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*Radovan Kovačević**

THE IMPACT OF PUBLIC DEBT ON ECONOMIC GROWTH IN SERBIA – AN EMPIRICAL STUDY USING THE ARDL APPROACH

ABSTRACT: *The paper analyses the relationship between public debt and economic growth in Serbia. The empirical analysis was conducted using the autoregressive distributed lag (ARDL) and non-linear autoregressive distributed lag (NARDL) approaches for the period 2001–2023. The estimated long-run parameters in NARDL show that a 1% increase in the public debt-to-GDP ratio is associated with a 0.25% decrease in real GDP per capita growth and that a 1% decrease in public debt is on average associated with a 0.7% increase in real GDP per capita growth, both with the first lag. This shows that real GDP per capita growth reacts asymmetrically to changes in public debt, such that the magnitude of the positive reaction to public debt reduction is greater than that of the negative reaction to an increase in public debt. The estimated short-term coefficients also confirm this asymmetry. The long-run coefficient of the public debt service parameter indicates the negative impact of debt service on economic growth, as a 1% increase in public debt service to GDP ratio is associated with a 0.17% decline in real GDP per capita growth. The long-run relationship between the current account deficit and economic growth is positive and shows that the increase in the current account deficit by 1% of GDP correlates with the increase in real GDP per capita growth by 0.26% with the first lag.*

KEY WORDS: *public debt, debt service, economic growth, ARDL and NARDL*

JEL CLASSIFICATION: C52, H63, Q47

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1. INTRODUCTION

The increase in Serbia's public debt (PD) can be seen in the period after 2008. Direct and indirect external PD grew more dynamically than the growth of internal PD in the period 2009–2016, followed by a decline in the absolute amount of external PD until 2019. The COVID-19 pandemic accelerated Serbia's external debt, resulting in a large gap between external and internal PD after 2020. The dimensions of this gap in absolute amounts, expressed in euros, are shown in Figure 1. It can be seen that the external public and publicly guaranteed debt increased from around 14 billion euros in 2019 to over 25 billion euros in 2023, with the expected trend of a further increase in the following period[1].

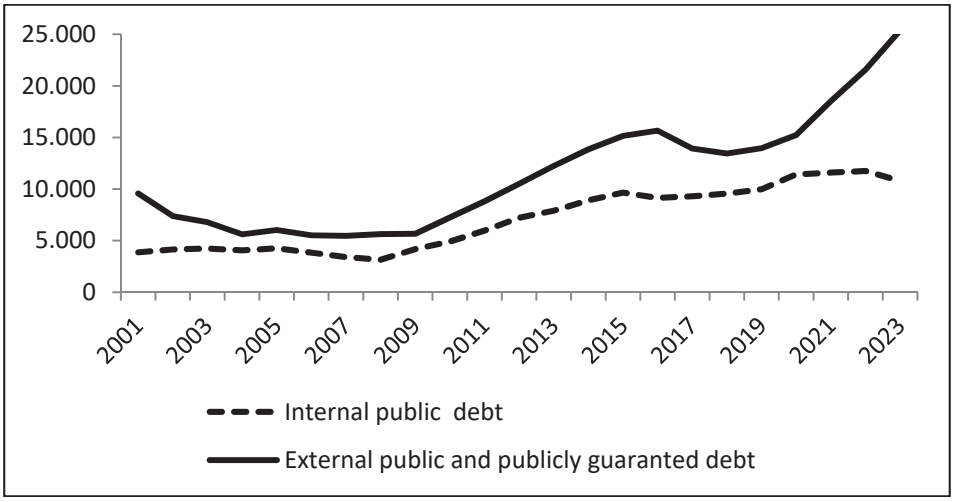
The increase in public investment in infrastructure projects in the period 2008–2015 not only led to an absolute increase in public debt, but also to an increase in the share of PD in gross domestic product (GDP) (Figure 2).

Thanks to GDP growth, PD as a percentage of GDP has been declining since 2015. According to the Ministry of Finance of the Republic of Serbia, the PD of the central government level reached 88.1% of GDP at the end of 2001 and stood at 25.8% of GDP in 2008. This was followed by an increase to 67.2% of GDP in 2015 and a decrease to 52.4% of GDP in 2022, followed by 48.0% in 2023. The trend of growth in external debt in relation to total PD has been observed since 2010. The growth of internal PD has followed the growth of external public debt, albeit at a slower pace.

The increase in external PD and the rise in interest rates led to an increase in the debt service burden on external PD from 1.0% of GDP in 2008 to 6.4% in 2019. The debt service burden of public external debt then declined and amounted to 2.7% of GDP in 2023 (Figure 2). The literature points out that the increase in public borrowing on the domestic capital market leads to a crowding out of private investment (Elmendorf & Mankiw, 1999) and that excessive public borrowing leads to an increase in long-term interest rates for new loans and an increase in the risk premium (von Hagen et al., 2011).

[1] The expected additional borrowing in connection with the infrastructure investments required for the organisation of the "EXPO 2027" exhibition in Belgrade.

Figure 1: Internal and external public and publicly guaranted debt of Serbia, euro millions



Source: Ministry of Finance of the Republic of Serbia, https://www.mfin.gov.rs/en/documents2-2/macroeconomic-and-fiscal-data2, accessed 27/01/2025

The costs of PD include not only the taxes necessary to service the debt, but also the distortions associated with these taxes. Since higher taxes reduce investment incentives, tax distortions form a natural fiscal limit for government debt (Leeper & Walker, 2011). Therefore, excessive PD becomes costly and contributes less and less to economic growth, and above a certain threshold it has a negative impact on economic growth (Reinhart & Rogoff, 2010). The sectoral use of external debt is also important for economic growth. External debt can encourage investment to a certain extent, but if foreign investors begin to doubt a country's ability to properly repay its obligations, a "debt overhang" (Krugman, 1988; Clements et al., 2003) will discourage investors from providing additional capital, negatively impacting investment and economic growth. General government fiscal deficits (public revenues minus public expenditure) can also influence national income. In the short run, general government fiscal deficits can stimulate aggregate demand and thus boost economic growth (while reducing domestic savings). In the long run, however, a decline in savings can reduce the growth of future production and investment, jeopardising long-run economic outcomes. Since 2019, Serbia has entered the general government fiscal deficit zone (in the period 2019–2023, the ratio of the general government fiscal deficit to GDP is -0.2; -7.7;

-3.9; -3.0; and -2.1, respectively)[2], which may make it difficult to service debt properly and reduce future economic growth. In addition, it is necessary that the increase in PD corresponds to the increase in the share of exports of goods and services in GDP, which is related to the purpose of public debt. If the expected growth in exports of goods and services fails to materialise, we can also expect increasing pressure on the foreign exchange market in the future.

The liberalisation of capital flows and the increasing softening of the domestic financial market have allowed a large inflow of foreign capital, while banks and domestic residents are increasingly investing in the purchase of domestic financial instruments. The optimal share of external debt in total PD is specific to each country. The decline in economic activity during the COVID-19 pandemic led to an increase in Serbia's external PD (debt/GDP ratio), which increased the risk of debt repayment. The cost of external government debt for emerging countries also increased due to the rise in risk premiums with the outbreak of the COVID-19 pandemic[3].

Rising public debt may lead to investors investing less in bonds denominated in local currency. This can lead to an increase in yields on domestic instruments, which has a negative impact on economic growth.

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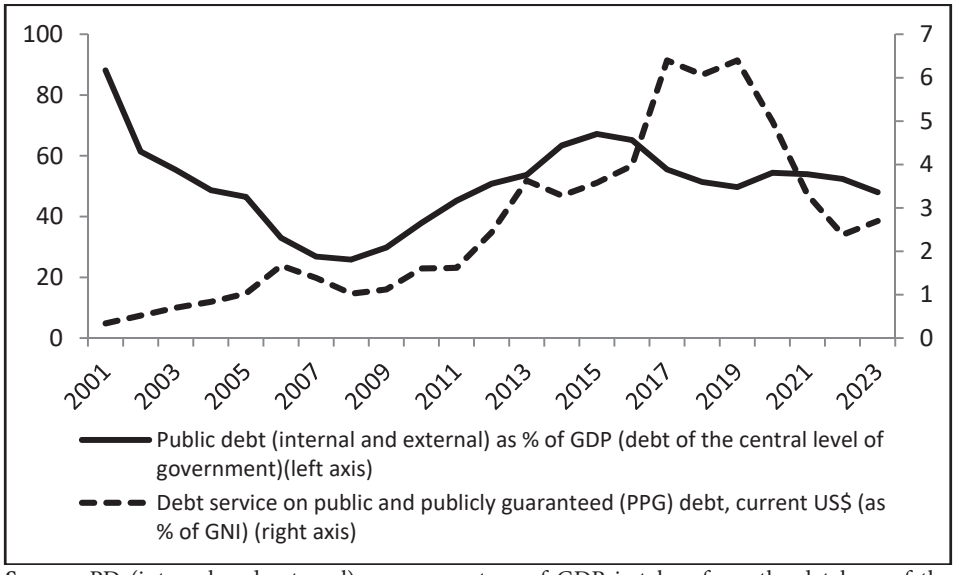
2 https://www.mfin.gov.rs/en/documents2-2/macroeconomic-and-fiscal-data2, accessed 05.01.2025.

3 Credit rating agencies have confirmed Serbia's creditworthiness for long-term foreign currency loans in 2024: **Standard and Poor's**, 04/05/2024 (BB+ / positive outlook), **Fitch Ratings**, 08/09/2024 (BB+ / positive outlook), **Moody's Investors Service**, 08/30/2024 (Ba2 / positive outlook). Despite the estimated positive outlook, the cost of borrowing in foreign currencies rose as investors perceived an increasing risk. On 4 October 2024 **Standard and Poor's** upgraded Serbia's credit rating to BBB-, which places Serbia in the investment grade category. The limited possibilities of borrowing on the insufficiently deep and liquid market for local currency bonds are prompting the central government to borrow in foreign currency. (https://nbs.rs/en/finansijsko_trziste/informacije-za-investitore-i-analiticare/kreditni_rejting/accessed 05.01.2025.

Figure 2: Public debt (internal and external, as % of GDP) and servicing of Serbia's public and publicly guaranteed debt (as % GNI), 2001–2023



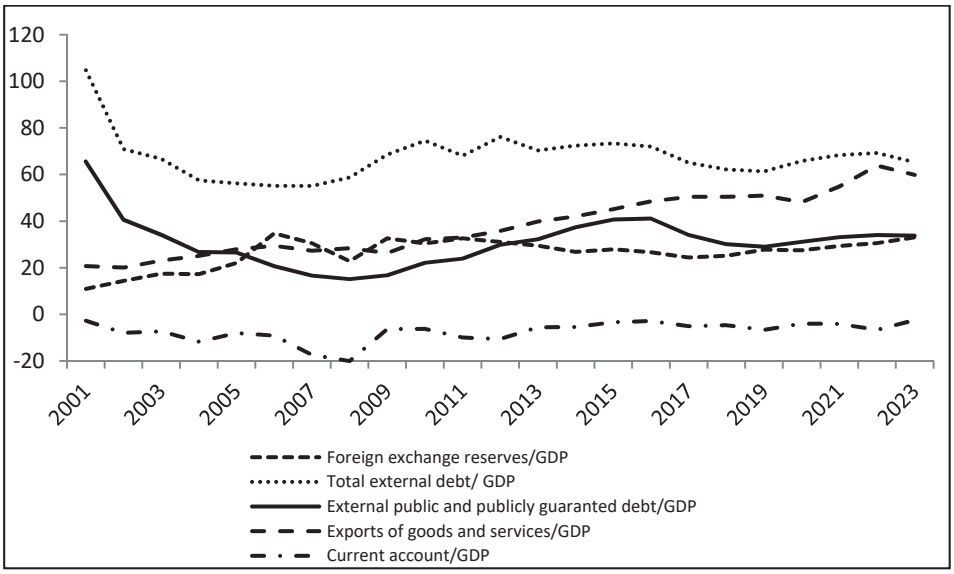
Source: PD (internal and external) as a percentage of GDP is taken from the database of the Ministry of Finance of the Republic of Serbia https://www.mfin.gov.rs/dokumenti2/makroekonomski-i-fiskalni-podaci; The data for debt service on public and publicly guaranteed debt, comes from the World Bank database: World Development Indicators, https://databank.worldbank.org/source/world-development-indicators. accessed 26/01/2025.

In contrast to public debt, which increased dynamically in the period following the global financial crisis of 2008–2009, the foreign exchange reserves of the National Bank of Serbia (NBS) (excluding the foreign exchange reserves of commercial banks) grew only slowly. As a result, the gap between these two macroeconomic aggregates widened until 2016. In 2007, the foreign exchange reserves were higher than Serbia's total public debt, and in 2023, the total PD was 11 billion euros higher than the foreign exchange reserves[4]. Since foreign exchange reserves are the guarantor of the proper servicing of external debt, it is important that their level instils confidence in foreign lenders. The trend of growth in foreign exchange reserves improved the performance of Serbia's

[4] The data on foreign exchange reserves are from the NBS (2024c), *Inflation Report* (November 2024), Table B, p. 71, and the data on public debt from the Ministry of Finance of the Republic of Serbia, https://www.mfin.gov.rs/en/documents2-2/macroeconomic-and-fiscal-data2, accessed 26/01/2025.

external liquidity, resulting in a ratio of foreign exchange reserves to imports of goods and services (in months) of 6.7 months in 2023. However, the current account deficit (CAD) to GDP ratio grew in the period 2001–2008 and reached 20% in 2008. Then this indicator declined and stood at 2.6% in 2023 (Figure 3). A continuous CAD requires borrowing abroad to cover it, which affects the accumulation of external debt.

Figure 3: Serbia's total external debt, public and publicly guaranteed external debt, exports of goods and services, foreign exchange reserves and current account balance (in % of GDP)



Source: Data on PD and GDP are from: https://www.mfin.gov.rs/en/documents2-2/macroeconomic-and-fiscal-data2 accessed on 26.01.2025. The data on foreign exchange reserves, exports of goods and services, and the current account are taken from the NBS (2006), *Inflation Report* (November 2006, data for the period 2001–2004); NBS (2024b), *Inflation Report* (May 2024, data for period 2005–2009; NBS (2024c*). Inflation Report* (November 2024, data for period 2010–2023).

The indicator for the ratio of public external debt to GDP of 33.1% in 2023 points to cautious further borrowing. This is because further growth in public external debt increases the risk of external liquidity in the event of a sudden reversal in capital flows. On the other hand, a reduction in central government debt is

unlikely in the coming period, especially if we take into account the stated investments related to Expo 2027.[5]

The growth of public debt service as a percentage of GDP in the period 2001–2019 (Figure 2) suggests that this indicator should be included as a variable in the analysis of the impact of Serbian PD on economic growth.

Our paper contributes to the existing literature by analysing the impact of Serbian PD on real GDP per capita growth (RGDP). To our knowledge, the impact of PD on RGDP in Serbia has not yet been widely discussed in the literature. Therefore, the contribution of this paper is to analyse and quantify the relationship between PD and RGDP and, on this basis, to show the possible consequences of an increase in PD. As the impact of public debt servicing (PDS) is also included in the analysis, it is possible to assess the impact of PD on RGDP more comprehensively.

The research question in this paper is whether Serbia's PD influences the RGDP in the short and long run and whether this influence is linear or non-linear.

The major findings of this study can be summarised as follows. The results of our empirical investigation using the non-linear autoregressive distributed lag (NARDL) method show that there is an asymmetric relationship between the PD and the RGDP of Serbia. The estimated long-run coefficient of the positive shock variable PD is negative and shows that a 1% increase in the PD-to-GDP ratio is associated with a 0.24% decrease in RGDP. On the other hand, a negative PD shock of 1% is associated with a 0.7% increase in RGDP. Both coefficients of the PD variable are lagged (-1). The observed asymmetric effects indicate that the stock of PD in Serbia has exceeded the threshold above which the contribution of additional public borrowing to RGDP decreases.

The estimated short-term coefficients also confirm the existence of an asymmetric relationship between positive and negative PD shocks and RGDP, with negative shocks having a stronger effect. This result also supports the

[5] Fiscal Council of Serbia (2024) estimates that Serbia's projected fiscal deficit of 3% of GDP for 2025 is relatively high and that the 2025 budget envisages a high level of public investment of 7.4% of GDP.

assumption that the stock of PD may have exceeded the threshold in PD. The estimated long-run coefficient of the PDS variable shows that a 1% increase in PDS is associated with a 0.17% decrease in RGDP at the first lag. Since the growth in the PD stock also entails an increase in service costs, the negative influence of this variable could increase in the future. Using the NARDL model, a positive relationship was found between CAD and RGDP, such that growth in CAD of 1% is associated with growth in RGDP of 0.27% at lag(-1). This result is to be expected, as CAD enables the transfer of foreign accumulation into the domestic economy, which leads to higher economic growth. The Granger causality test shows that there is a unidirectional Granger causality from PD to RGDP. The results of our study do not differ from the results of previous studies (Asteriou, et al., 2021; Gómez-Puig & Sosvilla-Rivero, 2015; Reinhart & Rogoff, 2010).

As Serbia's external PD has been growing more dynamically than its internal component since 2019 (Figure 1), a possible increase in interest rates on external PD would increase the negative impact on the RGDP. This would mean that more funds would have to be made available in the budget to service external PD. The results obtained indicate that special attention should be paid to the efficiency of PD funds in the coming period. If these funds are used to build high-quality institutions, improve the effectiveness of government, the quality of regulation and the provision of services to the private sector, it can be expected that PD will have a positive impact on RGDP. Higher investment in research and development (R&D) is necessary to improve the competitiveness of the economy[6].

It is important that the institutional environment has a stimulating effect on private investment by facilitating services to the commercial sector, controlling corruption and strengthening the rule of law. PD also offers the possibility of stabilising macroeconomic development in the event of disruptions, as was the case during the Covid-19 pandemic. It is important to avoid the risk of spending public money on infrastructure projects whose long-term contribution to economic growth is uncertain. It is also important that the level of PD is kept under control, as its accumulation can exceed the limit beyond which it becomes

[6] According to the OECD (2024, p.146), total investment in R&D in Serbia is at a low level (0.97% of GDP in 2022). At the same time, private sector participation in this type of investment is particularly low.

a major burden on normal debt servicing[7]. The results obtained in this study may also be useful for other Western Balkan countries with similar levels of public debt.

The rest of the paper is organised as follows. The second section provides an overview of previous research on the relationship between PD and RGDP, while the third section presents the data sources and outlines an econometric model. The fourth section discusses the results obtained. The final fifth section contains the conclusions derived from the most important results and the policy implications. Additional results are presented in the appendix.

2. LITERATURE REVIEW

The published works on this topic can be divided into two groups. One contains research findings in which there is no clearly defined threshold (PD as a percentage of GDP) that separates the positive from the negative effects of PD on economic growth. The second group comprises papers in which this threshold has been calculated. First, we present the results of papers that fall into the group without a clearly defined threshold. Calderón and Fuentes (2013) used a large sample of 136 countries from 1970 to 2010 to analyse whether PD promotes or hinders economic growth and whether economic policy mitigates this effect. The authors came to the conclusion that there is a negative relationship between PD and growth. They also concluded that an export-orientated economic policy can help to reduce this negative effect. Siddique et al. (2016) used an ARDL (autoregressive distributed lag) model to investigate whether the debt ratio affects the economic growth of 40 indebted countries in the period 1970–2007. The control variables in the model were trade, population and capital formation. The authors found that debt has a negative impact on economic growth, with the analysed short- and long-run coefficients being statistically significant. According to the authors, a higher level of debt ties an increasing proportion of production to the repayment of foreign loans, which acts as a barrier to investment.

[7] If public debt exceeds a sustainable level, it can become a generator of instability and a limiting factor for economic growth (Krugman, 1988).

Lim (2019) examines the relationship between total debt (private and public) and economic growth in a sample of 41 countries from 1952 to 2016 using a vector autoregression model (VAR), where the panel VAR is estimated using the generalised method of moments (GMM). The results show that there is a negative relationship between total debt and economic growth, with a one standard deviation change leading to a 0.2% decline in economic growth. By introducing exogenous variables into the system, the author obtained robust results. Asteriou et al. (2021) examine the relationship between PD and economic growth in the short and long run using 14 Asian countries for the period 1980–2012. The authors used the ARDL model and a mean group (MG) estimator to achieve heterogeneity in the short and long run relationship of the observed variables. Average educational age, trade openness and investment were included in the model as control variables. The authors calculated that a 1 percentage point increase in government debt relative to GDP leads to a decrease in economic growth of 0.012 to 0.125 percentage points. Based on these results, the authors came to the conclusion that the increase in PD has a significantly negative effect on economic growth.

