 10%, with a peak frequency observed around 5% to 6%. This suggests that low to moderate unemployment rates are the most common in the dataset. The right tail of the distribution extends towards higher unemployment rates, reaching up to approximately 25%. These high values represent outliers or regions experiencing exceptionally high levels of unemployment, which are relatively rare.

3.1.2. Boxplot Analysis

The boxplot complements the histogram by illustrating the central tendency and variability of unemployment rates. The median unemployment rate lies slightly below the center of the interquartile range (IQR), further confirming the asymmetric distribution. The IQR spans from around 5% to 10%, capturing the middle 50% of observations. Outliers are evident beyond the upper whisker, which extends to approximately 15%. These outliers correspond to the high unemployment rates observed in the histogram's right tail. The range of most unemployment rates, excluding outliers, is well within 15%, indicating that extreme values are limited to specific instances.

3.2. The Unemployment Rate Trend Over the Years

The unemployment rate in Canada from 2018 to 2023 reveals notable variations, highlighting the impact of the COVID-19 pandemic and subsequent recovery. A line plot was used to visualize this trend, capturing changes in unemployment rates across the years. The unemployment rate remained relatively stable from 2018 to 2019, averaging around 7% (Statics Canada, 2024a). However, 2020 saw a sharp increase, with unemployment rates peaking above 12%, coinciding with the onset of the COVID-19 pandemic, which caused widespread economic disruptions and job losses globally (OECD, 2020). This trend emphasizes the pandemic's significant impact on Canada's labor market, underscoring the importance of economic resilience and targeted interventions during crises.

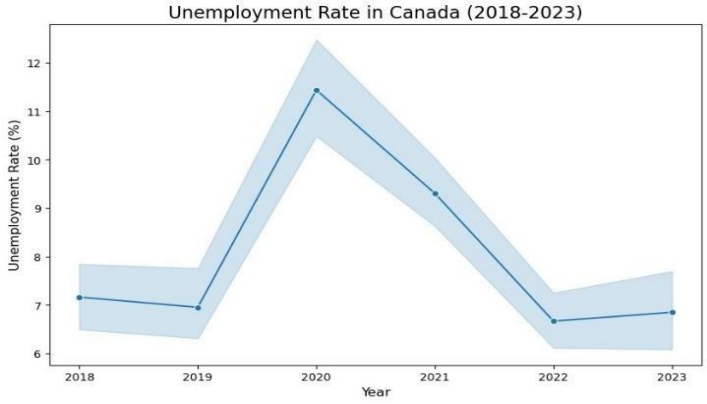

Figure 2: *The Unemployment Rate Trends in Canada (2018-2023).*

The analysis underscores the profound impact of the COVID-19 pandemic on Canada's unemployment rate, with 2020 representing a peak in economic disruption. The recovery observed in subsequent years highlights the resilience of the labor market and the effectiveness of post-pandemic economic policies. Understanding this trend provides valuable context for analyzing unemployment dynamics and planning for potential future disruptions.

3.4. Unemployment Rate by Education Level

The relationship between education level and unemployment rates was analyzed to uncover how varying levels of educational attainment influence employability. Weighted unemployment rates were calculated for each education level, providing a

nuanced view of the labor market challenges faced by different demographic groups. The analysis reveals a strong negative correlation between educational attainment and unemployment rates. Individuals with lower levels of education face significantly higher unemployment rates, while those with advanced education enjoy better job security.

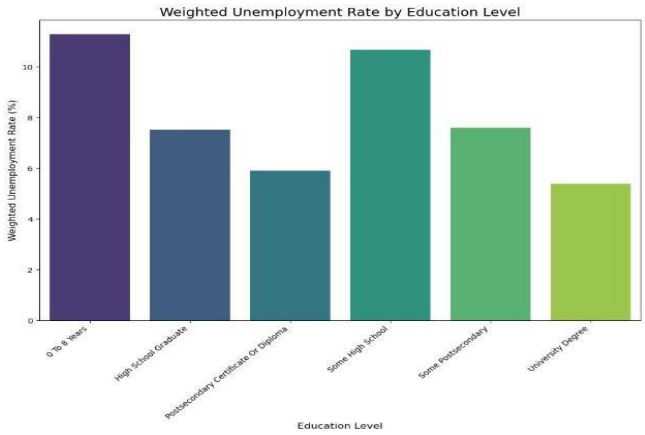

Figure 3: Unemployment Rates Over the Education Levels.