Ghourchian and Yilmazkuday (2020) compared the impact of government spending and PD on economic growth in 83 countries between 1960 and 2014 using a two-stage least squares method with the usual control variables as in other studies. According to the results of these authors, a 1 percentage point increase in the ratio of government debt to GDP leads to a decrease in real GDP growth of about 0.01 percentage points, while a 1 percentage point increase in the ratio of government spending to GDP leads to a decrease in real economic growth of about 0.1 percentage points, on average, across the countries in the sample. The authors point out that it is more important for countries with greater trade openness to prevent negative effects on economic growth by limiting government debt. Pegkas et al. (2020) investigated the impact of PD on economic growth of 12 Eurozone countries for the period from 1995 to 2016. The study analyses time series and applies a fully modified least squares approach, with control variables such as investment, human capital and trade openness. The results show that government debt has a long-run impact on economic growth. There is a long-run unidirectional causality from investment, trade openness and human capital to economic growth and a bidirectional causality between PD and economic growth. Based on the results obtained, the authors recommend that Eurozone countries

should base their growth strategies on fiscal consolidation, increasing exports, correcting the use of public investment and improving the quality of human capital, particularly in higher education.

Ješić (2023) analyses the potential determinants of GDP growth in a sample of 19 selected European countries from Central, Eastern and South-Eastern Europe in the period from 2014 to 2020. Using dynamic panel data modelling, the results of the model show that fiscal responsibility is one of the most important determinants of GDP growth. The author found that the effect of PD was small but significant for the observed sample of countries. He also found that PD has a negative effect on GDP growth in the observed countries, although the values of the obtained coefficients were not high in all specifications. The findings of his study support the conclusions of previous studies, according to which the threshold above which PD has a negative effect on economic growth is certainly lower in emerging countries. The second variable from the fiscal corpus – the structural budget balance – contributes significantly to economic growth in all specifications of the model used. According to the author, this result confirms the importance of the hypothesis that fiscal responsibility contributes significantly to GDP growth. Arsić et al. (2021) analysed the impact of PD uncertainty on economic growth for 10 emerging European economies in the period 2000–2015. Empirical analyses using time series and panel data approaches showed that PD uncertainty has a significant negative impact on GDP growth in these economies. This was especially the case during the 2008 recession.

We mention several studies that have identified a threshold as a turning point beyond which the growth of PD has a detrimental effect on economic growth. Reinhart and Rogoff (2010) conducted a thorough analysis of the relationship between debt and economic growth. The analysis was carried out on a sample of 44 countries. The findings of their study show that a high PD-to-GDP ratio (90% or more) (in both advanced and emerging economies) is associated with weaker economic growth. It was found that countries with a debt-to-GDP ratio of more than 90% have about 1.5 percentage points lower economic growth than the group of less indebted countries. Afonso and Jalles (2013) found a negative relationship between debt and economic growth in a sample of 155 countries for the period from 1970 to 2008. An increase in the debt-to-GDP ratio of 10 percentage points impairs economic growth by -0.2 percentage points for

countries with a debt-to-GDP ratio of over 90%. The authors find an endogenous threshold for the debt ratio at 59% of GDP for the entire sample. Padoan et al. (2012) examine the impact of fiscal policy on the growth path of the economy for 28 OECD countries from 1960 to 2011. The authors used a GMM instrumental variable estimation and investigated the existence of a threshold effect found between 82 and 91% of GDP. Namely, their findings show that an increase in PD by 1 percentage point on average reduces GDP growth in the next year by 0.012 percentage points, while average annual growth over the next five years decreases by 0.028 percentage points.

Égert (2015) uses a similar data set to Reinhart and Rogoff (2010) and applies an econometric test to examine whether PD has a negative non-linear effect on economic growth when PD exceeds 90% of GDP. Using a multivariate growth framework and Bayesian model averaging on a sample of 44 industrialised countries for the period 1960 to 2010, the author finds a positive relationship between debt and economic growth at low debt levels, while negative effects occur at higher debt levels. The study finds that the negative non-linear effect occurs at much lower levels of PD (between 20% and 60%), in contrast to most studies, where the negative effect occurs at a threshold of 60% to 100% of GDP. The authors point out that public investment can generate high returns at low levels of debt.

Baum et al. (2012) analyse the relationship between PD and economic growth. In their study, a dynamic threshold panel method is used to analyse the non-linear effects of PD on GDP growth. The sample consists of 12 Eurozone countries for the period 1990–2010. The empirical results indicate that the short-term impact of debt on GDP growth is positive and highly statistically significant, but declines to zero and becomes less significant beyond a PD ratio of around 67% of GDP. Debt above this ratio has a negative impact on economic activity. These authors also find that the long-term interest rate is subject to increased pressure when the PD-to-GDP ratio is above 70%. Woo and Kumar (2015) analyse the impact of high PD on long-term economic growth and the existence of threshold effects. The analysis is based on a panel of countries with almost 40 years of data. The results of the study show that a 10-percentage point increase in the initial debt-to-GDP ratio is associated with a slowdown in per capita GDP growth of about 0.2% per year. The study finds evidence of non-linearity, with only high debt

levels (above 90% of GDP) having a significant negative impact on economic growth. The authors conclude that the negative effect is reflected in the slowdown in labour productivity growth, which is mainly due to slower capital accumulation. Comprehensive robustness tests confirm the results.

Saloti and Trecroci (2016) analysed panel fixed effects for the period from 1970 to 2009 for a sample of 20 OECD countries using the system GMM estimator. The paper provides weak evidence for the existence of a threshold at 85–90% of GDP. The average country in the sample had an elasticity of investment to debt/GDP ratio of up to -0.10 at a debt level of 54%. Swamy (2020) uses the Solow growth model and estimates panel data growth regressions with country fixed effects and time fixed effects. The author uses a two-stage GMM estimator for a large data set for 252 countries from 1960 to 2009. The results show that there is a negative relationship between PD and growth. The econometric specification suggests that a 10-percentage-point increase in the debt ratio is associated with a 23-basis-point decline in average growth. These results are consistent with those of other studies (Afonso & Jalles, 2013; Woo & Kumar, 2015). The results of the study show that debt has a positive impact on growth for countries with debt below 60% of GDP, while the impact in the zone between 60 and 90% is negligible, while above 90% there is a sharp decline in economic growth.

Bentour (2021) analyses the relationship between PD and economic growth in a sample of 20 industrialised countries over the period 1880–2010 using the regression kink model with an unknown threshold proposed by Hansen (2017). Bentour shows that the relationship between PD and economic growth varies over time and is country specific. In particular, the relationship between PD and economic growth is volatile for each country in the sample over the entire period 1880–2010 and the post-war period 1950–2010 and is subject to data and country heterogeneities. These findings refute the existence of a common threshold that applies to all countries and call for more theory-based models that take into account the fundamentals that differ across countries and influence the interactions between debt and growth.

Andrić et al. (2016) analysed the development of the primary fiscal balance and PD in Serbia in the period 2004Q3–2014Q3. They conclude that the ratio of PD to GDP exhibits the behaviour of a (near) unit root with a general growth trend,

i.e. that the development of the PD-to-GDP ratio was not sustainable in the observed period.

3. DATA AND ECONOMETRIC METHODOLOGY

3.1 Data sources and description

In analysing the impact of PD on Serbia's economic growth, this paper uses annual time series data over the period 2000–2023 taken from the World Development Indicators (WDI) database of the World Bank, the Ministry of Finance of the Republic of Serbia and the National Bank of Serbia (NBS). The description and sources of the variables used can be found in Table 1.

Table 1: Definition of the variables and data sources

Variable	Description	Source
Real GDP per capita growth (RGDP)	GDP per capita growth (annual %)	World Development Indicators (World Bank, 2024)
Public debt (PD)	General government gross debt (% of GDP)	Ministry of Finance of the Republic of Serbia (2024)
Public debt service (PDS)	Public and publicly guaranteed debt service (% of GNI)	World Development Indicators (World Bank, 2024)
Current account (CA)	Current account balance (% of GDP)	World Development Indicators (World Bank, 2024)
Gross domestic savings (GDS)	Gross domestic savings (% of GDP)	World Development Indicators (World Bank, 2024)
Foreign direct investment, net inflows (FDI)	Foreign direct investmnet, net inflows (% of GDP)	World Development Indicators (World Bank, 2024)
Gross fixed capital formation (GFCF)	Gross fixed capital formation (% of GDP)	World Development Indicators (World Bank, 2024)

Note: Data for net foreign direct investment inflows for the period 2001–2006 are from the National Bank of Serbia, Balance of Payments 1997–2006 (NBS, 2024a); Data for current account for the period 2001–2006 are from the National Bank of Serbia (*Inflation Report*, November 2008, table B, p. 58). Data for PD as a percentage of GDP is taken from the database of the Ministry of Finance of the Republic of Serbia (2024).

Source: Author.

The variables selected are consistent with those commonly used in the literature to analyse the relationship between PD and RGDP (Checherita-Westphal & Rother, 2010; Kumar & Woo, 2010). In the empirical work published to date, there are mixed findings on the relationship between PD and RGDP. Several authors argue in favour of a negative relationship between PD and real GDP growth, especially above a certain threshold (Afonso & Jalles, 2013; Égert, 2015; Law et al., 2021; Liu & Lyu, 2020; Pattillo et al., 2002; Reinhart & Rogoff, 2010). In other studies, particularly those analysing the development of emerging economies, the results show a positive relationship between real GDP growth and PD (Fincke & Greiner, 2014). Based on numerous studies, it can be assumed that this relationship is specific to each country. In our study, we analyse the impact of Serbia's PD on RGDP.

A summary of the descriptive statistics of the variables used in our study can be found in Table A2 in the Appendix. The descriptive statistics show that all variables, with the exception of FDI, are normally distributed based on the Jarque–Bera statistics. The mean value of the PD variable is 3.9 and is therefore half the magnitude of the mean value of the RGDP, which indicates a high level of public debt. The maximum PD value of 4.5 draws attention to jumps in Serbia's PD in individual years. The maximum value of FDI of 2.5 and the minimum value of 1.7 also indicate an uneven dynamic of net inflows of foreign direct investment. The existence of outliers in some time series can be a hint of a structural break in the series, which we will check using unit root tests with breakpoint.

3.2 The econometric methodology

To analyse the relationship between PD and economic growth in Serbia, the following regression equation was estimated for the period 2001–2023:

$$\text{LogRGDP}_t = \alpha_0 + \beta_1\text{LogPD}_t + \beta_2\text{LogPDS}_t + \beta_3\text{LogCA}_t + \beta_4\,\text{LogGDS}_t + \beta_5\text{LogX}_t + \varepsilon_t \qquad (1)$$

Here Log denotes natural logarithm. $LogRGDP_t$ is a dependent variable corresponding to log real GDP per capita growth, as the usual approximation for real GDP growth. The regression equation includes several explanatory variables: α is a constant, ε_t represents the error term, $LogPD_t$ is the log of PD (% of GDP), $LogPDS_t$ is the log of public and publicly guaranteed debt service (% of GNI), $LogCA$ is the log of the current account (% of GDP), $LogGDS_t$ is the log of gross

domestic savings (% of GDP), and $LogX_t$ contains the control variables $LogFDI_t$, the log of net foreign direct investment inflows (% of GDP), and *LogGFCF*, the log of gross fixed capital formation (% of GDP). The variables included in the regression equation are also significant factors influencing Serbia's economic growth, so their inclusion can contribute to a more accurate separation of the impact of PD on economic growth. The CA balance is included as an explanatory variable because the continuous CA deficit (CAD) in the macroeconomic sense means the transfer of foreign accumulation, which can contribute to the acceleration of economic growth and development of the country. The net inflows of FDI to Serbia also partially contribute to productive investment and exports, which certainly has an impact on economic growth. The growth of domestic savings as a precondition for domestic private sector investment can significantly boost investment demand and thus economic growth. These are the reasons for including these variables in the regression analysis as control variables.

The empirical analysis applied in this paper is based on the bounds testing approach to cointegration (the linear ARDL approach to cointegration), in line with the recommendations in Cho et al. (2015). We also apply the NARDL to test whether Serbia's PD has an asymmetric impact on GDP growth. In contrast to the traditional ARDL models, which show a symmetric change in the dependent variable in response to changes in the independent variable, the NARDL model is able to separate asymmetric effects from changes in the independent variable on the dependent variable, if such effects exist. The NARDL framework proposed by Shin et al. (2014) is a model in which short-run and long-run nonlinearities are estimated as positive and negative sums of the changes in the explanatory variables.

ARDL models applied to cointegration are more efficient in identifying long-run relationships between variables on smaller samples, from 30 to 80 observations, compared to other cointegration methods, and provide good results regardless of whether the variables are stationary I(0) or I(1) or mutually cointegrated (Pesaran et al., 2001). It must first be established that the variables in the model are not integrated of order I(2). If this condition is met, we can apply the NARDL model in error correction (EC) form:

$$\Delta y_t = -\phi ECA_t + \sum_{j=1}^{p-1} \gamma_j \Delta y_{t-j} + \sum_{r=1}^{k} \left(\eta_r^+ \Delta x_{r,t}^+ + \eta_r^- \Delta x_{r,t}^-\right) + \sum_{r=1}^{k} \sum_{j=1}^{p_r^-} \left(\delta_{r,j}^+ \Delta x_{r,t-j}^+ + \delta_{r,j}^- \Delta x_{r,t-j}^-\right) + \sum_{i=1}^{m} \alpha_0 d_{i,t} + \epsilon_t, \quad (2)$$

where *ECA* is the asymmetric equilibrium error correction term defined as: $\sum_{j=1}^{p_r^-} \left(\delta_{r,j}^+ \Delta x_{r,t-j}^+ + \delta_{r,j}^- \Delta x_{r,t-j}^-\right) + \sum_{i=1}^{m} \alpha_0 d_{i,t} + \epsilon_t$.

$$ECA_t = y_{t-1} - \sum_{r=1}^{k} \left(\frac{\lambda_r^+}{\phi} x_{r,t-1}^+ + \frac{\lambda_r^-}{\phi} x_{r,t-1}^-\right), \quad (3)$$

where ϕ represents the error correction parameter, while λ_r^+ / ϕ and λ_r^- / ϕ for $r = 1,\ldots, k$ are the long-term equilibrium parameters for the explanatory variables, while $\eta_r^+, \eta_r^-, \delta_{r,j}^+, \delta_{r,j}^-$ represent short-run parameters for the explanatory variables.

Starting from the variables we use in our study, we can present the traditional (symmetric) ARDL model as:

$$\Delta LogRGDP_t = \beta_0 + \beta_1 LogRGDP_{t-1} + \beta_2 LogPD_{t-1} + \beta_3 LogPDS_{t-1} + \beta_4 LogCA_{t-1} + \beta_5 LogGDS_{t-1}$$

$$+ \sum_{i=1}^{p} \beta_6 \Delta LogRGDP_{t-i} + \sum_{i=0}^{q} \beta_7 \Delta LogPD_{t-i} + \sum_{i=0}^{r} \beta_8 \Delta LogPDS_{t-i} + \sum_{i=0}^{s} \beta_9 \Delta LogCA_{t-i} + \sum_{i=0}^{m} \beta_{10} \Delta LogGDS_{t-i} + u_t \quad (4)$$

Since in our study we also examine the asymmetric impact of *LogPD* on *LogRGDP*, this implies the introduction of positive and negative (PD_t^+ and PD_t^-) changes in *LogPD*. In this way, a partial decomposition of the variable PD_t is performed around the threshold PD_0, so that we get partial sums of values above and below this specific threshold, which represents the initial value of *LogPD*:

$$PD_t^+ = \sum_{i=1}^{t} \Delta PD_t^+ = \sum_{i=1}^{t} max(PD_i, 0) \quad (5)$$

$$PD_t^- = \sum_{i=1}^{t} \Delta PD_t^- = \sum_{i=1}^{t} min(PD_i, 0)$$

Equation (3) can be rearranged in the NARDL model, taking into account the aforementioned asymmetry in the PD variable:

$$\Delta LogRGDP_t = \beta_0 + \beta_1 LogRGDP_{t-1} + \beta_2 LogPD^+_{t-1} + \beta_3 LogPD^-_{t-1} + \beta_4 LogPDS_{t-1} + \beta_5 LogCA_{t-1} + \beta_6 LogGDS_{t-1} + \sum_{i=1}^{p} \beta_7 \Delta LogRGDP_{t-i} + \sum_{i=0}^{q} \beta_8 \Delta LogPD^+_{t-i} + \sum_{i=0}^{k} \beta_9 \Delta LogPD^-_{t-i} + \sum_{i=0}^{r} \beta_{10} \Delta LogPDS_{t-i} + \sum_{i=0}^{s} \beta_{11} \Delta LogCA_{t-i} + \sum_{i=0}^{m} \beta_{12} \Delta LogGDS_{t-i} + u_t, \quad (6)$$

where $\Delta LogRGDP_t$ is the dependent variable, $LogPD^+_{t-1}$, $LogPD^-_{t-1}$, $LogPDS_{t-1,}LogCA_{t-1,}$and $LogGDS_{t-1}$ are explanatory variables, β are coefficients of short-term and long-term dynamics and u_t is a random error. Δ is the first difference of the variables. The first part of the model represents the long-term relationship between the dependent variable and the explanatory variables, while the second part shows the short-term relationships between the variables. All regression models contain the variable *DAMMY*, which models the structural break in the RGDP series.

In contrast to the traditional cointegration tests proposed by Engle and Granger (1987), Phillips and Ouliaris (1990) or Johansen (1995), which assume that all variables in the VAR system are I(1), Pesaran et al. (2001) propose a cointegration test that is robust regardless of whether the variables are I(0), I(1) or mutually cointegrated. These bound tests are formulated as standard *F*-tests or Wald tests of the significance of parameters in the cointegration relationship of the conditional error correction (CEC) model for the following null and alternative hypotheses:

$H_0: \{\emptyset, \lambda_{1\ldots,}\lambda_k\} = 0,$

$H_1: \{\emptyset, \lambda_{1\ldots,}\lambda_k\} \neq 0.$

Pesaran et al. (2001) introduced critical values for the *F*-statistic (critical value bounds for the null hypothesis that there is no level relationship between the dependent variable and the regressors in the conditional error correction regression [CEC] mode – the lower bound is calculated assuming that all model variables are stationary in level, while the upper bound is based on the assumption that all series are stationary at the first difference). If the calculated value of the *F*-statistic is below the critical value of the lower bound, the null hypothesis cannot

be rejected, i.e. there is no cointegration between the variables. If the calculated value of the *F*-statistic is greater than the upper critical value, the null hypothesis that there is no level relationship is rejected, regardless of whether the integration level of the variable is I(0) or I(1). If the estimated *F*-statistic lies between the upper and lower critical values, the *F*-test is not meaningful, so that the test must be continued by determining the cointegration rank. If all variables are integrated I(1), the decision is made on the basis of the upper bound. If the variables are integrated with the order I(0), the decision is made on the basis of the lower bound. Before estimating the ARDL model, we check the level of integration of the time series used in the model. It is important to note that no variable in the model is I(2).

Since none of the time series in our study are of integration order I(2), we estimate the ARDL model and its NARDL variant. We apply diagnostic tests for specification, autocorrelation and stability of the selected models. We use the Ramsey RESET test and the test for omitted variables to check whether the regression equation is well specified. Then we use the standard Breuch–Godfrey Serial Correlation LM test to check for the presence of autocorrelation, while we use the CUSUM and CUSUMQ test of recursive residuals to assess the stability of the model (Brown et al., 1975). According to these tests, the parameters of the equation are stable if the calculated cumulative sum of the recursive residuals is within the critical limits of the interval (the critical line of 5%). To check whether there is heteroscedasticity of the residuals in the analysed model, we apply the Breusch–Pagan–Godfrey heteroscedasticity test. When estimating the NARDL model, we use the NARDL coefficient symmetry tests to check whether the explanatory variables have an asymmetric influence on the dependent variable. If the absence of autocorrelation and heteroscedasticity of the residuals in the analysed model and the stability of the model parameters are established, the presence of cointegration is checked according to the procedure described above. If there is cointegration between the variables of the model, we check whether the long-run coefficients of the estimated cointegration equation are statistically significant. Then we will estimate the speed of adjustment to equilibrium in the cointegration equation using the ARDL and NARDL error correction regression. The error correction term is one of the regressors of the ARDL and NARDL error correction regression and represents the speed of adjustment to equilibrium in each period.

4. EMPIRICAL RESULTS AND DISCUSSION

In order to check the stationarity of the time series, a modified Augmented Dickey–Fuller (ADF) test adjusted for series with structural breaks (Peron, 2006) was used in this study. A version of the ADF test in which the existence of a structural break is assumed both in the cross-section and in the trend of the time series was used. The results of the unit root tests are presented in Table A1 in the Appendix and show that all variables of the applied models are stationary either at the level or in the first difference, confirming that the ARDL approach is appropriate for our study. The variables *LogRGDP*, *LogGDS* and *LogFDI* are stationary at the level, while the other variables are stationary in the first difference. Thus, it has been confirmed that none of the variables in the regression equation is integrated with order I(2). The unit root test detected a break for the RGDP variable in 2008. Therefore, when estimating the regression models, we introduced a dummy variable that has the value 0 for the period before 2008 and the value 1 for 2008 and other observations. The structural break in the data for *LogPD* is also in 2008 according to the unit root test. When we look at the untransformed *LogPD* series, we also find that the structural break in the series occurred in 2008.

In the next step, we will estimate the ARDL and NARDL models. One lag for the dependent variable RGDP and two lags for the explanatory variables were used in the estimation, and the optimal model was selected according to the Akaike information criterion (AIC). We tested the dynamic stability properties of the variables using the break-unit root test and found that the ARDL model and its nonlinear extension (NARDL) were appropriate for our study. Using the NARDL model, we test whether the Serbian PD variable has an asymmetric effect on RGDP growth. In the study, we formed three regression models: one estimated using the ARDL approach (Model 1), the second based on the NARDL approach (Model 2), and the third model testing the robustness of the estimated NARDL model (Model 3). All three models contain the same set of variables, with an additional variable (gross fixed capital formation – GFCF) included as a control variable in the NARDL-ROBUST model. The ARDL and NARDL models were estimated for the period 2001–2023, while the third model (NARDL-ROBUST) was estimated for the period 2008–2023. The task of the NARDL-ROBUST model is to check the robustness of the estimated NARDL model for the entire time sample. Therefore, an additional explanatory variable was included in this model

and the observation period was shortened to 2008–2023. To check the robustness of the results for the NARDL, the period after the structural break in the PD series in 2008 (according to the unit root test in first difference) was analysed, and 2008 was also the time of the break for the RGDP variable. After the break in the PD data in 2008, there is a strong increase in PD relative to GDP. Diagnostic tests were performed for all three models (Table 2).

Table 2: Specification tests of the ARDL, NARDL, and NARDL-ROBUST models

Model specification	**Model 1**	**Model 2**	**Model 3**
Sample period	2001–2023		2008–2023
Lag of variable	ARDL (1,1,2,1,2)	NARDL (1,2,2,2,2)	NARDL-ROBUST (2,1,1,1,1,1)
Akaike info criterion	-4.82	-7.21	-8.93
Model specification tests	**Model 1**	**Model 2**	**Model 3**
	***p*-value**		
JB test for normality of the residuals, null hypothesis: the data follow a normal distribution	0.7301	0.3430	1.0573
Breusch-Godfrey Serial Correlation LM test, null hypothesis: no serial correlation at up to 2 lags	0.7966	0.5018	0.6058
Breusch-Pagan-Godfrey heteroscedsticaly test, null hypothesis: homoscedasticity	0.6343	0.9982	0.7187
Omitted variables test, null hypothesis: *LogFDI*, *LogGFCF* are jointly insignificant*	0.0746	0.6937	0.3656
Ramsey RESET test, null hypothesis: model is correctly specified	0.4489	0.5770	0.1128

CUSUM test	Correctly specified at 5% significance	Correctly specified at 5% significance	Correctly specified at 5% significance
CUSUM of squares test	Correctly specified at 5% significance	Correctly specified at 5% significance	Correctly specified at 5% significance
Coefficient symmetry test – long-run for *LogPD* variable** null hypothesis: coefficient is symmetric		0.0552	0.0198
Coefficient symmetry test – short-run for *LogPD* variable** null hypothesis: coefficient is symmetric		0.0685	

Note: *For NARDL and NARDL-ROBUST included *LogFDI* as additional explanatory variable, null hypothesis is: *LogFDI* is not significant. ** Only for NARDL and NARDL-ROBUST model.
Source: Author

Based on the diagnostic tests in Table 2, all three models fulfil the assumptions of a correct model specification (the residuals are normally distributed, not autocorrelated and the assumption of homoscedasticity is fulfilled). The test for omitted variables and the Ramsey test confirm that the models are correctly specified. The CUSUM test and the CUSUM of squares test also confirm the stability of all three models, i.e. that all models are well specified. The symmetry test for the PD variable (long-run and short-run) for the NARDL model shows that it is asymmetrically associated with RGDP, while the same variable in the NARDL-ROBUST model has an asymmetrical relationship with RGDP in the long run, but a symmetrical one in the short run (The test for asymmetry should show whether positive and negative effects are the same, symmetrical, or different, asymmetrical).

After performing the diagnostic tests, we tested the existence of a long-term relationship (cointegration) between the dependent variable and the independent variables in all three models. The results of the cointegration test are shown in Table 3.

Table 3: Cointegration test of variables in ARDL, NARDL and NARDL-ROBUST model

	Model 1		**Model 2**		**Model 3**	
Lag of variable	ARDL (1,1,2,1,2)		NARDL (1,2,2,2,2)		NARDL-ROBUST (2,1,1,1,1,1)	
F-statistic	10.64203		27.42279		47.78103	
t-statistics	-6.188152		-9.426854		-8.87630	
Critical bounds	**I(0)**	**I(1)**	**I(0)**	**I(1)**	**I(0)**	**I(1)**
F-statistic						
Sample size	30	30	30	30	30	30
10%	2.752	3.994	2.578	3.858	2.457	3.797
5%	3.354	4.774	3.125	4.608	2.970	4.499
1%	4.768	6.670	4.537	6.370	4.270	6.211
***t*-statistic**						
Sample size	Asympt.	Asympt.	Asympt.	Asympt.	Asympt.	Asympt.
10%	-2.570	-3.660	-2.570	-3.860	-2.570	-4.040
5%	-2.860	-3.990	-2.860	-4.190	-2.860	-4.380
1%	-3.430	-4.600	-3.430	-4.790	-3.430	-4.990

Note: Null hypothesis: No levels relationship.

Source: Author.

The results of the *F*-bounds test in Table 3 show that the calculated *F*-statistic is significantly higher than the upper bound critical value I(1) at the 1% level, which means that the null hypothesis that there is no level relationship can be rejected in all three models and confirms the existence of a cointegration relationship between the dependent variable (*LogRGDP*) and the observed explanatory variables.

After performing the ARDL, NARDL and NARDL-ROBUST *F*-bound test, we estimated the long-run (equilibrium) coefficients in the cointegration relationship. The results can be found in Table 4.

Table 4: Long-run regressors of the cointegration equation (dependent variable: RGDP)

Independent variable		**Model 1**	**Model 2**	**Model 3**
Variable lags		ARDL (1,1,2,1,2)	NARDL (1,2,2,2,2)	NARDL-ROBUST (2,1,1,1,1,1)
LogPD(-1)	Coefficient	0.017173		
	Std. Error	0.035080		
	p-value*	0.6376		
$LogPD^{+}$(-1)	Coefficient		-0.247286	-0.440055
	Std. Error		0.063389	0.063081
	p-value*		0.0599	0.0199
$LogPD^{-}$(-1)	Coefficient		0.703311	0.078408
	Std. Error		0.181762	0.025020
	p-value*		0.0608	0.0885
LogPDS	Coefficient			
	Std. Error			
	p-value*			
LogPDS(-1)	Coefficient	-0.003126	-0.178352	-0.041797
	Std. Error	0.026922	0.038841	0.007916
	p-value*	0.9104	0.0443	0.0340
LogCA(-1)	Coefficient	-0.000840	0.266483	0.231259
	Std. Error	0.032646	0.060211	0.040396
	p-value*	0.9801	0.0474	0.0292
LogGDS	Coefficient			
	Std. Error			
	p-value*			
LogGDS(-1)	Coefficient	-0.017926	0.857092	0.642610
	Std. Error	0.038723	0.200920	0.097238
	p-value*	0.6557	0.0508	0.0221
LogGFCF(-1)	Coefficient			0.096491
	Std. Error			0.036800
	p-value*			0.1199

Note: **p*-values do not account for model selection.

Source: Author.

In the context of the ARDL and NARDL models in our study, "long-run" should be interpreted as the average change over the sample period, while "short-run" refers to a period of one year. The estimates of the long-run coefficients can be found in Table 4. The coefficients in Model 1 are not statistically significant, indicating that the ARDL methods could not demonstrate a long-run relationship between PD and RGDP. In contrast to the ARDL approach, the application of the NARDL methodology provides statistically satisfactory results. Therefore, we will analyse the results of the NARDL model in more detail. As we have already seen, NARDL makes it possible to separate the influence of the explanatory variable on the dependent variable by showing the influence of positive and negative changes in the explanatory variable on the dependent variable separately. In our study, the influence of positive and negative PD shocks on RGDP was separated using the NARDL approach. The estimated coefficient for the positive PD shock of -0.247 is statistically significant at the level of 0.06 (less than 10% and slightly more than the usual 5%). This means that a positive shock to PD of 1% is associated with a decrease in RGDP of 0.25%. The estimated coefficient of the negative shock to PD of 0.70 is also statistically significant at the 0.06 significance level, which means that a negative PD shock of 1% is associated with an increase in RGDP of 0.7%. These coefficients show that the positive relationship between the reduction in the PD-to-GDP ratio and RGDP is stronger than the negative relationship in the case of an increase in PD. This discrepancy confirms that there is a non-linear relationship between PD and RGDP. Our empirical results are in line with the findings of other studies, such as Woo and Kumar (2015) and Reinhart and Rogoff (2010). The impact of an unexpected increase in PD on RGDP depends on the initial level of PD. Previous studies show that an unexpected increase in PD has a greater negative impact on growth in countries with a higher initial debt level (de Soyres et al., 2022, p. 12, Figure 4). Since the stock of external PD of Serbia rose after the COVID-19 pandemic, the country is sensitive to changes in the conditions for new external borrowing. Possible interest rate shocks can increase external debt burden and restrict fiscal space (Brunnermeier & Reis, 2023). The problems can be very serious if a potential external financial crisis leads to a withdrawal of foreign capital from the country.

The long-run impact of PDS on RGDP is negative (the estimated long-run coefficient in the NARDL approach, in lag(-1), is -0.17 and is statistically significant at the 5% level) and shows that growth in the stock of PD is

accompanied by an increase in PDS. An unexpected increase in interest rates could increase the burden of PDS, which would have a negative impact on RGDP. Using the NARDL model, a positive relationship was found between CAD and RGDP, such that growth in CAD of 1% is associated with growth in RGDP of 0.27% for lag(-1). The result is consistent with the theoretical expectation that the transfer of foreign accumulation, expressed by CAD, can stimulate the economic growth and development of the country. This can be seen in cases where CAD is used to finance investment, equipment imports and to improve the investment climate. The estimated long-run coefficient of the GDS variable is also statistically significant at the 5% significance level and shows that a 1% increase in GDS is associated with a 0.86% increase in RGDP. This result is also consistent with the theoretical expectation that growth in savings opens up the possibility of growth in private investment, with the expected positive effects on economic growth. However, if domestic PD continues to grow, the positive contribution of GDS to RGDP could decline. A higher absorption of GDS by the government reduces the amount of GDS that can be used to finance the private sector. This may also lead to an increase in domestic interest rates as crowding out occurs.

In order to check the robustness of the NARDL model analysed, Model 3 was estimated of the sample period being shortened to 2008–2023 and a control for the GFCF variable being introduced. It was previously shown that there was a structural break in the RGDP and PD series in 2008. The estimated coefficient of the parameter for the positive PD shock is -0.44 and is statistically significant at the 5% level. This means that a 1% increase in PD leads to a decrease in RGDP of 0.44, which is almost double the magnitude of the decrease observed in the entire period 2001–2023. The estimated coefficient of a negative PD shock of 0.08 is statistically significant at a level of 10% and shows that a negative PD shock of 1% is associated with 0.08 growth in RGDP. The movement of these coefficients with the PD variable shows that in the period after 2008, the influence of PD on the slowdown in RGDP increased. This is to be expected considering that there was dynamic growth in PD after 2008. The other explanatory variables in Model 3 show the same direction of influence on RGDP as in the NARDL model. The estimated control variable GFCF in Model 3 is not statistically significant, so its introduction as an explanatory variable had no effect on the change in conclusions based on the estimated NARDL model. It can therefore be concluded that Model 3 confirms the robustness of the results of the NARDL model estimated.

Table 5 shows the short-term coefficient estimates for all three models. In contrast to the long-run coefficients of the estimated ARDL model, which are not statistically significant, the short-run coefficient of the PB variable is statistically significant at the 1% significance level and shows that an increase in PD of 1% is associated with a decrease in RDGP of 0.2%, with the other terms remaining unchanged. In the short term, i.e. within one year, PDS growth also had a negative impact on RGDP: an increase of 1% in PDS is associated with a decrease of 0.03% in RGDP. Although the influence of PDS on RGDP is not strong according to this assessment, the negative coefficient shows that this variable has the potential to slow down RGDP growth.

The results of the NARDL model show that there is a non-linear relationship between PD and RGDP even in the short run. The estimated coefficients of the NARDL model show that a positive PD shock of 1% is associated with a slowdown in RGDP of 0.31%, while a negative PD shock is associated with increase in RGDP of 1.19%. The estimated coefficients are statistically significant at the 1% level. Therefore, the short-term coefficients also confirm the non-linear relationship between PD and RGDP. It can be observed that the effect of the negative shock of PD in the short run is larger than the effect of the negative shock in the long run. CAD and GDS have a significant positive impact on RGDP, and the estimated coefficients are statistically significant at the 1% level.

The estimated short-run coefficient in the NARDL-ROBUST model with the PD variable (symmetric variable in the short-run) is statistically significant at the 5% level and shows that an increase in PD of 1% is associated with a 0.24% decrease in RGDP. Therefore, this coefficient confirms the robustness of the NARDL model for the entire sample period.

Table 5 shows the estimated adjustment coefficients for all three models with correction for the equilibrium error (EC term). The EC term measures the speed of adjustment to the long-run relationship in the movement of the dependent and explanatory variables and, according to theory, should be negative in the interval between 0 and 1.

The estimated coefficient of the EC term for all three models estimated in our study has the expected negative sign, and the coefficients are highly statistically significant at the 1% level. However, the magnitude of the negative value of the

estimated coefficient is greater than 1, which is a deviation from the theoretical expectation. This may be a consequence of the rapid convergence of the RGDP to the equilibrium relationship with the other variables in the estimated equation if there was a disturbance in the previous period. In the estimated NARDL model, the EC term (-3.13) shows that the deviation of the dependent variable in the previous period is only corrected for a few months in the current year. This is a super-fast restoration of the equilibrium relationship between the variables in all three estimated models. The EC term also confirms that there is a long-run relationship between the variables in the model.

Table 5: Short-run regressors of the cointegration equation with error correction (dependent variable: RGDP)

Independent variable		**Model 1**	**Model 2**	**Model 3**
Lag order		ARDL (1,1,2,1,2)	NARDL (1,2,2,2,2)	NARDL-ROBUST (1,0,1,0,0,1)
Δ *LogPD*	Coefficient	-0.197085		-0.249289
	Std. Error	0.032951		0.007890
	p-value*	0.0001		0.0000
$\Delta LogPD^{+}$	Coefficient		-0.314225	
	Std. Error		0.020303	
	p-value*		0.0000	
$\Delta\ LogPD^{+}$(-1)	Coefficient		-0.019213	
	Std. Error		0.023606	
	p-value*		0.4425	
$\Delta\ LogPD^{-}$	Coefficient		1.190489	
	Std. Error		0.059015	
	p-value*		0.0000	
$\Delta\ LogPD^{-}$(-1)	Coefficient		-0.378014	
	Std. Error		0.031391	
	p-value*		0.0000	
Δ *LogPDS*	Coefficient	-0.035874	0.033469	0.081092
	Std. Error	0.015341	0.005638	0.003640
	p-value*	0.0375	0.0006	0.0000
	Coefficient	-0.052449	0.123767	

Δ *LogPDS*(-1)	Std. Error	0.016441	0.007724	
	p-value*	0.0078	0.0000	
Δ *LogCA*	Coefficient	0.0116457	0.188474	0.056149
	Std. Error	0.008446	0.009289	0.001512
	p-value*	0.0751	0.0000	0.0000
Δ *LogCA*(-1)	Coefficient		0.027471	
	Std. Error		0.004798	
	p-value*		0.0007	
Δ *LogGDS*	Coefficient	-0.001630	0.338304	0.221967
	Std. Error	0.008889	0.020496	0.004456
	p-value*	0.8576	0.0000	0.0000
Δ *LogGDS*(-1)	Coefficient	-0.016309	-0.077018	
	Std. Error	0.007731	0.008814	
	p-value*	0.0566	0.0001	
ΔLogGFCF	Coefficient			0.130559
	Std. Error			0.005695
	p-value*			0.0000
$EC_{(t-1)}$**	Coefficient	-1.412802	-3.131626	-5.959423
	Std. Error	0.158139	0.130498	0.162929
	p-value*	0.0000	0.0000	0.0000
C	Coefficient	6.537557	13.50430	25.88476
	Std. Error	0.731244	0.562303	0.707908
	p-value*	0.0000	0.0000	0.0000
DUMMY	Coefficient	-0.016007	-0.005172	
	Std. Error	0.017515	0.008131	
	p-value*	0.3787	0.5450	

Note: **p*-values do not account for model selection; ** Error correction term – *EC*. Deterministic: *C*. Due to the introduction of lags, the number of observations is smaller than the original sample (Model 1: 21, Model 2: 20, Model 3: 16).

Source: Author.

To test the direction of causality between RGDP and PD, we applied the Granger causality test (Granger, 1969) (see Table 6).

Table 6: Pairwise Granger Causality Tests

Null hypothesis:	Obs	*F*-statistic	*p*-value
LogPD does not Granger cause *LogRGDP*	20	5.63673	0.0107
LogRGDP does not Granger cause *LogPD*		1.10189	0.3835

Note: Sample: 2001–2023; Lags: 3.

Source: Author.

According to the *F*-statistic and the *p*-value in Table 6, we cannot reject the hypothesis that RGDP is not a Granger cause of PD, but we do reject the hypothesis that PD is not a Granger cause of RGDP. This means that Granger causality runs in one direction, from PD to RGDP.

5. CONCLUSION AND POLICY IMPLICATIONS

This study examines the relationship between the RGDP and PD of Serbia using the ARDL and NARDL methods. The estimated coefficients using the ARDL approach, which shows the long-run relationship between the observed variables, are not statistically significant. Unlike the ARDL approach, the application of the NARDL methodology gives satisfactory statistical results. The results obtained show that the positive relationship between the reduction in PD and RGDP is stronger than the negative relationship observed between these variables in the case of an increase in PD. This gap confirms that there is a non-linear relationship between PD and RGDP in Serbia. The results are consistent with recent empirical studies that show the existence of a non-linear relationship between the PD of some countries and their economic growth (Gómez-Puig & Sosvilla-Rivero, 2015; Reinhart & Rogoff, 2010).

Public and publicly guaranteed debt service (% of GNI) increased from 1.6% in 2010 to 6.7% in 2019. The growth of this burden is the result of the accumulation of public external debt and the rise in interest rates on the international capital market. Our results suggest that the government needs to plan for higher fiscal reserves, which would act as a shock absorber in the event of a sudden rise in international interest rates.

The limitation of the research in this paper is reflected in the fact that the directions of consumption expenditure based on PD (structural budget) have not been taken into account. This is a recommendation for future research. In addition, future research could investigate the channels through which PD growth affects real GDP, taking into account the macroeconomic performance of the country. If PD is used for public investment (infrastructure, environmental protection, energy sector, education) the increase in PD could have a positive effect on economic growth (Furceri et al., 2018). However, if the increase in PD is used for non-investment expenditures or investments that do not generate new production or the export of goods and services, the impact on GDP may be different.

The recommendation for policymakers is that caution should be exercised with regard to additional public borrowing for several reasons. Firstly, the scope for forced additional borrowing due to a possible unexpected development in the global market as a result of global geopolitical fragmentation should be preserved. The rise in imported energy prices could be a reason for additional public borrowing. The risk of a sudden rise in interest rates on the global market could then further increase the country's debt burden. The fact that the increase in the burden of servicing PD could tighten the country's fiscal policy (tax increases), which would have a negative impact on economic growth, should also be taken in account. It should also be noted that the country has a significant presence of foreign capital, and any disruption in the international capital markets could trigger the withdrawal of this capital, which would put considerable pressure on the exchange rate. An important policy implication of these findings is that high PD could be a limiting factor in stabilising the country's macroeconomic performance. This should be considered when determining the future level of public debt. One of the possible consequences of excessive public borrowing must not be forgotten. Namely, if the long-run interest rates on the PD (r) are higher than the output growth rate (g), an increasing proportion of GDP will have to be used to service the public debt.

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APPENDIX

Table A1: Unit root test with breakpoints (Augmented Dickey–Fuller test)

Variable	At levels		At first difference		Inference
	t-statistics	Break date	*t*-statistics	Break date	
Log*RGDP*	--6,067661*	2009	-7.077820*	2009	I(0)
Log*PD*	-3.534193	2008	-5.658729*	2008	I(1)
Log*PDS*	-3.235420	2009	-5.628136*	2017	I(1)
Log*CA*	-4.288563**	2014	-5.303265*	2008	I(1)
Log*GDS*	-6.195839*	2012	-6.882583*	2007	I(0)
Log*FDI*	-5.061282*	2011	-7.843691*	2006	I(0)
Log*GFCF*	-4.459348**	2016	-4.981261*	2009	I(1)

Notes: * Indicates significance at the 1% level (rejecting the null hypothesis, H_0 – *Has a unit root*); ** Indicates significance at the 5% level; *** Indicates significance at the 10% level. Break selection: Minimise Dickey–Fuller *t*-statistics; Lag length: Automatic – based on Schwarz information criterion, maxlag=4. Break selection: Minimise Dickey–Fuller *t*-statistics. Break in the intercept and trend.

Source: Author.