The findings highlight the urgent need for targeted government interventions to support groups with lower levels of education, who are especially vulnerable to economic crises. These interventions could include job training programs, subsidized education and upskilling opportunities, employment support services and economic safety nets. By prioritizing support for these at-risk groups, governments can reduce the disproportionate impact of economic downturns on lower-educated individuals, fostering a more equitable and resilient labor market.

3.5. Unemployment Rate by Gender and Year

This project analyzes unemployment trends among males and females over six years, focusing on the impact of the COVID-19 pandemic. The dataset spans pre-pandemic years (2018–2019), pandemic years (2020–2021), and the post-pandemic recovery period (2022–2023). During the pre-pandemic years, unemployment rates for men and women were similar, averaging around 7%, indicating minimal gender disparities in employment opportunities. However, the pandemic significantly disrupted labor markets, with women experiencing higher unemployment rates than men. Women accounted for 53.7% of year-over-year job losses from March 2020 to February 2021, driven by their overrepresentation in sectors like retail, hospitality, and personal services, which were among the hardest hit by economic shutdowns (Statistics Canada, 2021). Women earning less than $800 per week saw their employment drop by nearly 30%, compared to a 24% decline for men, reflecting the pandemic's disproportionate impact on women (RBC Wealth Management, 2021).

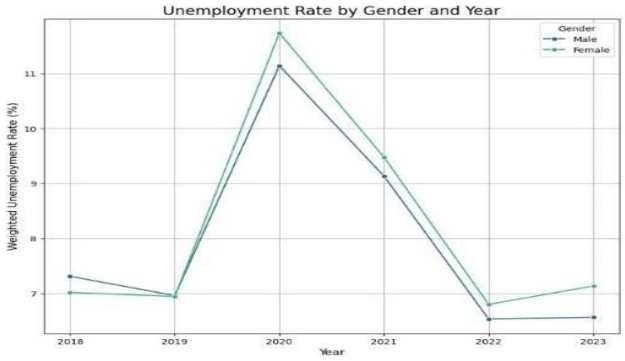

Figure 4: *Unemployment Rates Across Genders.*

Several factors contributed to this disparity. Female-dominated industries faced the brunt of the economic disruptions, while increased caregiving responsibilities, such as childcare due to school closures, further limited women's workforce participation. Part-time jobs, which are more prevalent among women, were also more likely to be eliminated during the downturn (Fuller & Qian, 2021). In the post-pandemic period, unemployment rates declined for both genders, but women faced a slower recovery. By 2023, male unemployment rates had fallen slightly below pre-pandemic levels, whereas female rates stabilized closer to those of 2018–2019, highlighting persistent structural barriers. Furthermore, The Canadian Human Rights Commission (2022), emphasized the long-term and far-reaching consequences of the pandemic's disproportionate impact on women, stating that social and economic recovery efforts in Canada must adopt a feminist approach to restore progress toward gender equality.

To reduce these gendered impacts, policymakers must address the barriers women face during crises and recovery periods. Expanding access to affordable childcare, supporting female-dominated industries, offering gender-inclusive reskilling programs, and encouraging flexible work policies can promote equitable labor market outcomes. Such targeted measures are critical to addressing disparities and ensuring women are not disproportionately affected during future economic disruptions.

3.6. Unemployment Rate by Age Group and Year

Unemployment rates in Canada vary significantly across age groups, highlighting distinct vulnerabilities in the labor market. From 2018 to 2023, trends reveal the disproportionate impact of the COVID-19 pandemic in 2020 and subsequent recovery patterns. Youth unemployment has remained a persistent concern. According to Benchetrit (2040), "*There has been almost no employment growth among youth between the ages of 15 and 24 since December 2022*". This situation underscores the significant impact of economic fluctuations on young Canadians, particularly during the pandemic. The crisis further exacerbated youth unemployment as heavily impacted sectors such as retail and hospitality, which employ many young workers, experienced severe job losses (Lord, 2024).