Table A2: Descriptive statistics of the variables used in the applied models

	Mean	Median	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis	Jarque–Bera	Probability
Log*RGDP*	4.641719	4.649134	4.691096	4.577250	0.030438	-0.407530	2.282836	1.129963	0.568371
Log*PD*	3.867240	3.939638	4.475062	3.165475	0.305560	-0.604625	3.210312	1.443743	0.485842
Log*PDS*	0.688666	0.867121	1.860531	-1.074061	0.824865	-0.342321	2.233764	1.011858	0.602945
Log*CA*	1.812525	1.785070	2.966018	0.875469	0.578904	0.226910	2.370721	0.576858	0.949440
Log*GDS*	1.964067	1.726602	2.843666	0.753674	0.690117	-0.279763	1.884475	1.492572	0.472224
Log*FDI*	1.731316	1.869633	2.549445	0.262364	0.499448	-1.060271	4.493159	6.445961	0.039836
Log*GFCF*	2.939579	2.957733	3.174553	2.470668	0.177502	-0.621615	3.207031	1.522295	0.467130

Source: Author.

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EXPLORING THE LINK BETWEEN THE COVID-19 CRISIS AND NON-EMPLOYMENT IN SERBIA: WHO WAS LEFT BEHIND?

ABSTRACT: *The global health crisis that began in early 2020 also affected Serbia. The national lockdown and subsequent social distancing measures had a considerable effect on both the economy and the population. The quarantine, followed by social distancing measures, had a significant impact on the economy and population. Despite the overall satisfactory performance of the labour market, there are signs that the majority of workers who were not protected by the government's measures either lost their jobs or even left the labour market and moved into inactivity. Therefore, instead of focusing on unemployment, the aim of the paper is to analyse the impact of the health crisis on non-employment (unemployment and inactivity). Applying the probit model to LFS data, we examined the probability of non-employment in the years before and during the COVID-19 outbreak. Controlling for the individual characteristics, we found that young and old people as well as those with a lower level of education fared slightly worse than the overall population. While the active labour market measure 'My First Salary' probably helped to improve the relative position of youth, the position of elderly and people with a low level of education deteriorated further in 2021.*

KEY WORDS: *COVID-19, labour market, non-employment, vulnerable groups, Serbia.*

JEL CLASSIFICATION: J08, J38, J63, J64.

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1. INTRODUCTION

The COVID-19 pandemic was a major challenge for policymakers around the world, who had to respond quickly and efficiently. Like other countries, Serbia also faced this challenge. The first case of infection was registered at the beginning of March 2020, and by the end of the same month there were already over 1,000 confirmed cases. In an effort to stop the spread of the virus, a state of emergency was declared on March 15 (Government of the Republic of Serbia [RS], 2020a). Under the given circumstances, the state had the right to impose working conditions, restrict the right to strike, and also issue decrees during the state of emergency. In the second wave of the crisis that followed in the fall, major restrictions on freedom of movement were largely avoided. Instead of a nationwide quarantine, the spread of the virus was prevented by measures such as social distancing.

The impact of the pandemic on the Serbian economy was layered. Economic agents in the so-called high-contact sectors (tourism, hospitality, transportation, personal services, etc.) were particularly affected by the supply shock that occurred at the beginning of the epidemic. The impact then spilled over to the demand side, which fell due to reduced income caused by job losses, reduced working hours, and general uncertainty about the duration and intensity of the crisis and delayed spending. In this respect, it can be said that the health crisis affected all sectors of the economy and had significant social consequences. To mitigate the negative impact of the health crisis, the government developed the most comprehensive economic support packages in recent history. The support packages comprised several measures, including an increase in healthcare costs, the creation of a state guarantee scheme for bank loans to small and medium-sized enterprises, direct subsidies to preserve jobs, and the deferral of tax and contribution payments (International Monetary Fund [IMF], 2021).

Although Serbia was not an exception regarding the negative impact of the pandemic, the response of the labour market was noticeably different to that on a global level. While unemployment rose in most countries during the first wave of the crisis, unemployment in Serbia remained at roughly the same level. Moreover, the year-on-year unemployment rate actually fell slightly under 2%. Serbia was one of only three countries in Europe where the annual unemployment rate fell, with the decline in Serbia being by far the sharpest.

Parallel to the decline in unemployment, inactivity also increased. In other words, the adjustment pattern in Serbia was such that only a small portion of laid-off workers moved into unemployment, while most of them moved into inactivity. In this respect, it would be misleading to focus solely on the link between the pandemic and unemployment. Instead, one would get a broader picture by looking at non-employment – a single term for unemployment and inactivity.

Despite the government's efforts to minimise the negative effects, the pandemic created winners and losers in the labour market, which became increasingly apparent over time. This is consistent with the findings of studies confirming that the pandemic particularly affected vulnerable groups – groups that were at risk even in times of economic prosperity (Lariau & Liu, 2022). In this regard, the main objective of this paper is to examine the impact of the pandemic on the labour market as a whole, but also on some of its structures and participants. To achieve this, we will conduct an empirical analysis estimating the probability of non-employment in the period 2019–2021. The first year will serve as a benchmark for the regular year, which will be compared with 2020, when the impact of the crisis was most severe, and 2021, when the negative effects were still present but less pronounced. By controlling for individual characteristics, we can see how COVID-19 affected the labour market transition of different vulnerable groups.

The paper contributes to the existing literature in several ways. First, in contrast to the few previous studies for Serbia, which focus on the outcome in 2020, we have extended the analysis to 2021 to assess the longer-term impact of COVID-19 on the Serbian labour market. Second, Serbia is one of the few countries where unemployment did not increase during the pandemic. Considering the nature of the labour market response in Serbia, we decided to analyse the impact of COVID-19 on the unemployed and the inactive together. Instead of relying on unemployment only, which is a standard approach, we calibrated the model to adapt it to the current situation. Third, we found that COVID-19 did not have a significant structural impact on the labour market in Serbia when it comes to the probability of being non-employed.

The paper is organised in the following manner. This introductory section will be followed by an overview of the most important studies that have dealt with this

topic. In the third part, we will take a detailed look at the measures adopted by the Serbian government to neutralise the negative consequences of the health crisis. To provide a glimpse of labour market performance in the period analysed, the subsequent section will be dedicated to the trend of the most common labour market indicators. The fifth part is reserved for the description of the data used for the empirical analysis and the presentation of the methodology. In the sixth section, we present the main results of the estimated econometric model, while the last section of the paper is devoted to the conclusions.

2. LITERATURE REVIEW

The impact of the COVID-19 pandemic on labour market outcomes for vulnerable groups has been widely studied, with findings that highlight its diverse effects. However, the literature is largely centred on developed countries, with significantly more research available on economies with stronger institutional frameworks and social safety nets. In contrast, studies focusing on developing countries, including Serbia, remain scarce. This lack of research on developing countries leaves an important gap in understanding how vulnerable groups, such as workers who are young and with a low level of education, were affected in economies with weaker labour protections and limited financial support.

Certain studies focused on evaluating the pandemic's effects within a single country, providing in-depth insights into localised labour market impacts. For instance, Lariau and Liu (2022) provided evidence that the pandemic exacerbated existing inequalities, particularly affecting certain groups on the Spanish labour market. Using a combination of labour force data and quantitative modelling, the study highlights that women, youth, and workers in precarious or temporary employment faced the greatest challenges. The authors attribute these trends to the pandemic's disproportionate impact on sectors such as hospitality and retail. They also evaluate policy interventions, such as job retention schemes, and discuss their effectiveness in mitigating these inequalities. Bruckmeier et al. (2021) introduced a method to evaluate the distributional effects of macroeconomic shocks and policies in real time, applied to Germany during COVID-19. By integrating various models, the analysis reveals a decline in gross labour income across all income levels, while tax-benefit systems and crisis responses helped stabilise disposable incomes, benefiting lower-income groups and slightly impacting higher-income households. The paper highlighted that the

rapidly evolving nature of the COVID-19 crisis created significant challenges for policymakers in implementing timely income-stabilising measures. Lee et al. (2021) examined the employment effects of COVID-19 in the United States using a linear regression model based on Current Population Survey data. Their findings indicate that young workers (aged 20–35) were hit the hardest at the end of the first quarter of 2020, with unemployment rates increasing by 13 percentage points and non-participation rates rising by around 4.5 percentage points year-over-year. Even after controlling for other factors, the study found that the negative employment effects were more pronounced for young workers, women, and those with lower levels of education. This aligns with findings from Serbia and the Visegrad region, emphasising the global vulnerability of these groups to economic shocks. Additionally, Cortes and Forsythe (2023) examined how the COVID-19 pandemic impacted employment distributionally in the United States, focusing on its onset and subsequent months. Using data from the Current Population Survey, they found that the pandemic worsened existing inequalities. Job losses were more severe and persistent in lower-paying sectors, disproportionately affecting Hispanic and non-white workers. These disparities were not solely due to overrepresentation in low-paying roles but also higher probabilities of job displacement. Additionally, the study showed that black workers faced widening job displacement gaps compared to white workers, and that the pandemic also accelerated retirement rates among older workers.

Some studies, particularly those conducted by international organisations, offer comparative analyses of how the pandemic affected labour market outcomes across different countries. The IMF's departmental paper (Ando et al., 2022) on European labour markets found that women, young workers, and those with low education levels faced significant disruptions. The pandemic amplified existing structural issues, such as sectoral shifts and skill mismatches. The study revealed that policies such as targeted wage subsidies played a key role in cushioning employment shocks but revealed gaps in coverage, especially for gig and self-employed workers. The study published within the World Bank (Khamis et al., 2021) showed that the COVID-19 pandemic-induced economic crisis significantly curtailed mobility and economic activity, severely impacting global labour markets. The study examined the crisis's early effects in nearly 40 countries. Key findings reveal that work stoppages were more common in industry and services than agriculture, emphasising the negative impact of the

pandemic for rural women, youth and workers with a low level of education in terms of the rise in unemployment and inactivity rates. The Western Balkans regular economic report published by the World Bank (2020) shows that the pandemic disproportionately impacted women, young workers, and those in low-skill and informal sectors. These groups experienced higher rates of job losses and income reductions due to their overrepresentation in precarious or contact-intensive occupations. This trend aligns with global observations on labour market inequalities exacerbated by the pandemic. In the Western Balkans, the report also reveals that agriculture showed greater resilience compared to the industrial and service sectors, where employment disruptions were more pronounced. Tourism-dependent economies within the region, for example Croatia and Montenegro, faced particularly severe challenges. The report highlights that countries such as Serbia implemented substantial economic support measures to mitigate income losses, including wage subsidies and social transfers. These efforts were partly successful in preventing a sharp rise in poverty and inequality but could not fully shield vulnerable groups from the economic shock. In countries such as Kosovo[1] and Albania, high migration rates and lower labour force participation compounded the challenges during the pandemic, highlighting the need for policies to strengthen workforce integration and retention. Zieliński (2022) analysed the impact of the pandemic on labour markets in the Visegrad countries (Czech Republic, Hungary, Poland, and Slovakia) using descriptive statistics and quarterly observations. The study found that while the pandemic did not lead to a deterioration in employment among women, it significantly affected young workers (aged 15–24), older workers (55–64), and those with lower education levels. Among the observed countries, Poland experienced the strongest negative effects on youth employment.

It is particularly important that the literature on the impact of COVID-19 on the labour market in Serbia is scarce, with only few papers addressing this issue, to the best of our knowledge. Vladisavljević and Lebedinski (2023a) examined job loss rates and job-finding probabilities among vulnerable groups in Serbia. Their analysis, based on labour force survey panel data and transition probabilities, revealed that while the overall increase in job losses was insignificant, young workers (aged 20–29) faced a significant rise in job loss rates by around 2

[1] This designation is without prejudice to positions on status and is in line with UNSCR 1244/1999.

percentage points during the first year of the pandemic. This finding highlights the heightened vulnerability of younger workers to economic disruptions, possibly due to their lower job security and a higher prevalence of temporary contracts. A similar study by the same authors (Vladisavljević & Lebedinski, 2023b) utilised a difference-in-differences methodology to compare employment outcomes before (2019) and after (2020) the pandemic. Their findings indicate that while individuals aged 30–64 experienced no significant changes in employment, youth employment declined by 3 percentage points in the second quarter of 2020. However, this effect appeared transitory, as no significant differences were observed in the fourth quarter. In contrast, the study found that individuals with lower education levels faced persistent employment reductions in both the third and fourth quarters, with declines of 2.4 and 3.0 percentage points, respectively. This suggests that individuals with lower education levels bore a heavier burden in terms of labour market disruptions, possibly due to their concentration in sectors with lower job stability and fewer opportunities for remote work.

3. THE GOVERNMENT STIMULUS MEASURES

In this section, we will take a closer look at the Serbian government's aid package and its relief potential. It did not take long after the declaration of the state of emergency for the government to launch the first and most generous fiscal stimulus. According to the World Bank, the total size of the stimulus programme is estimated at around 13% of GDP (World Bank, 2021). In early April 2020, the 'Decree on tax breaks and direct benefits for private sector companies and financial support for citizens to mitigate the economic consequences of the COVID-19 disease' was adopted (Government of RS, 2020b). The decree included measures aimed at mitigating the consequences of COVID-19 on several levels.

In order to protect jobs, the government created two different types of subsidies: one for small businesses and entrepreneurs and one for large companies. The first type of subsidy meant that every full-time employee was paid the net minimum wage during the three months of the state of emergency. This subsidy was paid to more than one million workers employed by entrepreneurs, micro, small and medium-sized private enterprises, excluding those in the financial sector. The subsidy amounted to a uniform amount of just under 300 euros per month per

employee and was not dependent on the activity, previous salary or estimated losses of the individual company. In order to receive the subsidy, companies were not allowed to reduce the number of their employees by more than 10% compared to the number at the beginning of the state of emergency. The same group of beneficiaries went through this procedure again for the next two months, but this time the subsidy amount was 60% of the net minimum wage, i.e. around 200 euros. The second type of subsidy involved the payment of half of the minimum wage to any employee who received a decision to suspend work activity during the state of emergency. This type of subsidy was one of the measures to protect jobs in large companies.

With the second series of measures, the government created the possibility of postponing taxes. During the state of emergency, the payment of taxes and social security contributions on wages and income was postponed until the beginning of January 2021. In addition, the advance payment of corporate income tax for the months of March, April, and May 2020 was postponed until the submission of the final income tax return for 2020, for which the deadline was the end of June 2021. As a third form of support, the government set up guarantee schemes through commercial banks aimed at subsidised loans to maintain operating capital and liquidity of small and medium-sized enterprises and agricultural producers.

In an effort to provide additional assistance to the most severely affected industries in the field of tourism, hospitality, and passenger transportation, the state approved around 160,000 vacation vouchers in locations across Serbia. A similar practice continued until the end of the year, with a greater emphasis on direct support for vulnerable companies in the affected sectors. Companies operating in these sectors were able to apply for loans from the Development Fund of the Republic of Serbia on more favourable terms in order to maintain their operating capital and liquidity.

In addition to initiatives to directly support the economy and protect jobs, the government introduced a one-time programme of universal financial support of 100 euros for all adult residents of the Republic of Serbia to stimulate demand and indirectly help businesses. The Ministry of Finance estimates that more than 6.1 million citizens received this support (Ministry of Finance of the RS, 2020).

The generosity of the measure is also confirmed by the results of a study that ranked this measure among the top 10 most inclusive measures in the world, as around 90% of the population benefited from it (Almenfi et al., 2020). Furthermore, additional financial assistance was granted to all pensioners on two separate occasions in 2020.

Although the consequences of the pandemic were much milder in 2021, the government largely maintained its original decision in favour of universal rather than selective support for the economy and population. However, due to limited fiscal space, the support package in 2021 was less generous. Although on a relatively small scale, selective assistance was granted to sectors most affected by social distancing, such as catering businesses, travel agencies, and transport companies. Universal assistance to the population also continued in 2021, with the distribution of 60 euros to all adults and 50 euros to those over 65 years of age being particularly noteworthy. In addition, all registered unemployed were granted one-off additional assistance of 60 euros.

From the workers' point of view, the most important measure taken by the government was the subsidy to preserve jobs in non-large businesses. Although the subsidies were paid to the companies, the imposed condition of the ban on reducing the number of employees had a direct impact on the position of the workforce, primarily protecting the employees in the workforce. Above all, this contributed to widening the already noticeable gap between the employed on the one side and the unemployed and inactive on the other. With the intention of maintaining the overall level of employment in the country, the government subsidies thus created a barrier between the employed and the non-employed. On the one hand, companies did not need to hire unemployed due to falling demand; on the other hand, they had no incentive to lay off existing employees due to the aforementioned subsidy condition. These circumstances significantly hindered transition on the labour market. The non-employed were therefore mainly helped by direct cash transfers to the overall population, which could only partially contribute to their income preservation, and later by modest financial aid reserved for the registered unemployed.

4. LABOUR MARKET PERFORMANCE

In the early phase of COVID-19, an international study assessed the impact of the health crisis on the labour market across the Western Balkan region (International Labour Organization [ILO], 2020). In the case of Serbia, the rapid assessment highlighted women and youth as the two demographic groups potentially most affected by the negative impact of COVID-19. Therefore, Table 1 presents three basic labour market indicators for selected groups that are most commonly used as a reference for labour market performance.

Table 1. Labour market indicators for different groups of population

	Year	Working age population (15–64)	Male	Female	Young population (15–24)
Activity rate	2019	66.1	73.1	59.0	28.6
	2020	65.7	72.8	58.6	27.9
	2021	69.7	76.8	62.6	33.0
Employment rate	2019	58.3	64.9	51.8	20.2
	2020	59.1	65.7	52.5	20.3
	2021	61.7	68.6	54.8	24.4
Unemployment rate	2019	11.7	11.2	12.2	29.3
	2020	10.1	9.7	10.5	27.3
	2021	11.5	10.7	12.5	26.0

Source: Labour Force Survey 2019-2022, Statistical Office of the Republic of Serbia (SORS).

Despite the negative effects of the crisis, the number of employed people fell by only nine thousand compared to 2019, with the decline among men being slightly higher than for women. The employment rate of the working-age population increased by 0.8 percentage points compared to the previous year, which is due to an extremely small decline in employment and a significant trend of depopulation. It can be seen that there was no gender discrimination in the change in the employment rate. Even if the quantitative indicators give the impression that women did not fare any worse than men, this is not necessarily the case, as there are some issues that this data cannot reveal. For example, the transition to working from home during the national quarantine disproportionately jeopardised the position of women, who had to balance professional and private commitments.

From the unemployment standpoint, the labour market in Serbia performed even better, with annual unemployment falling by more than 50,000. The trend in gender dynamics was the reverse of that observed in employment, with women experiencing a greater decline in unemployment – around 55% of the total decline. This trend also contributed to the decline in the overall unemployment rate of the working-age population. The annual unemployment rate fell by around 1.6 percentage points, approaching a single-digit figure (10.1) for the first time in recent history. Compared to other countries, Serbia was one of the few countries in Europe where the unemployment rate fell.

However, the decline in unemployment has a less favourable aspect if one also considers the data on labour market transition. The decline in economic activity of around 0.4 percentage points compared to the previous year can best explain the fall in unemployment. Due to the very low demand for labour as a result of the health crisis, the majority of the unemployed stopped actively looking for work and thus moved into inactivity. The former can be seen very clearly in the quarterly data. In the second quarter, there was a significant decline in both activity and unemployment, although the employment rate fell only slightly. This decline was mainly due to the implementation of stricter curfews during the state of emergency. Therefore, the increase in the inactive population in the second quarter was mainly due to the transition of the unemployed into the population outside the labour force.

The statistics on the inactive population by main source of income also confirm the previous assertion. According to the quarterly Labour Force Survey (LFS) data, the number of inactive people among those whose main source of income is their spouse's salary or pension increased significantly in Q2 of 2020, precisely when the impact of the crisis was strongest and movement was most limited. As early as the following quarters, this category of inactive people decreased by more than 150,000, i.e. by one-fifth, returning to pre-crisis levels. In order to reduce the costs associated with looking for work, so-called secondary workers, those who could rely on the income of other household members, stopped searching for work and became inactive. As the measures to restrict freedom of movement eased, these people rejoined the labour market. This was clearly visible from the trend in the number of inactive people by income type. According to the Eurostat data, while the number of inactive people whose main source of income is

earnings/pensions of spouses, parents, or other household members rose sharply in the second quarter (by around 150,000), it returned to pre-crisis levels in the third quarter and continued to fall over time.

Compared to young people in the European Union (EU), young people in Serbia consistently have a much weaker position on the labour market. Moreover, the differences in the Serbian labour market between the young and adult populations are also greater than in other EU countries. The health crisis further worsened the already unfavourable starting position of young people in Serbia, as the young population performed worse than the working-age population in all labour market indicators. As far as the data for 2020 is concerned, there was a sharper decline in the youth employment rate, a more intense increase in the inactivity rate among young people, and a smaller decline in the unemployment rate compared to the working-age population. In 2021, the opposite was the case – young people experienced a stronger upswing than the working-age population. Not only did the activity and employment rates among young people rise faster in relative terms, but the unemployment rate for this group also fell, despite the rise in the unemployment rate of the broader working-age population.

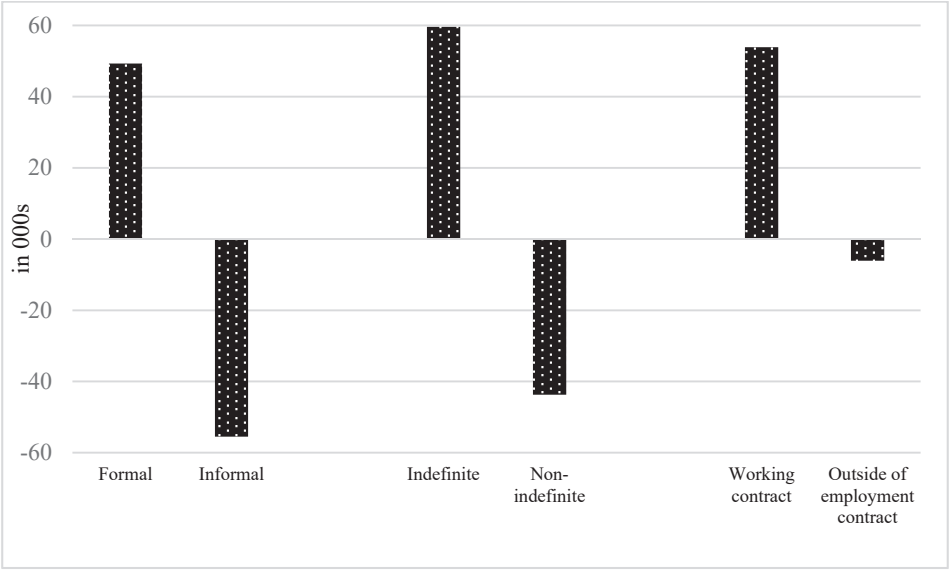
In addition to the groups traditionally vulnerable due to their demographic characteristics, several other groups emerged during the pandemic. Although the employed fared much better than the other two categories of population, the negative effects of COVID-19 were unevenly distributed within the group of employed. It is a well-known fact that employment is a very heterogeneous category. It includes anyone who carries out a particular activity, regardless of the type of engagement. Depending on the form in which they are employed, their job security varies. The most favourable arrangement is working through a standard employment contract. Workers engaged under non-standard arrangements outside an employment relationship, for example under a service contract, have a significantly higher risk of losing their job.

Similar to the type of work arrangement, the job security of employees also varies depending on the type of contract. From the company's perspective, it is most difficult to dismiss employees with a permanent contract, followed by those with fixed-term contracts, while it is easiest to part with employees hired through service contracts. Finally, the concept of employment in the LFS includes both

employees engaged in formal employment and those in informal employment. It is quite clear that the latter category does not enjoy any employment protection and as such is the easiest to dismiss in times of recession.

Figure 1 shows the annual changes in employment based on the various forms of employment discussed above. As can be seen, all three observed forms of precarious employment (informal, non-indefinite, and employment outside formal arrangements) decreased in 2020 compared to 2019. In contrast, all three favourable employment categories increased compared to 2019. This development is probably a direct consequence of the design of subsidies to preserve jobs. As already mentioned, companies that did not lay off more than 10% of their employees relative to the beginning of the pandemic did not have to repay the subsidy. However, it turned out to be important that only employees with permanent contracts were included in this 10%. This left companies free to lay off informal workers and workers working outside of an employment arrangements without hindrance. Similarly, companies were not obliged to renew the contracts of employees whose fixed-term contracts expired.

Figure 1. Year-on-year change in various categories of employment, 2020/2019 (in 000s)



Source: Authors' calculations based on LFS (first two indicators) and CROSO (last indicator).

5. METHODOLOGY AND DATA

To examine how the COVID-19 pandemic affected certain vulnerable groups on the labour market in Serbia in terms of non-employment, the paper utilises the following empirical strategy. The estimated probit model takes the form:

$$NonEmployed_i = \alpha + \beta_1 Gender_i + \beta_2 Loc_i + \beta_3 Age_i + \beta_4 Edu_i + \beta_5 Reg_i + \varepsilon. \quad (5.1)$$

The model (5.1) is used to determine how selected characteristics affect the probability that the person will be non-employed in the observed year. In the model (5.1):

(1) $NonEmployed_i$ is a dependent dummy variable that takes the value 1 if the person is non-employed, where the non-employment refers to persons that are unemployed or inactive;
(2) $Gender_i$, Loc_i, Age_i, Edu_i, Reg_i are independent variables that refer to the gender of the person, the location of the person, the age group to which the person belongs, educational level of the person, and the region of Serbia in which the person lives, respectively;
(3) α and ε represent the constant and random error of the model, respectively.

Using the probit regression model specified in equation (5.1), the average marginal effects of various selected characteristics on the likelihood of being non-employed were calculated. In terms of characteristics that were included in the empirical analysis, the model consists of variables that refer to gender, location, age group, educational level, and region since these characteristics are usually linked with higher vulnerability on the labour market. Equation (5.1) was evaluated for 2019, 2020, and 2021. The key idea is that by evaluating three probit equations for the year before and during the different intensities of the COVID-19 crisis, the possible impact of the corona crisis on certain vulnerable groups in the labour market can be identified. By comparing the differences in the estimated marginal effects for two periods, 2020 in relation to 2019 and 2021 in relation to 2020, it is possible to obtain an indicative picture of whether and in what way the COVID-19 pandemic affected the non-employment of certain groups on the Serbian labour market.

The variables were selected based on several theoretical frameworks which are familiar within labour economics and have been confirmed empirically. For instance, the labour market segmentation theory claims that many labour markets are segmented, often along gender lines, and that women are disproportionately represented in low-paid, part-time, or precarious jobs with limited opportunities for advancement (Peck, 1989). Research shows that women, on average, earn less than men and face higher unemployment rates globally, and that women are also more likely to be in informal employment, with less job security and fewer benefits. In addition, according to spatial mismatch theory, rural residents are often geographically distant from job opportunities, particularly those in high-growth sectors (e.g., technology and finance), which tend to cluster in urban areas (Arnott, 1998). Data shows that unemployment rates are generally higher in rural areas. Rural workers often have fewer high-paying job opportunities and are more dependent on seasonal or agricultural work, which is vulnerable to economic and environmental shifts. Conversely, human capital theory asserts that lower levels of education and skills reduce employability and wage potential, as higher education often correlates with job-relevant skills and knowledge. Individuals with a low education level have higher unemployment rates and are more likely to work in low-wage, low-skill jobs with limited job security. They are also less resilient to economic shocks, as they lack the qualifications to transition easily to new industries (Young et al., 2007). Studies indicate that individuals with limited formal education face slower wage growth and fewer promotion opportunities compared to their more highly educated counterparts. Dual labour market theory posits that young workers are more likely to enter secondary labour markets characterised by insecure, low-paid, and part-time jobs rather than stable, well-paid, primary market jobs (Ashton & Maguire, 1984). Data consistently shows that the youth unemployment rate is higher than the general unemployment rate in many countries, reflecting the barriers youth face in finding stable employment. The 'scarring effect' is also documented, where periods of unemployment or underemployment early in life can have long-term negative impacts on future job stability and earning potential (Gregg & Tominey, 2005). All of this suggests that gender, location, education, and age group can influence a person's likelihood of being non-employed. Lastly, since Serbia is known for significant regional disparities, a variable related to the region in which a person lives is also included in the model. The list of variables included in the model with a description is given in Table 2.

Table 2. Description of variables included in estimation of the model (5.1)

Variable	Description
Dependent variable	
NonEmployed	1 if the person is unemployed or inactive, 0 otherwise
Independent variables	
Female	1 if the person is female, 0 otherwise
Rural	1 if the person lives in rural area, 0 otherwise
YoungAge	1 if the person belongs to the young age group (15–29), 0 otherwise
MiddleAge	1 if the person belongs to the middle age group (30–54), 0 otherwise
OldAge	1 if the person belongs to the old age group (55+), 0 otherwise
LowEducation	1 if the highest level of education of the person is primary education, 0 otherwise
SecondaryEducation	1 if the highest level of education of the person is secondary education, 0 otherwise
HighEducation	1 if the highest level of education of the person is tertiary education, 0 otherwise
Belgrade	1 if the person lives in Belgrade, 0 otherwise
Vojvodina	1 if the person lives in Vojvodina, 0 otherwise
SumadijaWest	1 if the person lives in Sumadija or West Serbia, 0 otherwise
SouthEast	1 if the person lives in South or East Serbia, 0 otherwise

Empirical estimates were performed based on LFS cross-sectional databases for Serbia. In the paper, three LFS survey waves for Serbia were used, from 2019 to 2021 (Statistical Office of the Republic of Serbia, 2021), with 2020, as the year in which the COVID-19 pandemic occurred, being the reference year. The analysis was conducted at the individual level, allowing for the identification of factors that influence the probability of non-employment on the labour market of certain groups recognised as vulnerable. The sample size ranges from 98,500

observations in 2021 to 110,000 in 2019. Among the non-employed in the sample for the years observed, the number of unemployed is 5,562; 4,081; and 5,015, while the number of inactive individuals is 56,441; 52,919; and 53,542, respectively. For each year, the probit regression that follows the model (5.1) was assessed with estimated average marginal effects. The individual weights were included in the estimation, and the robust standard errors were estimated. As for the restriction of the sample, it should be noted that the analysis includes observations of individuals aged 15 and over. To check the robustness of the results, probit regressions were separately evaluated in all three years for the female and young population. Table A1 in the Appendix provides the descriptive statistics.

6. RESULTS AND DISCUSSION

The results of the probit regression evaluation in terms of estimated average marginal effects within the defined model for years 2019–2021 for the total population in Serbia are presented in Table 3. Table A2 in the Appendix provides the estimates of the probit regressions. The results indicate that in all three years observed, all the selected variables that are related to greater vulnerability in the labour market in terms of the probability of being non-employed are statistically significant (except for some regions in certain years, e.g. in the case of the variable SumadijaWest for 2020 and 2021).

The results for the reference year 2020 show, for instance, that females, young and old age groups, people with a low education level, and people from urban areas were especially vulnerable on the Serbian labour market regarding the probability of being non-employed, which is expected. Characteristics such as gender, low education level, and young and old age group are positively associated with the probability that the person will be non-employed. In contrast, characteristics such as high education level and rural area appear to be negatively correlated. Regarding the magnitude of these marginal effects, age group stands out. If a person is female, the probability of being non-employed increases by 10 percentage points, on average, compared to the case for a male person. In addition, people in the young and old age groups have a higher probability of being non-employed than those in the prime age group, with estimated average marginal effects of 0.34 and 0.39, respectively. In contrast to people with a secondary education, the probability that a person with a low level of education

will be non-employed increases by around 14 percentage points, while it decreases by 10 percentage points in the case of people with a high level of education, on average. In addition, people from the Vojvodina region are less likely to be non-employed than their counterparts from the Belgrade region, with an observed average marginal effect of -0.05.

Table 3. Empirical estimation of factors affecting probability of being non-employed in Serbia, 2019–2021, adult population – 15+ (marginal effects)

Dependent variable	Probability of being non-employed					
Independent variables	2019		2020		2021	
	Marginal effect	95% Conf. interval	Marginal effect	95% Conf. interval	Marginal effect	95% Conf. interval
Female	0.107*	[0.102,	0.099*	[0.094,	0.100*	[0.095,
	(0.003)	0.112]	(0.003)	0.105]	(0.003)	0.105]
Young	0.338*	[0.331,	0.341*	[0.333,	0.276*	[0.269,
	(0.003)	0.345]	(0.004)	[0.348]	(0.004)	0.283]
Old	0.383*	[0.378,	0.392*	[0.388,	0.401*	[0.397,
	(0.002)	0.387]	(0.002)	0.396]	(0.002)	0.405]
LowEducation	0.139*	[0.133,	0.144*	[0.138,	0.171*	[0.165,
	(0.003)	0.144]	(0.003)	0.150]	(0.003)	0.177]
HighEducation	-0.118*	[-0.125,	-0.102*	[-0.109,	-0.122*	[-0.129,
	(0.004)	-0.111]	(0.004)	-0.095]	(0.004)	-0.116]
Rural	-0.128*	[-0.133,	-0.128*	[-0.133,	-0.093*	[-0.099,
	(0.003)	-0.122]	(0.003)	-0.122]	(0.003)	-0.088]
Vojvodina	0.003	[-0.004,	-0.049*	[-0.056,	0.029*	[0.022,
	(0.004)	0.011]	(0.004)	-0.041]	(0.004)	0.037]
SumadijaWest	-0.033*	[-0.040,	-0.002	[-0.009,	-0.004	[-0.011,
	(0.004)	-0.025]	(0.004)	0.006]	(0.004)	0.004]
SouthEast	-0.010**	[-0.017,	0.007***	[-0.001,	-0.023*	[-0.030,
	(0.004)	-0.002]	(0.004)	0.015]	(0.004)	-0.015]
N	110,320		100,008		98,473	

Notes:
(1) average marginal effects from probit regression are estimated;
(2) *, **, *** refer to statistically significant impact at 1%, 5% and 10 % significance levels, respectively;
(3) robust standard errors were estimated;
(4) standard errors in parentheses;
(5) individual weights were included in the estimation;
(6) the reference variables are male, middle age, secondary education, urban area, Belgrade region.
Source: Authors' calculations based on LFS data.

To assess whether the COVID-19 crisis was associated with higher vulnerability of certain groups on the labour market in terms of being unemployed or inactive (non-employment), the results from 2020 were compared with those from 2019, the year preceding the crisis, and with those from 2021, the year immediately following it. The results in Table 3 show that certain groups in 2019 and 2021 were more vulnerable in terms of the probability of being non-employed, with similar estimated average marginal effects compared to 2020. This indicates that the COVID-19 crisis did not have significant negative effects on specific groups classed as vulnerable on the labour market in Serbia. This conclusion follows from the fact that the probability of being non-employed did not change significantly for most of the observed groups before and after the crisis compared to 2020. For example, the estimated average marginal effect for women is about 0.10 and for people with a higher education level around -0.11 in all three years observed.

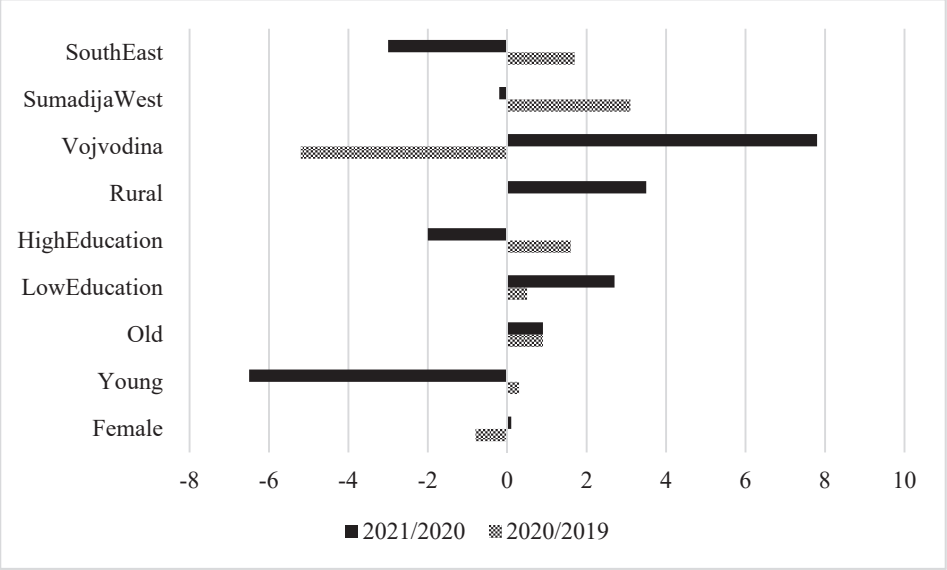
A better insight into the differences in the observed marginal effects is provided by Figure 2, which depicts the differences between the marginal effects for 2020 compared to 2019, and for 2021 compared to 2020. In the case of the female population, a slight negative change in 2020/2019 (-0.8) indicates that women unexpectedly faced slightly better outcomes on the labour market than men during this period, with a negligible positive change in 2021/2020. The higher share of women employed in the public sector (education, health and social care, etc.) could possibly explain why women's relative position improved during the crisis. Unlike in the private sector, layoffs in the public sector were rare, if any, and the public sector served as a shield against non-employment. People from the old age group in both periods experienced an increase in the probability of being non-employed by around 1 percentage point. Therefore, unlike the consistent improvement of the relative position in the case of women, the vulnerability of older workers worsened during the pandemic. Young people experienced a negligible increase in the probability of being non-employed in 2020/2019 (+0.3). But a significant decline in 2021/2020 of -6.5 percentage points is observed, highlighting a substantial positive change in the likelihood of young people being outside employment. The increase in the non-employment probability of young people in 2020 was in line with expectations, as companies usually adopt a last-in-first-out approach during recessions to reduce the cost of layoffs. The sharp decline in this probability in 2021, on the other hand, was likely a consequence of the active labour market measure ‘My First Salary’, the full implementation of

which began in 2021. The measure provided work engagement for more than 10,000 young people, which contributed to the reduction in their inactivity.

In terms of education level, the marginal effects increased by 0.5 percentage points for people with a low education level and by 1.5 percentage points for those with a high level in 2020/2019. In the next period observed, the probability of being non-employed then increased for people with a low education level by almost 3 percentage points, while it decreased for those with a high level by 2 percentage points. One possible explanation for the increase in the probability for people with a low education level in 2021 is related to the nature of the crisis. In contrast to the first phase, which was characterised by national quarantine, the second phase, which took place at the end of 2020 and in the first half of 2021, was marked by social distancing measures. As a result, people with low levels of education, who are overrepresented in the high-contact sectors (tourism and hospitality, manufacturing, personal care, etc.), fared relatively worse in 2021. The opposite is the case for people with higher education levels. For rural workers, the figure shows no change in marginal effects of being non-employed in 2020/2019 and a deterioration in 2021/2020 as marginal effects increased by 3.5 percentage points. As regards the region, the only region where significant changes in the marginal effects of being outside employment occurred is Vojvodina. In the case of people from this region, the likelihood of being non-employed decreased by 5 percentage points in 2020/2019 and then increased by almost 8 percentage points in 2021/2020. One explanation for this phenomenon lies in the economic structure of the region. Of all the regions observed, Vojvodina has the highest share of the agricultural sector. Even during the strictest lockdown, some exemptions were made for agricultural workers due to the low risk of infection. The lower restriction on movement and the higher ability to work reduced the probability of being non-employed in Vojvodina in 2020. With the easing of movement restrictions in 2021, the probability increased. In closing, the figure shows that for most groups on the labour market in Serbia the difference in the two periods observed was moderate (less than 5 percentage points). Among the analysed categories, statistically significant differences in both periods were found for older workers, individuals with higher education levels, residents of the Vojvodina region, and those from the SouthEast region. Additionally, for female workers, no significant difference was found between the two periods, suggesting relative stability in their labour market outcomes.

Certainly, the most notable change occurred among young people in the 2020–2021 period, in which a very strong statistical significance was observed.[2]

Figure 2. Differences in the estimated marginal effects between years (in pp), total population



Source: Authors' calculations based on LFS data.

Similar to our findings, Vladisavljević and Lebedinski (2023a, 2023b) reported that young workers in Serbia faced an increase in job loss rates during the first year of the pandemic, although this effect was found to be transitory. These authors also found no significant gender disparities for the Serbian labour market in employment effects due to the pandemic; thus, their findings align with our results in the sense that women were not disproportionately affected. Finally, similar to our study, Vladisavljević and Lebedinski (2023a, 2023b) showed that workers with low levels of education experienced a significant decline in employment during the crisis. Considered in the broader context of comparison, the study by Lariau and Liu (2022) examined labour market inequalities in Spain during the COVID-19 crisis, and the authors indicated that women, young

[2] The conclusion on statistical significance is based on the confidence intervals presented in Table 3.

individuals, and workers with a lower level of education were the most affected by the pandemic-induced labour market disruptions. Additionally, another study (Zieliński, 2022) examined the impact of the COVID-19 pandemic on the labour markets of four Central European countries and showed that while the pandemic did not significantly worsen the labour market situation for women, greater challenges were faced by youth, old workers, and people with lower education levels. Thus, the findings of these studies align with the conclusions of our study, highlighting the increased labour market vulnerability of certain groups during the pandemic.

Probit regressions were separately estimated for the female and young population and are presented in Table 4 and Table 5[3]. The probit regression estimation in the case of the female population shows that all the variables included are statistically significant with the expected sign. The results show, for instance, that women from the young and old age groups and women with low education levels experience a higher probability of being non-employed, and that women with higher levels of education and women from rural areas have better chances on the labour market. This is the case in all three years observed, whereby the estimated average marginal effects are particularly pronounced in relation to age, indicating that young and old women are especially vulnerable on the Serbian labour market. For example, in 2020, a young female had a significantly higher likelihood of being outside of employment compared to a prime-aged female, with an estimated average marginal effect of 0.34.

In the case of the young population, the results again show that all the variables included are statistically significant with the expected impact. The probit regression estimation indicates that young women and young people with a low level of education experience a higher probability of being non-employed. The opposite is the case for young people with a high level of education and young people from rural areas. This conclusion is valid in all the three years observed. Among the young population, those with a low level of education represent a particularly vulnerable group, according to the value of the estimated average marginal effect. In 2020, for instance, the fact that a young person had a low level

[3] Unlike in the case of the main model, the estimated coefficients of these probit regressions are not presented here to conserve space but are available upon request.

of education increased the probability of being non-employed by almost 40 percentage points in comparison to a young secondary-educated person.