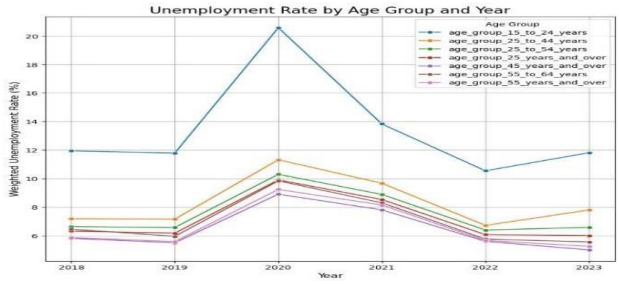

Figure 5: *Unemployment Rate Across Different Age Groups.*

According to the project, youth unemployment emerged as a critical issue, particularly during the COVID-19 pandemic. The 15–24 age group experienced the highest unemployment rates, with a dramatic spike exceeding 20% in 2020, driven by the pandemic's disproportionate impact on entry-level and part-time jobs. Despite some recovery, unemployment levels for this group remained elevated compared to others, reflecting their heightened vulnerability in the labor market. In contrast, prime working age groups (25–44 and 25–54 years) showed moderate unemployment rates, with a less severe increase in 2020 and a return to pre-pandemic levels by 2023. Older age groups (45+ years) and seniors (55+ years) maintained relatively low and stable unemployment rates, highlighting differences in job security and retirement trends. The project emphasizes the need for targeted interventions, such as skill development programs, job placements in resilient sectors, protections for entry-level roles, and youth-specific stimulus measures to address the challenges faced by younger workers during economic disruptions.

4. Model Evaluation and Pipeline

This section evaluates six machine learning models for predicting unemployment rates using a pipeline. The models were assessed based on Mean Squared Error (MSE) and R^2 scores to determine their accuracy and explanatory power.

4.1. Best Model: Random Forest

The Random Forest model emerged as the best performer, achieving the lowest MSE (1.53) and the highest R^2 (0.92), indicating its ability to explain 92% of the variance in unemployment rates. Its superior performance is attributed to its capacity to handle non-linear relationships and aggregate multiple decision trees, making it highly robust.

4.2. Other Models

The Decision Tree model demonstrated strong performance with an MSE of 2.00 and an R^2 of 0.89, although it was less robust than Random Forest due to its reliance on a single tree, which makes it more prone to overfitting. Linear Regression and Ridge Regression produced comparable results, with MSE values of 2.80 and 2.91 and R^2 scores of 0.85 and 0.84, respectively. While these models captured linear trends effectively, they struggled with non-linearities in the data. Lasso Regression performed the worst, with an MSE of 10.33 and an R^2 of 0.43, largely due to excessive regularization leading to underfitting. K-Nearest Neighbors (KNN) exhibited moderate performance, with an MSE of 5.50 and an R^2 of 0.70, but its sensitivity to local data patterns limited its generalizability.

4.3. Feature Importance

The Random Forest model highlighted key factors influencing unemployment predictions. The most critical feature was the age group 15–24 years (importance: 0.287), emphasizing the significant role of youth unemployment in driving overall trends. The COVID-19 pandemic's impact (importance: 0.197) underscored its profound effect on employment. Lower educational attainment (0–8 years) and partial high school education also emerged as influential factors, with importances of 0.136 and 0.119, respectively. The temporal feature "year" (importance: 0.059) captured time-based variations, while features such as postsecondary and university education, sex (female and male), and the age group 25–44 years further aligned with known socioeconomic patterns linking age, education, and pandemic-related disruptions to unemployment. These insights reinforce the model’s robustness and its capacity to identify critical drivers of unemployment trends.