Table 4. Empirical estimation of factors affecting probability of being non-employed in Serbia, 2019–2021, female population (marginal effects)

Dependent variable	Probability of being non-employed					
Independent variables	2019		2020		2021	
	Marginal effect	95% Conf. interval	Marginal effect	95% Conf. interval	Marginal effect	95% Conf. interval
Young	0.330*	[0.320,	0.337*	[0.326,	0.263*	[0.253,
	(0.005)	0.340]	(0.005)	0.347]	(0.005)	0.273]
Old	0.358*	[0.352,	0.360*	[0.353,	0.357*	[0.351,
	(0.003)	0.363]	(0.003)	0.366]	(0.003)	0.362]
LowEducation	0.129*	[0.121,	0.139*	[0.130,	0.170*	[0.161,
	(0.004)	0.137]	(0.004)	0.147]	(0.004)	0.178]
HighEducation	-0.159*	[-0.169,	-0.138*	[-0.148,	-0.155*	[-0.163,
	(0.005)	-0.150]	(0.005)	-0.129]	(0.005)	-0.146]
Rural	-0.107*	[-0.114,	-0.108*	[-0.116,	-0.070*	[-0.078,
	(0.004)	-0.099]	(0.004)	-0.101]	(0.004)	-0.063]
Vojvodina	0.011**	[0.001,	-0.045*	[-0.056,	0.019*	[0.009,
	(0.005)	0.022]	(0.005)	-0.035]	(0.005)	0.029]
SumadijaWest	-0.034*	[-0.044,	-0.009***	[-0.019,	0.003	[-0.007,
	(0.005)	-0.024]	(0.005)	0.002]	(0.005)	0.013]
SouthEast	-0.014*	[-0.024,	0.013*	[0.002,	-0.025*	[-0.035,
	(0.005)	-0.004]	(0.005)	0.024]	(0.005)	-0.015]
N	57,131		51,976		51,223	

Notes:
(1) average marginal effects from probit regression are estimated;
(2) *, **, *** refer to statistically significant impact at 1%, 5% and 10 % significance levels, respectively;
(3) robust standard errors were estimated;
(4) standard errors in parentheses;
(5) individual weights were included in the estimation;
(6) the reference variables are middle age, secondary education, urban area, Belgrade region.

Source: Authors' calculations based on LFS data.

The previous results, unrelated to the pandemic, show that in the labour market of Serbia, young women and young people with a low education level are the groups whose position is the worst in terms of being employed. This is consistent with the findings of the official statistics and results of previous studies dealing

with this issue. It would be expected then that these groups would be more vulnerable to crises, and that the negative effects of the pandemic should be particularly pronounced for these groups. To test this assertion, the differences in the observed marginal effects in 2020 versus 2019 and in 2021 versus 2020 were calculated to gain an insight into the changes that occurred in these two periods.

Table 5. Empirical estimation of factors affecting probability of being non-employed in Serbia, 2019–2021, young population – 15–29 (marginal effects)

Dependent variable	Probability of being non-employed					
Independent variables	2019		2020		2021	
	Marginal effect	95% Conf. interval	Marginal effect	95% Conf. interval	Marginal effect	95% Conf. interval
Female	0.144* (0.006)	[0.131, 0.156]	0.149* (0.007)	[0.136, 0.163]	0.151* (0.007)	[0.137, 0.164]
LowEducation	0.352* (0.007)	[0.338, 0.366]	0.380* (0.008)	[0.364, 0.395	0.379* (0.008)	[0.363, 0.394]
HighEducation	-0.192* (0.009)	[-0.210, -0.174]	-0.188* (0.010)	[-0.206, -0.169]	-0.197* (0.010)	[-0.217, -0.177]
Rural	-0.123* (0.006)	[-0.136, -0.110]	-0.121* (0.007)	[-0.134, -0.107]	-0.119* (0.007)	[-0.133, -0.105]
Vojvodina	-0.029* (0.010)	[-0.048, -0.010]	0.058* (0.010)	[0.038, 0.077]	0.087* (0.010)	[0.066, 0.107]
SumadijaWest	0.056* (0.009)	[0.038, 0.075]	0.086* (0.010)	[0.067, 0.106]	-0.004 (0.011)	[-0.025, 0.017]
SouthEast	0.062* (0.009)	[0.043, 0.080]	-0.004 (0.010)	[-0.024, 0.016]	0.036* (0.010)	[0.016, 0.057]
N	17,160		14,799		14,313	

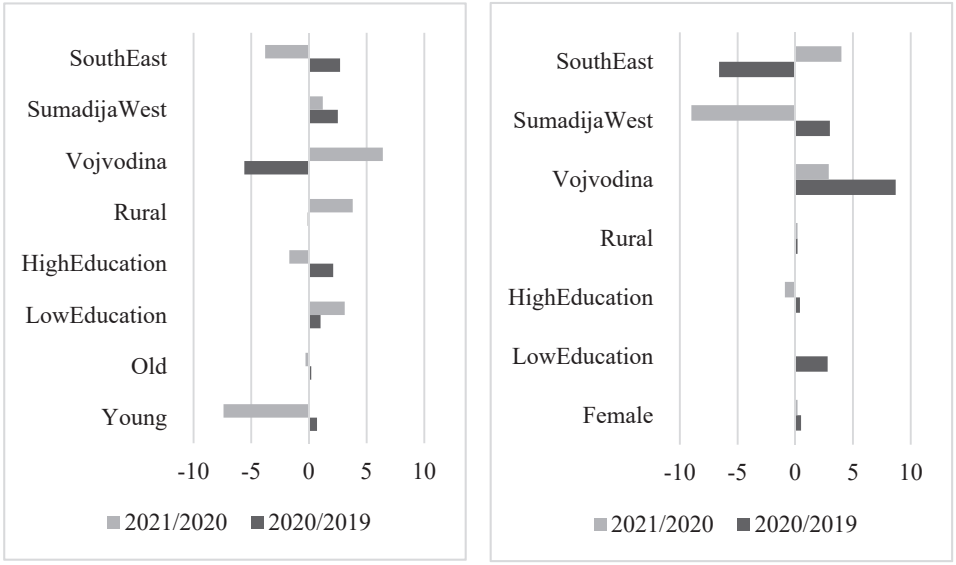
Notes:
(1) average marginal effects from probit regression are estimated;
(2) *, **, *** refer to statistically significant impact at 1%, 5% and 10 % significance levels, respectively;
(3) robust standard errors were estimated;
(4) standard errors in parentheses;
(5) individual weights were included in the estimation;
(6) the reference variables are male, secondary education, urban area, Belgrade region.

Source: Authors' calculations based on LFS data.

Figure 3 depicts the differences in the estimated marginal effects obtained from the probit regressions for the female and the young populations. The figure in the left panel shows than in 2020 compared to 2019, the likelihood of being non-

employed did not increase for various groups within the female population on the labour market in Serbia. When examining the difference between 2021 and 2020, it can be observed that in the case of young women, the probability of being non-employed decreased by 7.5 percentage points (the reference category is prime-aged women). The figure in the right panel indicates that, in 2020 compared to 2019, the difference in marginal effects was not substantial for most subgroups within the young population, except for young people in the Vojvodina region, who experienced an increase in the probability of being non-employed of almost 7 percentage points.

Figure 3. Differences in the estimated marginal effects between years (in pp), female population (left panel) and young population (right panel)



Source: Authors' calculations based on LFS data

7. CONCLUSION

The health crisis facing the world in 2020 was an unprecedented global challenge for at least two reasons. First, the last pandemic of this magnitude, the Spanish flu outbreak, had occurred more than 100 years earlier, with the result that there was insufficient institutional memory to prepare states for an effective response. Second, the world was far less globalised and interconnected at the time of the

Spanish flu outbreak, which means the measures to prevent the spread of the virus must have been markedly different. Like other countries in the world, Serbia faced uncertainty in two respects – how to prevent the spread of the virus, and what measures to implement to mitigate the impact of the health crisis on the economy and population.

The aid package introduced by the Serbian government was extremely generous, with the decision to give more weight to universality than selectivity when designing the measures. Guided by the logic that insisting on a precise targeting of vulnerable groups in a short period of time would lead to major inclusion and exclusion errors, they opted for universality, at least when it came to the most important stimulus measures for the economy and the population. Since the share of the population/workers in most of the key measures was relatively high, it was obvious that the performance of the economy would largely depend on the measures themselves.

Seen from this distance in time, it can be said that the government was relatively successful with its intentions. Gross domestic product fell only slightly in 2020, while the key indicators on the labour market actually improved – the employment rate of the working-age population rose and the unemployment rate fell. Nevertheless, it is already clear from the macro data that certain groups on the labour market fared significantly worse than others. Although overall employment remained unchanged, a large number of precarious workers, for example, lost their jobs, i.e. those engaged through non-standard work arrangements, on fixed-term contracts, and employees working in the informal labour market.

Despite the decline in unemployment, however, there was a significant increase in inactivity. This is an important fact that distinguishes the pandemic crisis from other recessions in economic history (Organisation for Economic Co-operation and Development [OECD], 2021). To find out which groups of workers were most affected by leaving employment, it was necessary for us to look beyond the macro data. Therefore, we carried out an econometric analysis based on microdata from the LFS. As it turns out, the COVID-19 pandemic did not have a strong negative impact on most vulnerable groups, as the probability of being non-employed for most of them did not differ significantly before and during the

pandemic years. However, some deterioration in the relative position was observed for young and older people, as well as those with a lower level of education. A strong government response helped young people to reduce the probability of non-employment even below the pre-pandemic level. On the other hand, the government's measures were not as effective when it came to targeting the elderly and people with low levels of education, which is why their relative position deteriorated further in 2021.

It is fair to say that the groups we have singled out as most affected by the crisis would likely have fared much better if the state had opted for selective measures aimed at them. The following represent some of these possible options: subsidies for the most vulnerable companies instead of all companies, including those operating in the online environment even under regular conditions; a more generous programme for young people, such as 'First Chance' in 2009, which guaranteed employment, instead of 'My First Salary', which did not include a work obligation; more support for the unemployed, especially those from such hard-to-employ categories as older people and people with a low level of education, instead of universal support for the entire population. However, this type of government response would most likely result in somewhat slower economic growth and lower overall labour market performance. It was the strong universal stimulus to the population that primarily helped to maintain and perhaps even increase aggregate demand. Without it, the selective measures on the supply side would certainly have been less effective.

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APPENDIX

Table A1 Descriptive statistics, 2019–2021 (15+)

2019					
Variable	Obs	Mean	Std. Dev.	Min	Max
Employed	110320	.489	.499	0	1
NonEmployed	110320	.510	.499	0	1
Male	110320	.482	.499	0	1
Female	110320	.517	.499	0	1
Young	110320	.190	.392	0	1
Old	110320	.408	.491	0	1
Middle	110320	.400	.490	0	1
LowEducation	110320	.290	.453	0	1
MiddleEducation	110320	.513	.499	0	1
HighEducation	110320	.196	.397	0	1
Urban	110320	.599	.490	0	1
Rural	110320	.400	.490	0	1
Belgrade	110320	.242	.428	0	1
Vojvodina	110320	.267	.442	0	1
SumadijaWest	110320	.276	.447	0	1
SouthEast	110320	.212	.409	0	1
2020					
Employed	100008	.491	.500	0	1
NonEmployed	100008	.509	.500	0	1
Male	100008	.482	.500	0	1
Female	100008	.518	.500	0	1
Young	100008	.189	.391	0	1
Old	100008	.410	.492	0	1
Middle	100008	.401	.490	0	1
LowEducation	100008	.282	.450	0	1
MiddleEducation	100008	.518	.500	0	1
HighEducation	100008	.199	.399	0	1
Urban	100008	.589	.492	0	1
Rural	100008	.411	.492	0	1
Belgrade	100008	.244	.430	0	1
Vojvodina	100008	.276	.447	0	1
SumadijaWest	100008	.212	.408	0	1
SouthEast	100008	.268	.443	0	1

2021					
Employed	98,473	.486	.499	0	1
NonEmployed	98,473	.509	.499	0	1
Male	98,473	.482	.499	0	1
Female	98,473	.517	.499	0	1
Young	98,473	.186	.389	0	1
Old	98,473	.411	.492	0	1
Middle	98,473	.401	.490	0	1
LowEducation	98,473	.275	.446	0	1
MiddleEducation	98,473	.518	.499	0	1
HighEducation	98,473	.205	.404	0	1
Urban	98,473	.585	.492	0	1
Rural	98,473	.414	.492	0	1
Belgrade	98,473	.245	.430	0	1
Vojvodina	98,473	.210	.407	0	1
SumadijaWest	98,473	.267	.442	0	1
SouthEast	98,473	.275	.446	0	1

Source: Authors' calculations based on LFS data.

Table A2 Probit regression estimates, 2019–2021

2019					
NonEmployed	Coef.	St.Err.	[95% Conf. interval]		Sig.
Female	.345	.008	.329	.361	*
Young	1.09	.013	1.065	1.114	*
Old	1.234	.009	1.216	1.253	*
LowEducation	.447	.01	.428	.467	*
HighEducation	-.381	.012	-.404	-.358	*
Rural	-.411	.009	-.429	-.394	*
Vojvodina	.011	.013	-.014	.036	
SumadijaWest	-.105	.012	-.13	-.081	*
SouthEast	-.032	.012	-.056	-.007	**
Constant	-.666	.013	-.69	-.641	*
Pseudo R-squared	0.200				
Number of obs.	110320				

** p<.01, ** p<.05, *** p<.1*

2020					
NonEmployed	Coef.	St.Err.	[95% Conf. interval]		Sig.
Female	.324	.009	.307	.341	*
Young	1.109	.014	1.083	1.136	*
Old	1.277	.01	1.257	1.296	*
LowEducation	.469	.011	.448	.49	*
HighEducation	-.332	.012	-.356	-.308	*
Rural	-.415	.01	-.434	-.397	*
Vojvodina	-.158	.013	-.184	-.133	*
SumadijaWest	-.005	.013	-.031	.02	
SouthEast	.023	.013	-.004	.049	***
Constant	-.686	.013	-.712	-.66	*
Pseudo R-squared	0.204				
Number of obs.	100008				

** p<.01, ** p<.05, *** p<.1*

2021					
NonEmployed	Coef.	St.Err.	[95% Conf. interval]		Sig.
Female	.339	.009	.322	.357	*
Young	.94	.014	.913	.967	*
Old	1.366	.01	1.345	1.386	*
LowEducation	.582	.011	.561	.604	*
HighEducation	-.417	.012	-.441	-.393	*
Rural	-.318	.01	-.337	-.299	*
Vojvodina	.1	.013	.074	.126	*
SumadijaWest	-.012	.014	-.039	.014	
SouthEast	-.077	.013	-.103	-.052	*
Constant	-.759	.013	-.786	-.733	*
Pseudo R-squared	0.231				
Number of obs	98473				

** p<.01, ** p<.05, *** p<.1*

Source: Authors' calculations based on LFS data.

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WHAT ARE THE PRIMARY SOURCES OF AIR POLLUTION IN INDIAN CITIES?

ABSTRACT: *India is the world's third most polluted country, with most of its cities ranking among the worst. This calls India's ambitions for sustainable urban growth into question. In this perspective, the present study investigates the sources of city air pollution in India. Due to the paucity of data, we consider 36 metropolitan cities (cities with a million-plus population) for the analysis. Eight pollutants are considered to measure air pollution at the city level. Based on several Sustainable Development Goals, indicators for infrastructure, population agglomeration, transport, waste generation, climate action, energy use, life on land are considered for the assessment. Using principal component analysis, we created pollution and infrastructure indices. The results show that Delhi is the most polluted city and Bangalore has the highest availability of infrastructure of all cities in India. The ordinary regression results show that infrastructure, waste generation, registered motor vehicles, and population size positively affect (increase) air pollution. Additionally, clean fuel usage, light-emitting diode bulb distribution, and open space negatively impact (decrease) air pollution. The study concludes with important policy interventions to address urban air pollution effectively for higher and sustainable urban growth in India.*

KEY WORDS: *Urbanisation, air pollution, infrastructure, clean energy, India*

JEL CLASSIFICATION: R11, Q53, 018

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1. INTRODUCTION

Urbanisation is one of the most influential human activities of the Anthropocene (McPhearson et al., 2021). The positive impacts of urbanisation on economic growth have been extensively studied (Northam, 1979) and are considered a vital catalyst for social advancement (Kates & Parris, 2003). Cities, the epicentres of urbanisation, have become hubs of innovation and opportunities, attracting people from diverse backgrounds and fostering a culture of inclusivity and growth. However, rampant urbanisation has caused severe air pollution, particularly in metropolitan areas with more concentrated and complicated human activities, undermining urban sustainability (Sun et al., 2023). This poses a threat to the environment and has severe implications for human health and well-being (Brook et al., 2010). According to the World Health Organisation (WHO), in 2019, 99% of the world's population was living in places where the WHO's air quality guidelines were not met, leading to an estimated 4.2 million premature deaths due to ambient air pollution, with a significant proportion of these occurring in urban areas.[1] Urbanisation and air pollution are both closely linked to sustainable development and human well-being (Chen et al., 2022). This connection is explicitly recognised in the United Nations Sustainable Development Goals (SDGs), particularly SDG 11, which aims to "make cities and human settlements inclusive, safe, resilient, and sustainable" (United Nations, 2015). Achieving this goal necessitates a comprehensive understanding of the dynamics of urbanisation and its impact on air pollution.

Most developed countries have achieved decoupling of economic growth from air pollution or emissions; this means that their emissions have decreased even as their GDP has increased (Hubacek et al., 2021). This achievement is attributed to strategic planning, sustainable infrastructure investments, and effective regulatory measures in managing urbanisation. In contrast, many developing countries, including India, are experiencing rapid and often unplanned urbanisation, exacerbating air pollution problems. The combination of increased industrial activities, transportation, and household emissions, coupled with limited infrastructure and regulatory frameworks, has resulted in severe air

[1] https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health (accessed on 19 March, 2025)

quality degradation in major Indian cities (Nagdeve, 2006) with significant implications for public health (Misra et al., 2019).

Agglomeration benefits associated with higher per capita income may cause higher pollution in cities via higher production and consumption. A high per capita income leads to affordability and the demand for private vehicles, which in turn causes environmental degradation and increased energy use. Cities' expansion mostly depends on the advantages of the agglomeration economy, but after a certain point, negative externalities, such as an increase in pollution, cause cities' growth to stagnate. Indeed, these harmful externalities can be linked to policy failures and the absence of regulatory mechanisms.

Between 2001 and 2011, the percentage of private vehicles in India that are specifically designed for urban use, such as motorcycles and scooters, climbed from 24.7% to 35.2%. Moreover, the proportion of cars, jeeps, and vans rose from 5.6% in 2001 to 9.7% in 2011 (Tripathi & Kaur, 2018). Deterioration of the environment is caused by an increase in the number of vehicles. Air pollution is produced by the principal greenhouse gases carbon monoxide (CO), sulphur dioxide (SO2), carbon dioxide (CO2), and nitrogen dioxide (NO2). After the China and the United States (US), India was ranked the third largest producer of greenhouse gas emissions in 2022 (European Commission, Joint Research Centre, 2023).

Building upon the existing literature on urbanisation and air pollution, this study aims to provide a comprehensive assessment of the impact of various urbanisation indicators on air pollution in 36 metropolitan cities across India. While previous research has often focused on specific pollutants or employed broad geographical scales, this study addresses these limitations by utilising city-level data encompassing a wide range of air quality indicators, urban infrastructure, transportation, waste generation, and population dynamics. By adopting this approach, the study offers a more nuanced understanding of the intricate relationship between urbanisation and air pollution, particularly within India's rapidly growing urban centres. Through granular analysis, the study seeks to identify key drivers of air pollution in Indian metropolitan cities and inform targeted policy interventions to mitigate its adverse effects. This study contributes

to the broader discourse on sustainable urban development and human well-being by bridging the gap between research and policy.

The study adopts the following structure. In the next section, a brief review of the literature is presented. Section 3 explains the main conceptual framework of the study. Section 4 provides the data and methods and Section 5 the empirical results. Sections 6 and 7 present the discussion and conclusions, respectively. Finally, Section 8 highlights the main limitations of the study.

2. REVIEW OF LITERATURE

Early studies of the relationship between urbanisation and environmental pollution focused on the relationships between population growth, resources, economic growth, and the environment. Grossman and Krueger (1991) integrated the Kuznets curve concept into exploring how economic development impacts environmental pollution, proposing the environmental Kuznets curve (EKC). They discovered an inverted U-shaped correlation between economic growth and environmental pollution (Grossman & Krueger, 1995). Dinda (2004) confirmed that the dynamic between economic growth and environmental pollution in developed nations adheres to the EKC hypothesis. Population increase has also been identified as a significant contributor to environmental pollution (Jorgensen and Clark, 2010).

Nonetheless, urbanisation encompasses more than just demographic shifts; it involves population, economy, society, and spatial organisation transformations. The impact of urbanisation on environmental pollution varies across countries and regions, depending on their level of development (Grimm et al., 2008). In their examination of 99 countries, Poumanyvong and Kaneko (2010) investigated how urbanisation affects energy consumption and carbon emissions, considering population size, GDP per capita, the urbanisation rate, and industrial composition. They observed that in low-income nations, urbanisation leads to reduced energy consumption. In contrast, it increases energy use in middle-income and high-income countries and consistently contributes to higher carbon emissions. Martínez-Zarzoso and Maruotti (2011) demonstrated that the relationship between urbanisation and carbon emissions in developing countries also follows an inverted U-shaped curve.