5. Scenario Testing

Scenario testing was conducted to assess the impact of changes in key features on unemployment rates. The baseline scenario, representing current conditions without modifications, served as the reference point for comparison. When the proportion of individuals aged 15–24 years increased by 15%, the predicted unemployment rate rose above the baseline. This reflects the vulnerability of younger individuals to job instability and economic disruptions. Similarly, a return to pandemic-like conditions resulted in a substantial rise in unemployment, highlighting the severe labor market disruptions caused by COVID-19 and the sensitivity of employment rates to economic shocks. An increase of 20% in individuals with low education levels (0–8 years) also led to higher unemployment, as limited skills and opportunities are strongly associated with joblessness. A 20% increase in the female population resulted in a slight rise in unemployment, though its impact was less pronounced compared to other factors like education or the pandemic. To simulate compounded vulnerabilities, two combined scenarios were tested. In the first, a 15% increase in the youth population coupled with pandemic conditions led to a significant rise in unemployment, emphasizing the heightened susceptibility of younger age groups during economic crises. The second scenario, combining higher proportions of low education levels with pandemic conditions, produced a similarly sharp increase in unemployment, underscoring the critical role of education in mitigating joblessness during disruptions.

6. Building the Synthetic Data

To project unemployment trends in Canada for the period 2024 to 2030, synthetic data was generated using historical data sourced from Statistics Canada. The dataset, titled "clean_unemployment.csv," provides a comprehensive overview of unemployment trends and demographic factors between 2018 and 2023. The synthetic data was developed to simulate potential future scenarios, incorporating demographic shifts such as a declining youth population, an increasing older

workforce, and economic disruptions comparable to the COVID-19 pandemic. Projections for 2024 to 2030 were based on assumptions reflecting anticipated demographic and economic trends. The proportions of younger age groups (15–24 years) were adjusted to show a gradual decline, while older cohorts (55+ years) were projected to increase steadily. These adjustments align with Statistics Canada's "Population Projections for Canada (2023 to 2073), Provinces and Territories (2023 to 2048)," which detail a shrinking youth demographic and an aging population. By 2030, the youth population was expected to decrease by approximately 7%, while the older population was projected to grow by 10% (Statics Canada, 2024c).

Educational attainment levels in the synthetic data were represented by mean values from the historical dataset, maintaining consistent proportions across categories such as "high school graduate" and "university degree." Gender representation was similarly held constant using historical averages for male and female proportions, ensuring stability in these variables. A binary variable for pandemic impact was introduced to simulate economic shocks during the years 2026–2028. During this period, the youth population (15–24 years) was adjusted downward by 10%, while the older workforce (55–64 years) was increased by 10%, reflecting differential impacts of a hypothetical pandemic.

The unemployment rates for 2026–2028 were adjusted to account for anticipated economic disruptions. A baseline unemployment rate was established using historical data, which was increased by specific factors to simulate heightened job instability. For example, unemployment rates were raised by 3.5% in 2026, 5.0% in 2027, and 4.0% in 2028. To ensure alignment with Canada’s current labor market conditions, a scaling factor was applied to the synthetic unemployment rates. This adjustment ensured consistency with the observed 2023 unemployment rate of 5.4%, while the 2024 rate was set at 6.5%, reflecting projections for that year (Alberta, 2024). The synthetic dataset was then integrated with the historical data, creating a unified dataset that transitions seamlessly from observed to predicted trends. This dataset serves as a robust foundation for analyzing various scenarios and informing policy decisions. The approach underscores the value of synthetic data in examining hypothetical situations, particularly in assessing the effects of demographic changes and economic disruptions on unemployment rates.

6.1. Interpretation of Model Integration and Unemployment Rate Prediction

This analysis integrates the synthetic dataset with historical data and applies machine learning techniques to evaluate models, tune hyperparameters, and forecast unemployment rates for Canada from 2024 to 2030. The goal is to project unemployment trends, particularly under scenarios of economic disruption, and provide actionable insights into labor market dynamics. The evaluation of multiple regression models revealed varying degrees of predictive performance: Random Forest demonstrated the highest accuracy with a mean squared error (MSE) of 1.66 and an R2 of 0.87, indicating its superior ability to capture complex, non-linear relationships in the data. To optimize model performance, hyperparameters were fine-tuned. For instance, the Random Forest regressor performed best with 100 estimators, while the Decision Tree regressor achieved optimal results with a maximum depth of 10. The tuned models significantly improved prediction accuracy, particularly for the Random Forest model.