In the context of developing countries, the relationship between urbanisation and air pollution becomes even more complex. Rapid urbanisation in these regions often outpaces infrastructure development and regulatory frameworks, increasing pollution (Cohen, 2006). For instance, in many African cities, rapid urban growth has led to increased vehicle emissions, industrial pollution, and waste burning, contributing to poor air quality (Songsore, 2003). Similarly, in Latin America, urbanisation has been linked to increased deforestation and land degradation, leading to increased carbon emissions (Perz & Skole 2003). The situation is particularly concerning in India, a country experiencing rapid urbanisation. Indian cities are among the most polluted in the world, with high levels of PM2.5 and PM10 (Balakrishnan et al., 2019). The rapid growth of cities and a lack of effective pollution control measures have led to severe air quality issues. Studies have shown that in India, urbanisation has a significant positive relationship with CO_2 emissions (Paul and Bhattacharyya, 2004).

Table 1 summarises the empirical studies on the impact of urbanisation on air pollution. The existing research on air pollution often focuses on a limited set of pollutants or employs broad geographical scales. In contrast to existing studies in India that often focus on a restricted range of emissions and indicators of urbanisation, this study tries to fill that gap by utilising a comprehensive set of city-level data.

Table 1: A selected review of empirical studies

Author	Objective	Variable	Methodology	Source of Data	Conclusion
International context					
Wang et al. (2021)	Analyse impacts of urbanisation on carbon emissions in OECD countries	Independent variables: economic growth, energy efficiency, final energy consumption of industry, transport, residential sectors, urban population ratio. Dependent variables: CO2 emissions per capita, total CO2 emissions, CO2 emission intensity	Dynamic panel autoregressive distributed lag (ARDL) model	Carbon Dioxide Information Analysis Center (CDIAC), World Banks's World Development Indicators (WDI), International Energy Agency (IEA) World Energy Balances	Urbanisation negatively impacts carbon emissions in OECD countries. Decoupling between urbanisation and emissions is observed, indicating potential for sustainable urban development.
Khoshnevis Yazdi and Dariani (2019)	Explore urbanisation's impact on CO2 emissions in Asian countries	Dependent variable: CO2 emissions Independent variable: GDP/capita, energy consumption, urban population (in %), trade (export + import)/GDP) (1980–2014)	Stochastic impacts by regression population; affluence and technology (STIRPAT) model and panel data analysis	World Bank's World Development Indicators (2015)	Found a positive link between urbanisation and CO2 emissions in Asia, driven by economic growth and increased energy use. Urges policies blending urban development with environmental goals for sustainable growth.
Bereitschaft and Debbage (2014)	To explore the relationships between urban form and air pollution among 86 large US metropolitan areas.	Dependent variables: O3, NOx, VOCs, PM2.5, CO2 Independent variables: sprawl index, population density, land use mix, and urban continuity/urban shape complexity. Control variables: temperature, moisture, metropolitan population, and metropolitan land area.	Ordinary least squares (OLS)	US Census Bureau and the National Land Cover Database, US Environmental Protection Agency's Air Quality System (AQS).	Metropolitan areas with higher levels of urban sprawl generally exhibited higher concentrations and emissions of air pollution and CO2. Metropolitan areas with higher population density and more mixed land use patterns generally exhibited lower concentrations and emissions of air pollution and CO2.
Borck, R., & Schrauth (2021)	Analyse the impact of population density on urban air quality in Germany.	NO2, PM10, PM2.5, O3, Aggregate AQI	Panel data analysis for German districts. Instrumental variables and long difference regressions.	Administrative panel data from Germany for 2002–2015. Emission data from the German Environmental Agency for 2002–2015.	Denser cities increase NO2 and PM10 by 0.25% and 0.07%, respectively. PM2.5 results are less precise but similar to PM10. O3 concentrations decrease with denser cities, while aggregate AQI decreases with population density.

Indian context					
Misra et al. (2019)	Estimate the impact of urban growth on air quality in Indian cities using a hierarchical Bayesian approach	PM 2.5, urban land-use, brick kiln, vehicle kilometers travelled, emission intensity, seasonal emission activity, meteorological data	Hierarchical Bayesian framework, land-use regression model incorporating remote sensing and meteorological data	Moderate resolution imaging spectroradiometer (MODIS), Google Earth imagery, Ministry of Road Transport and Highways, World Resource Institute	Successful prediction of rising PM2.5 levels due to urban growth, identification of primary contributors to PM2.5 emissions, seasonal emission activity effects, and importance of considering socioeconomic factors in policy formulation.
Sridhar (2018)	Aims to analyse the determinants of carbon emissions in India and China, with a focus on the relationship between urban land use regulations and emissions in Indian cities.	Dependent variable: CO2 emissions Independent variables: exports & imports, urban population, electric power consumption, industry, value added, electricity production from coal sources, GDP per capita (1971–2011)	Cross-national regression analysis	World Bank's World Development Indicators	Analysis of carbon emissions data in India and China suggests a positive correlation with electricity consumption and GDP per capita. Surprisingly, urbanisation shows no significant impact on emissions per capita or per unit area.
Ahmad et al. (2015)	Discuss carbon dioxide emissions from direct energy use of urban households in India and their determinants across 60 major Indian cities.	Household income, household size, urban density, access to urban amenities, energy consumption for cooking, water heating, lighting, air conditioning	Panel regression analysis	National Sample Survey (NSS) "Household Consumer Expenditure" (July 2009–June 2010)	The conclusion of the study is that income and household size are the most important determinants of household emissions. Urban density is negatively correlated with emissions except for cooking fuel emissions. Access to urban amenities increases overall emissions.

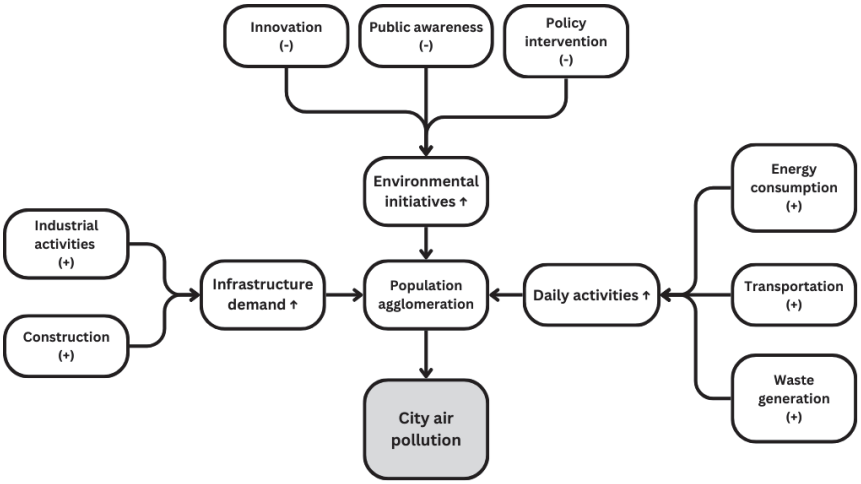
Source: Authors' compilation

3. CONCEPTUAL FRAMEWORK IN THE CONTEXT OF INDIA

Urban agglomeration has both positive and negative effects on the environment. Krugman's (1992) core-periphery model considered increasing returns to scale and transport costs and explained that centrifugal and centripetal forces form the urban system (Fujita et al., 2001). Agglomeration drivers include diversity preference, the home market effect, and increasing returns; centrifugal forces include crowding impacts, the rising cost of living, and pollution. A common belief is that environmental pollution slows down agglomeration (Wang & Wei, 2019). Agglomeration does not always result in more pollution, though, as the management of pollutant emission abatement may benefit from economies of scale. The spatial concentration of possible polluters may help with processing or limiting pollutant emissions (Kyriakopoulou & Xepapadeas, 2013; Verhoef & Nijkamp, 2002; Wei & Ewing, 2018; Wei, 2016; Lu & Feng, 2014).

Agglomeration, however, has the potential to degrade the environment by increasing pollutant emissions (Mao & He, 2017). Based on the *pollution haven hypothesis*, district-level abatement policies may encourage polluting companies to relocate to less developed areas (Shen at al., 2017; Copeland & Taylor, 2004; Wang & Wei, 2019).

Figure 1: Diagrammatical representation of the relationship between urbanisation and city air pollution



Source: Authors' compilation

Rapid urbanisation in India presents a complex challenge. While cities fuel economic growth, they also concentrate multiple activities within a confined space, leading to several environmental issues, with air pollution at the forefront. Figure 1 presents a conceptual framework that examines the impacts of urbanisation on air quality in urban India. According to Carozzi and Roth (2023), dense urban living limits emission dispersion among polluters due to reduced average distance between individuals. However, poor urban planning makes things worse. As the urban agglomerations expand, energy demands increase to meet the needs of the burgeoning population. This increases industrial activity and daily life emissions (Yang et al., 2021). The relentless demand for housing and transportation infrastructure leads to congested roads and longer commutes, further intensifying reliance on vehicles and their associated emissions (Yang et al., 2021).

In nearly every Indian city, transportation is the primary source of air pollutants, largely due to the escalating number of vehicles, which is outpacing existing infrastructure, such as roads and fuel stations (Gurjar et al., 2004). Gurjar et al. (2016) found that from 1951 to 2012, the number of motorised vehicles in India surged from 0.3 million to 159.5 million. They also argued that urban areas such as Delhi, Mumbai, Bengaluru, and Kolkata bear a significant burden of vehicular emissions, with road traffic being a major contributor to air pollution. Road dust notably contributes to particulate matter (PM) emissions in major cities like Delhi, Mumbai, and Kolkata (Gurjar, 2021). Moreover, inadequate municipal solid waste (MSW) management practices add to air pollution issues. Approximately 80% of MSW is disposed of in open dumping yards and landfills, leading to various greenhouse gas emissions and environmental concerns (Gurjar, 2021). In Delhi alone, burning garbage and MSW generates substantial PM10 and PM2.5 annually (Nagpure et al., 2016). India's energy usage is central to air pollution and climate change challenges, with implications for the growing urban population (International Energy Agency [IEA], 2021). The rapid industrialisation witnessed in recent decades has further deteriorated air quality, particularly in urban areas. Certain industries, categorised by the Central Pollution Control Board, contribute significantly to pollution, emitting pollutants such as SPM, SOX, NOX, and CO2 (Gurjar et al., 2016).

Construction activities also contribute to air pollution through dust and emissions from machinery (Tomar & Tyagi, 2022). Even after completion, construction waste adds to pollution and potential greenhouse gas emissions (Guttikunda & Goel, 2013). Integrating green building technologies and materials could mitigate these issues and maintain cleaner air quality (Tomar & Tyagi, 2022).

Despite the challenges, it is important to acknowledge the potential mitigating factors that can emerge from urbanisation. Densely populated urban areas can incentivise a shift from polluting industries to cleaner, more sustainable ones. Furthermore, urbanisation can foster technological innovation for emission reduction and pollution control. As cities grow, environmental awareness among residents can also rise, potentially leading to increased demand for cleaner air and prompting stricter environmental regulations (Yang et al., 2021).

The conceptual framework suggests that as the concentration of population increases within urban areas, there is an anticipated rise in the demand for infrastructure and daily activities, subsequently contributing to elevated levels of city air pollution. However, environmental efforts implemented within these densely populated regions can potentially mitigate this pollution.

4. DATA AND METHODS

4.1 Data

The study includes the following 36 Indian metropolitan cities: Agra, Ahmadabad, Allahabad, Amritsar, Aurangabad, Bangalore, Bhopal, Chennai, Coimbatore, Delhi, Dhanbad, Mumbai, Gwalior, Hyderabad, Indore, Jaipur, Jodhpur, Kanpur, Kolkata, Kota, Lucknow, Ludhiana, Madurai, Nagpur, Nashik, Patna, Pune, Raipur, Rajkot, Ranchi, Srinagar, Surat, Vadodara, Varanasi, Vijayawada, and Visakhapatnam.

Table 2 outlines the study's variables and their respective sources. The emissions data for Chennai, Pune, Jaipur, Kanpur, Nagpur, Indore, Bhopal, Patna, Ludhiana, Agra, Varanasi, Amritsar, Coimbatore, Raipur, Bangalore, and Ranchi are sourced from 2015. For Mumbai, Hyderabad, Ahmedabad, Kolkata, Allahabad (Prayagraj), Gwalior, Surat, Lucknow, Vishakhapatnam, Vadodara,

Nashik, Rajkot, Srinagar, Aurangabad, Dhanbad, Vijayawada-Guntur, Jodhpur, Madurai, and Kota, the data pertain to 2018. Lastly, the emissions data for Delhi-NCR are from 2020. Furthermore, the data on waste generation (tonnes per day) correspond to 2015–16.

Table 2: Variables used and their sources

Variable	Source
Air pollution indicators:	urbanemissions.info and Sahu et al. (2023) for Delhi-NCR
Particulate matter 2.5 (PM 2.5)	
Particulate matter 10 (PM 10)	
Black carbon (BC)	
Organic carbon (OC)	
Nitogen oxides (NOx)	
Carbon monoxide (CO)	
Volatile organic compounds (VOC)	
Sulphur dioxide (SO2)	
Infrastructure indicators:	2011 Census data, GOI. (https://censusindia.gov.in/census.website/)
Pucca road length (km) (road)	
Total number of latrines (latrines)	
Total number of electricity connections (electricity)	
Total number of hospitals (hospitals)	
Total number of schools (schools)	
Total number of colleges (colleges)	
Total number of working women's hostels (women hostels)	
Total number of banks (banks)	
Total number of credit societies (credit soc)	
Population agglomeration factors:	
Growth rate (growth)	
Density (density)	
Total population (pop)	
Transport indicators:	Road Transport Yearbook (2019-20) by Ministry of Road Transport and Highways (https://morth.nic.in/road-transport-year-books)
Total registered motor vehicles (vehicles)	
Waste generation:	Central Pollution Control Board (CPCB) (https://cpcb.nic.in/)
Waste generation (tonnes per day) (waste)	

SDG 13 (Climate Action) indicators:	SDG Urban Index 2021-22 by NITI Aayog (https://sdgindiaindex.niti.gov.in/urban/#/)
LED bulbs distributed under UJALA per 1,000 population (bulbs)	
SDG 7 (Affordable and Clean Energy) indicators:	
Percentage of households using clean fuel for cooking (clean fuel)	
SDG 15 (Life on Land) indicators:	
Area under green cover as a percentage of total area (green cover)	
Open space for public use as a share of total area (percentage) (open space)	

Source: Authors' compilation

4.2 Methodology

This study employed the following OLS regression model:

$$Air\ pollution = \alpha_0 + \sum_{i=1}^{7} \alpha_i X_i + \epsilon, \quad (1)$$

where air pollution is a dependent variable and is measured by a total of eight pollutants, X_i are independent variables including infrastructure, population agglomeration, transport, waste generation, climate action, energy use, and *life on land* indicators, and ϵ is a well-behaved error term.

Based on previous research, this study identifies the following as significant determinants of air pollution: urban population (Wang et al., 2021; Khoshnevis Yazdi & Dariani, 2019; Sridhar, 2018), density (Bereitschaft & Debbage, 2014; Ahmad et al., 2015), transport (Wang et al., 2021), and energy consumption (Wang et al., 2021; Sridhar, 2018; Ahmad et al., 2015).

We employ principal component analysis (PCA), a powerful statistical tool for condensing complex datasets by extracting essential information into more manageable summary indices. Reducing dimensionality helps uncover patterns and highlights the most critical parameters within a dataset. Unlike subjective weighting methods, PCA objectively assigns weights to variables based on their variability, offering a robust data analysis and interpretation approach. On the basis of PCA, we calculated pollution and infrastructure indices.

5. EMPIRICAL RESULTS

5.1 PCA analysis

We estimated the eigenvalues displayed in Table 3 using the PCA technique. Kaiser (1960) suggests retaining principal components with eigenvalues greater than 1; we analysed the eigenvalues for both the emission and infrastructure indices. In the emission index, only the first principal component (comp1) has an eigenvalue greater than 1, while in the infrastructure index, the first three principal components (comp1, comp2, and comp3) meet this criterion. Hence, we focus on these components for further analysis.

Table 4 displays the weights derived from a rotated orthogonal varimax. For the emission index, PM 2.5, PM 10, and BC stand out with the highest weight among the indicators, although the difference between the weights of all indicators is minimal. As for the infrastructure index, pucca (i.e. metalled) road length ranks first in component 1.[2] The total number of hospitals holds the highest weight in component 2, while the total number of credit societies ranks first in component 3.

Table 3: Principal components estimates for emission and infrastructure indicators

Emission					Infrastructure				
Component	Eigenvalue	Difference	Proportion	Cumulative	Component	Eigenvalue	Difference	Proportion	Cumulative
Comp1	**6.70062**	6.14995	0.8376	0.8376	Comp1	**5.34982**	4.2478	0.5944	0.5944
Comp2	0.55067	0.245241	0.0688	0.9064	Comp2	**1.10202**	0.053915	0.1224	0.7169
Comp3	0.30543	0.045742	0.0382	0.9446	Comp3	**1.0481**	0.410729	0.1165	0.8333
Comp4	0.259688	0.14226	0.0325	0.9771	Comp4	0.637376	0.303911	0.0708	0.9041
Comp5	0.117428	0.086139	0.0147	0.9917	Comp5	0.333465	0.131707	0.0371	0.9412
Comp6	0.031289	0.00429	0.0039	0.9956	Comp6	0.201758	0.024474	0.0224	0.9636
Comp7	0.026999	0.019129	0.0034	0.999	Comp7	0.177284	0.046678	0.0197	0.9833
Comp8	0.007871	.	0.001	1	Comp8	0.130606	0.11104	0.0145	0.9978
					Comp9	0.019566	.	0.0022	1

[2] Pucca roads are paved roads that are typically found in towns and cities and are made of materials like concrete or tar.

Table 4: Varimax rotated component loadings (pattern matrix)

Emission			**Infrastructure**				
Variable	Comp1	Unexplained	Variable	Comp1	Comp2	Comp3	Unexplained
PM 2.5	0.3571	0.1455	road	**0.463**	-0.1145	0.0268	0.1373
PM 10	0.3752	0.05694	latrines	0.292	**0.3397**	-0.0553	0.09336
BC	0.3764	0.05074	electricity	0.3072	**0.3124**	0.0244	0.08373
OC	0.3601	0.131	hospitals	-0.1194	**0.7389**	-0.0271	0.2371
NOx	0.3583	0.1396	schools	**0.4075**	0.0354	0.0178	0.1756
CO	0.3393	0.2287	colleges	**0.4167**	-0.139	0.1633	0.2875
VOC	0.3401	0.225	women hostels	**0.4624**	-0.1962	-0.199	0.2008
SO2	0.3181	0.3219	banks	0.1955	**0.4108**	0.063	0.2602
			credit soc	-0.0026	-0.0089	**0.9614**	0.0246

Source: Authors' calculation

Table 5 presents the ranking of cities on the basis of emission and infrastructure indices according to the PCA. The ranking indicates that Delhi stands out with the highest level of emissions among the listed cities. On the other hand, Bangalore takes the lead in infrastructure, signifying the most developed infrastructure. Other notable cities with high emission rankings include Kolkata, Chennai, and Greater Mumbai. Cities such as Surat, Ahmadabad, and Hyderabad also have relatively high emission rankings. In terms of infrastructure, Pune, Chennai, and Greater Mumbai show strong rankings. At the lower end of the emission ranking spectrum, Coimbatore, Aurangabad, and Madurai have lower emission levels. As for infrastructure, Varanasi, Delhi, and Kanpur, and are among the cities with lower-ranking infrastructure.

Table 5: Emission rank and Infrastructure rank of the cities

City	Emission rank	Infrastructure rank
Agra	34	22
Ahmadabad	7	8
Allahabad	17	20
Amritsar	28	15
Aurangabad	31	23
Bangalore	11	1
Bhopal	36	12
Chennai	3	3
Coimbatore	30	30
Delhi	1	35
Dhanbad	5	32
Greater Mumbai	4	4
Gwalior	33	24
Hyderabad	8	10
Indore	32	13
Jaipur	21	7
Jodhpur	25	19
Kanpur	16	34
Kolkata	2	2
Kota	22	28
Lucknow	13	5
Ludhiana	24	14
Madurai	35	26
Nagpur	9	9
Nashik	20	16
Patna	19	25
Pune	18	6
Raipur	12	29
Rajkot	26	21
Ranchi	27	33
Srinagar	23	31
Surat	6	11
Vadodara	15	17
Varanasi	29	36
Vijayawada	14	27
Visakhapatnam	10	18

Source: Authors' calculation

5.2 Regression analysis

Table 6 displays the descriptive statistics and diagnosis of the multicollinearity test. The variance inflation factor (VIF) values range from 1.28 to 15.02, with cities' population having the highest VIF. While the mean VIF remains within acceptable limits (<10), some variables exhibit higher multicollinearity with higher VIFs. Therefore, we use parsimonious regression models to avoid the multicollinearity problem.