7. Forecasting Canadian Unemployment: Model Accuracy, Insights, and Policy Implications

The updated unemployment rate predictions for Canada provide crucial insights into future labor market trends, highlighting an increase in unemployment in 2024 due to inflationary pressures, sectoral adjustments, and slow employment recovery (Gellatly & McCormack, 2024). The projections also emphasize the potential impact of a prolonged pandemic from 2026 to 2028, with unemployment peaking at 8% in 2027, reflecting a sustained economic downturn with slower recovery compared to the sharp yet short-lived spike during the 2020 pandemic. This underscores the importance of long-term policy interventions to mitigate disruptions. Key factors driving these predictions, such as gender and aging demographics, align with established labor market dynamics. The model's behavior and outputs are consistent with domain expertise, accurately identifying vulnerable sectors like healthcare, retail, and manufacturing, which are expected to face significant strain during future crises. The integration of parameters such as pandemic impact, demographic changes, and sector-specific

vulnerabilities ensures the model is contextually relevant and robust. The model avoids drastic overestimations or underestimations, as it provides a reasonable unemployment projection of 8% during prolonged crises. Such results align with historical data, indicating the model avoids intolerable errors. However, while the Random Forest model performs well for non-linear relationships, testing alternative models (e.g., Gradient Boosting or Neural Networks) could confirm whether they yield better performance or complementary insights.

While the model demonstrates validity and provides actionable insights for planning, incorporating additional data—such as regional economic variations or global economic trends—could further enhance its accuracy. Overall, the predictions highlight the structural vulnerabilities and opportunities in Canada's workforce, emphasizing the need for proactive, targeted policies to enhance labor market resilience and address demographic challenges.

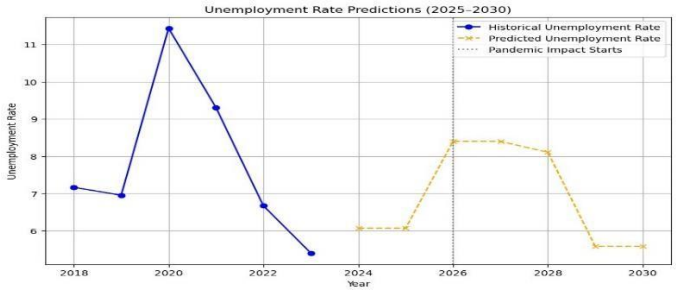

Figure C: *Unemployment Rate Predictions for 2025-2030.*

7.1. Analysis of Prolonged Pandemic Impact and the Role of Gender and Aging Population

The gender dimension remains a critical factor in these predictions. During the 2020 pandemic, women experienced disproportionate job losses due to their overrepresentation in vulnerable sectors such as retail, hospitality, and caregiving services (Grekou & Lu, 2021). This trend is expected to repeat during the simulated 2026–2028 pandemic unless specific policies are implemented to mitigate these disparities.

The aging population adds another layer of complexity to these projections. According to Global News's report (2024), "Canada's 85-and-over population set to triple over next 40 years". With older workers comprising an increasing proportion of the workforce, demographic shifts are expected to lead to a contraction in the labor pool as retirement rates rise. Older workers may also face heightened risks of unemployment during crises due to potential skill mismatches and health vulnerabilities. The growing dependency ratio associated with an aging population will place additional strain on social security systems, necessitating higher productivity from a shrinking active workforce. To counteract this, policies encouraging increased female workforce participation and supporting the retention of older workers will be essential (Vézina and others, 2024). To address these challenges, Canada should adopt policies targeting structural vulnerabilities and fostering labor market resilience. Gender-sensitive measures like childcare subsidies and support for female-dominated sectors are crucial, alongside financial incentives for manufacturing and services. Workforce development through reskilling, upskilling, and targeted hiring subsidies for youth and women is essential. Flexible work options, including hybrid and remote arrangements, can further support workforce participation and caregiving responsibilities.

Finally, economic stimulus measures are essential for stabilizing unemployment in 2024 and addressing potential disruptions in 2026–2028. Priority should be given to supporting industries like retail, tourism, and hospitality, fostering innovation-driven entrepreneurship, and providing temporary wage subsidies to protect vulnerable groups. Targeted, long-term interventions addressing gender disparities, demographic shifts, and sector vulnerabilities will enhance labor market resilience and ensure sustainable economic growth.

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