Table 6: Descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max	VIF
emission index	36	0.0	2.6	-2.3	11.6	
infra index	35	0.0	2.2	-2.1	10.3	7.55
growth	33	26.2	21.8	-11.7	97.0	4.23
density	36	11,298.7	7,081.7	1,901.0	3,5420.0	2.08
pop	36	2,301,756.0	2,076,912.0	108,534.0	9,356,962.0	15.02
bulbs	36	841.1	611.1	38.9	2,559.0	1.69
clean fuel	36	88.0	12.8	27.6	98.8	1.75
vehicles	34	2,540.4	2,450.8	337.0	1,1893.0	7.51
green cover	30	21.6	21.8	0.1	92.5	1.37
open space	34	10.9	13.9	0.1	43.9	1.28
waste	33	1,737.3	2,446.1	150.0	11,000.0	13.47
Mean VIF						5.60

Source: Authors' calculation

Table 7 displays the correlation coefficient matrix. Strong positive correlations exist between population size and infrastructure (0.78), as well as between waste generation and emissions (0.76). Moderate positive correlations are observed between infrastructure and population growth (0.58), population and population growth rate (0.38), and clean fuel usage and total number of vehicles (0.38). Conversely, a moderate negative correlation is found between emission index and open space (-0.38).

Table 7: Correlation coefficient

	growth	infra index	emission index	density	pop	bulbs	clean fuel	vehicles	green cover	open space	waste
growth	1.00										
infra index	0.58	1.00									
emission index	-0.22	0.00	1.00								
density	-0.08	0.35	0.03	1.00							
pop	0.38	0.78	0.15	0.49	1.00						
bulbs	0.17	-0.16	-0.31	-0.27	-0.36	1.00					
clean fuel	0.04	0.35	0.34	0.12	0.48	-0.51	1.00				
vehicles	0.04	0.51	0.78	0.18	0.41	-0.26	0.38	1.00			
green cover	-0.07	-0.22	-0.19	-0.21	-0.09	0.15	-0.12	-0.35	1.00		
open space	-0.12	-0.11	-0.38	0.09	-0.20	0.16	-0.21	-0.32	-0.01	1.00	
waste	-0.29	0.27	0.76	0.28	0.58	-0.49	0.46	0.70	-0.06	-0.29	1.00

Source: Authors' calculation

Table 8 presents the results of size models of the pollution index employing the OLS method. Regression models 1–4 present the findings for a parsimonious model that addresses the issue of multicollinearity. Due to the lack of data, the regression models show the best-fit models in terms of predicted signs, significance level of variables, and goodness of fit of regressions based on the different number of variable observations available. All the regression models report OLS results with robust standard errors in parentheses to correct heteroscedasticity.

The results reveal that infrastructure, waste generation, and registered motor vehicles exhibit a statistically significant positive impact on air pollution at the 5% significance level. Moreover, the cities' population demonstrates a positive correlation with air pollution, reaching statistical significance at the 1% level. Conversely, variables related to the SDG Urban Index, such as households using clean fuel for cooking (significant at 1%), LED bulbs per 1,000 population distributed under Unnat Jyoti by Affordable LEDs for All (UJALA) (significant at 5%), and open space for public use as a share of total area (significant at 5%), display statistically significant negative relationships with air pollution. In particular, the area under green cover as a percentage of total area shows a negative relationship with air pollution, but does not achieve statistical significance.

Additionally, it is observed that population growth and density variables do not significantly impact air pollution across the models. While the link is weak, density shows a negative relationship with air pollution, which indicates that higher density decreases air pollution due to low mobility. These findings contribute to a comprehensive understanding of the factors influencing air pollution, highlighting the crucial role of infrastructure, adoption of clean energy, population density, and management of vehicular emissions.

Table 8: OLS regression results

			Dependent variable: air pollution (emission index)	
Independent variables	**Model 1**	**Model 2**	**Model 3**	**Model 4**
Infrastructure				
infra index	0.334**			
	(0.134)			
Population agglomeration				
pop				6.38e-07***
				(2.29e-07)
density				-0.000108
				(0.000159)
growth	-0.0394			-0.0497
	(0.0348)			(0.0459)
Transport				
vehicles		0.000843**		
		(0.000311)		
Waste generation				
waste			0.000702**	
			(0.000334)	
SDG 13: Climate action				
bulbs		-0.00108**		
		(0.000465)		
SDG 7: Affordable and clean energy				
clean fuel		-0.0630***		
		(0.0218)		
SDG 15: Life on land				
open space			-0.0382**	
			(0.0164)	
green cover		0.0129	-0.0121	
		(0.0171)	(0.0122)	
Constant	1.007	4.097**	-0.428	0.874
	(1.223)	(1.825)	(0.749)	(2.723)
Observations	32	28	27	33
R-squared	0.096	0.643	0.562	0.193

Note: robust standard errors in parentheses: *** $p<0.01$, ** $p<0.05$, * $p<0.1$

6. DISCUSSION

The empirical analysis underscores key factors exacerbating urban air pollution in Indian cities, including infrastructure, waste generation, transportation, and population agglomerations. While the government of India has initiated several measures to combat air pollution, such as revising standards, promoting renewable energy, and implementing the National Clean Air Programme (NCAP), further policy interventions are imperative to address the root causes effectively.

The policy implications of green infrastructure are profound and multifaceted, as highlighted by the strategic positioning of vegetation within urban areas. By leveraging green infrastructure, cities can effectively mitigate downwind pollution exposure, safeguarding public health. Additionally, urban trees offer indirect yet significant benefits for air quality improvement (Kumar et al., 2019). Moreover, incentivising the integration of green infrastructure into urban planning and development projects is paramount (Kumar et al., 2019). By offering incentives such as tax breaks, grants, or expedited permitting processes, policymakers can encourage developers and stakeholders to prioritise the incorporation of green roofs, walls, and vegetated swales. Trees play a crucial role in reducing air conditioning needs during hot weather, thereby mitigating energy demand, particularly in regions heavily reliant on coal for energy production (Akbari et al., 1997). Their shading properties and cooling effects collectively alleviate the strain on energy resources, consequently curbing emissions associated with energy production. Thus, integrating green infrastructure into urban planning and development enhances air quality and contributes to broader sustainability objectives, promoting healthier and more resilient urban environments.

The digitalisation of waste management in India has the potential to significantly improve the efficiency and effectiveness of waste collection and recycling (Manuja & Sodhi, 2024). By implementing digital tools such as the Sansadhan Portal, cities can track waste trends, monitor material recovery facilities (MRFs), and make data-driven decisions to improve waste management practices. This can lead to increased recycling rates, reduced waste disposal, and a more sustainable waste management system. Additionally, digitalisation can promote transparency and accountability within the waste management sector, ensuring

all stakeholders are involved and benefiting from improved waste management practices.

According to the Institute for Transportation and Development Policy (ITDP, 2020), low-emission zones (LEZs) create zones where only cleaner vehicles can enter, either by charging fees for high-polluting cars or entirely banning them. This incentivises people to switch to cleaner vehicles, for instance electric cars, which reduces overall traffic and harmful emissions, such as particulate matter and nitrogen oxide. Congestion pricing tackles the problem from a different angle. Charging drivers a fee to enter busy zones during peak hours discourages unnecessary trips, frees up road space, and encourages people to consider public transport, cycling, or walking. Electrifying public transportation, especially buses, also offers a significant opportunity to cut emissions. Since buses make frequent trips compared to private vehicles, replacing them with electric alternatives drastically reduces tailpipe emissions and improves air quality. Finally, people-centred solutions such as Barcelona's superblocks demonstrate that car restrictions do not have to be explicit bans. These superblocks are designated areas where car traffic is discouraged through one-way streets and lower speed limits, prioritising pedestrians and cyclists. This creates a car-unfriendly environment that encourages residents to explore alternative ways of getting around within the zone, leading to a shift towards cleaner transportation options.

However, it is essential to acknowledge the limitations of existing studies, particularly in terms of data availability and temporal analysis, underscoring the need for continued research and monitoring to inform evidence-based policymaking for long-term air quality improvement and urban sustainability.

7. CONCLUSIONS

In conclusion, this study offers a comprehensive analysis of the sources of urban air pollution in Indian metropolitan cities, shedding light on the intricate relationship between various socioeconomic, environmental, and infrastructural factors. Using principal component analysis and regression modelling, we have identified key drivers of air pollution and evaluated the effectiveness of policy interventions to mitigate its adverse effects.

Our findings underscore the pressing need for concerted efforts to address the root causes of air pollution, particularly in rapidly urbanising regions of India. The empirical evidence presented in this paper emphasises the importance of infrastructure development, waste management, transportation policies, and the adoption of clean energy technologies in combating urban air pollution. Furthermore, incorporating indicators for the Sustainable Development Goals (SDGs) into policy frameworks highlights the interconnected nature of environmental sustainability, public health, and socioeconomic development.

Policy implications from this study offer actionable insights for policymakers, urban planners, and stakeholders to design and implement targeted interventions to improve air quality and promote sustainable urban development. By prioritising investments in green infrastructure, digitalising waste management systems, implementing innovative transportation solutions, and fostering community engagement, Indian cities can transition towards cleaner, healthier, and more liveable urban environments.

In essence, this paper contributes to the growing body of research on urban air pollution in India, offering evidence-based policy formulation and implementation recommendations. By embracing a holistic approach to urban planning and governance, India can mitigate air pollution, enhance public health, and foster sustainable development, ultimately creating vibrant, resilient, and environmentally sustainable cities for present and future generations.

8. LIMITATIONS OF THE STUDY

The main limitation of the study is the sample size. The data availability at the city level is minimal. We could only access data for 36 metropolitan cities in India. Therefore, the sample size used to apply multiple linear regression models is very small. Furthermore, the limiting factor is the emission data for some cities. For example, emission data for some cities is from 2015, some cities from 2018, and one from 2020. Therefore, the recommendation is that conclusions should be taken with a measure of caution. Once data are available, estimations of panel data regression models will be necessary for robust conclusions.

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DETERMINANTS OF URBAN ECONOMIC RESILIENCE: INSIGHTS FROM THE COVID-19 LOCKDOWN EXPERIENCE IN SIXTEEN CITIES OF THE GLOBAL SOUTH

ABSTRACT: *The COVID-19 pandemic underscored the critical role of economic and financial resilience in enabling local governments to sustain own-source revenues (OSR) amidst severe disruptions. Drawing on data from 16 cities globally, collected through the United Nations' urban economic resilience performance assessment framework, this study analyses how performance across five key resilience areas – labour market, local business environment, financial system, basic services, and economic governance – affected OSR losses during the pandemic. The primary hypothesis is that stronger resilience performance leads to smaller revenue losses. Cities with stronger labour market resilience experienced, on average, a 20-percentage point smaller decline in OSR than weaker performers; cities with stronger business environments showed a 10-point advantage. By contrast, economic governance showed a negative association with OSR outcomes, likely reflecting structural differences such as city size. The study also tests auxiliary hypotheses and finds that higher-income cities suffered greater losses due to deeper integration into global value chains, while larger cities were more exposed to shocks. These findings offer insight into the complex interplay of resilience factors and structural characteristics.*

KEY WORDS: *COVID-19 response, urban resilience, own-source revenue, local government finance*

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1. INTRODUCTION

The COVID-19 pandemic underscored the critical importance of economic and financial resilience at the local government level. Disruptions to economic activity and fiscal operations during the pandemic posed significant challenges for local governments, particularly in generating own-source revenues (OSR). However, the scale of these challenges varied widely across cities, highlighting the role of resilience in mitigating such disruptions and the need to identify the key factors driving urban economic resilience (Brada et al., 2021; Pozhidaev, 2022; Wu et al., 2023).

This paper draws on data collected using a diagnostic framework developed by the United Nations to measure the impact of COVID-19 on global cities from an economic resilience perspective. The framework was part of the joint project on urban economic and financial recovery and resilience building, implemented between 2020 and 2022 across 16 cities worldwide (UN-Habitat Urban Resilience Hub, 2024). The study leverages a unique dataset that provides a comprehensive analysis of resilience performance in these 16 diverse developing cities. While the sample may not be fully representative, the dataset's uniqueness justifies its introduction to the research community, offering a valuable foundation for broader discussions on urban resilience.

The primary hypothesis of this study is that stronger resilience performance across five key areas leads to better economic outcomes, specifically by reducing OSR losses during the COVID-19 pandemic. Additionally, the study examines three auxiliary hypotheses to explore the impact of structural factors – income levels, city size, and lockdown measures – on urban resilience.

The paper is organised as follows: The next section introduces the theoretical foundations of urban economic resilience and provides an overview of the United Nations' urban economic resilience performance assessment framework, situating it within the broader resilience literature. The subsequent data and methodology section details the unique dataset and outlines the empirical approach, including hypotheses and regression models. The results and discussion section presents key findings, evaluates their alignment with the research hypotheses, and explores the factors influencing urban resilience. Finally, the conclusion discusses the implications of the findings and provides

policy recommendations to strengthen urban economic resilience in the face of future crises.

By situating the findings within the broader discourse on resilience, this study emphasises the importance of a multifaceted approach that integrates economic, social, and environmental dimensions (Briguglio et al., 2008; Coaffee & Lee, 2016). The paper evaluates the framework's alignment with established resilience models, such as the City Resilience Framework (Rockefeller Foundation, 2015) and the City Prosperity Index (UN-Habitat, 2016), while incorporating insights from the literature on critical resilience factors, including labour markets (Pike et al., 2015), financial systems (Bartle et al., 2011), and governance (Rodríguez-Pose & Bwire, 2004).

This study is related to research on socioeconomic resilience in shock absorption, mitigation, and recovery (O'Hare & White, 2013; Régibeau & Rockett, 2013) and contributes to the growing body of literature on the determinants of economic resilience, including its regional dimensions – a field that gained prominence during the COVID-19 pandemic (Hu et al., 2022; Pierri et al., 2023; Shekarian et al., 2023). By extending this discussion to the Global South, the paper addresses the pandemic's impact on economic resilience in developing countries, an area often underexplored due to the lack of reliable subnational data. The study situates urban resilience experiences within this context, offering fresh insights into the challenges and strategies for enhancing economic resilience in cities worldwide.

2. UN PERFORMANCE ASSESSMENT FRAMEWORK AND ITS FOUNDATIONS

2.1. Overview of the UN performance assessment system

This paper accepts the UN resilience model as a given as it comes with a set of data on the performance of 16 participating cities in five areas of urban economic resilience: business environment, labour market, financial environment, economic governance, and basic infrastructure and connectivity (Table 1). Each of these resilience areas is further operationalised through a number of indicators (16 in total) which are designed to measure a positive or negative relationship with resilience. Together, they form a framework for urban resilience diagnostic and planning (UN Capital Development Fund [UNCDF], 2021).

Table 1: Overview of the diagnostic and planning tool

Resilience areas	**Resilience indicators**
RA1: Resilience of the local business environment	RPI 1-1: Local economy diversity RPI 1-2: Openness and external markets integration RPI 1-3: Entrepreneurship and innovation RPI 1-4: Productivity, economic and financial capacity
RA2: Resilience of the local labour market	RPI 2-1: Labour market flexibility RPI 2-2: Labour mobility RPI 2-3: Social protection of labour
RA3: Resilience of the local financial system	RPI 3-1: Size and depth of the financial system RPI 3-2: Financial performance and soundness RPI 3-3: City fiscal space RPI 3-4: City financial health and stability
RA4: Resilience of economic governance	RPI 4-1: Strength of economic governance structures and leadership RPI 4-2: Scope and quality of city planning RPI 4-3: Investment readiness
RA5: Resilience of basic infrastructure and connectivity	RPI 5-1: Coverage and functionality of basic infrastructure RPI 5-2: Health service coverage RPI 5-3: Connectivity and mobility

Source: UNCDF (2021)

The UN performance assessment framework assigns specific scores to various performance indicators that are assumed to reflect a city's economic and financial resilience (UNCDF, 2021). The framework combines quantitative and qualitative measures. A performance-based approach is used to score the measures. They are rated on a Likert-type five-point 'ABCDF' scale according to specific rating criteria. 'A' indicates the performance associated with a very strong capacity to ensure economic and financial resilience and implies minimum negative impact while also allowing for a rapid recovery. The other scores refer to progressively inferior performance. All dimensions and indicators are positively related to

resilience performance, either at the aggregate level or within the performance areas (Pozhidaev, 2021).

While this paper does not attempt to identify determinants of resilience – as a conventional study might – it is important to underline the robust theoretical and empirical foundation of the UN performance framework. This foundation reflects a broad agreement among practitioners and academics on the factors contributing to regional (local) resilience. The following brief review of the literature demonstrates that the framework aligns closely with the prevailing academic discourse on urban and regional resilience.

2.2. Literature review

The UN urban economic resilience performance assessment framework defines resilience as "the capacity and related capabilities of cities or urban areas to plan for, anticipate negative shocks, including long-term stresses, to their economies, allocate, reallocate and mobilize resources to withstand those shocks, recover from the shocks, and rebuild better, while placing their economies on the path to sustainable economic growth and simultaneously strengthening their capacity to deal with any future shocks" (UNCDF, 2021, p. 4). This definition reflects two important areas of consensus among academics and practitioners.

First, regional (urban) resilience is widely recognised as a multifaceted concept encompassing economic, social, and environmental dimensions (Coaffee & Lee, 2016, Régibeau & Rockett, 2013). This is reflected in the multi-dimensional approach used in the City Resilience Framework (CRF) developed by Arup with support from the Rockefeller Foundation (2015), which identifies four key dimensions: Health & Wellbeing, Economy & Society, Infrastructure & Environment, and Leadership & Strategy, each comprising specific drivers that contribute to a city's resilience. Similarly, the UN-Habitat City Prosperity Index (CPI) includes six dimensions (UN-Habitat, 2016): Productivity, Infrastructure Development, Quality of Life, Equity and Social Inclusion, Environmental Sustainability, and Governance and Legislation.

Second, resilience is considered dynamically as a set of abilities of a regional economy to withstand, adapt to, and recover from external shocks (Briguglio et al., 2008; Coaffee & Lee, 2016). This area of consensus emphasises the agency of

policymakers and private economic agents which enable a locality to withstand or recover from the negative effects of shocks through a variety of anticipatory and coping capacities (Boin & Lodge 2016; Klagge & Martin, 2005;).

The UN framework's areas of resilience align closely with the resilience factors and dimensions in the other frameworks. For instance, the UN's focus on the strength of the local business environment (RA1) and the local labour market (RA2) corresponds to the CRF's Economy & Society dimension. The indicators under RA1 are generally recognised as essential factors of resilience, such as economic diversity (Brown & Greenbaum, 2017; Xiao & Drucker, 2013), the openness of the local economy (Briguglio et al., 2008), and its ability to innovate and adapt under stress (Healy & Bristow, 2020).

The labour market dimension (RA2) overlaps with such dimensions as Health & Well-being in the CRF and Productivity in the CPI. Various studies identified human capital as a critical factor of resilience (Wang & Wei, 2021). Bristow et al. (2014) and Pike et al. (2015) emphasise labour market flexibility and mobility as essential for adjusting to economic disruptions, aligning closely with the indicators under RA2. Additionally, social protection measures, as noted by Healy and Bristow (2020), play a critical role in ensuring that vulnerable populations are not disproportionately affected during economic downturns, reinforcing the importance of RPI 2-3.

The UN framework's focus on the resilience of the local financial system (RA3) aligns with other tools, such as the CPI and the Financial Condition Index developed by Groves et al. (1981), which highlight the criticality of a sound and well-performing financial system and an adequate fiscal space for local economic resilience. Bahl and Bird (2018), Bartle et al. (2011), and others argue that the soundness of local financial systems and a strong revenue base are pivotal for resilience, as they determine a city's capacity to mobilise resources and respond to crises. The UN framework's financial indicators (RA3) reflect these insights, particularly in their emphasis on financial performance and soundness (RPI 3-2), city fiscal space (RPI 3-3), and financial health (RPI 3-4).

The inclusion of economic governance (RA4) as a resilience dimension aligns with the CRF's Leadership and Strategy dimension and the CPI's Governance and Legislation and reflects a broad consensus among researchers on the importance

of effective and efficient institutional arrangements. Various studies have identified effective governance and strategic planning as key to fostering economic stability and recovery (Blakely & Leigh, 2013; Rodríguez-Pose & Bwire, 2004), particularly in situations where there are evolving multi-agent and multi-scalar institutional environments (Pike et al., 2015).

Similarly, the UN's emphasis on basic infrastructure and connectivity (RA5) parallels the CRF's Infrastructure & Environment dimension, highlighting the importance of reliable infrastructure and environmental stewardship and the CPI's Infrastructure Development dimension. Extensive research provides convincing evidence of the role of infrastructure in sustainable economic development and growth (Calderón & Servén, 2004; Esfahani & Ramírez, 2003; Kodongo & Ojah, 2016). The research argues that the coverage and functionality of infrastructure are fundamental for maintaining connectivity and ensuring the continuity of essential services during crises, as explored, for example, by Hall et al. (2014).

Thus, the UN performance assessment framework is grounded in a robust theoretical foundation that reflects a broad consensus among practitioners and academics regarding the critical factors influencing urban resilience. This alignment underscores the framework's validity as a comprehensive tool for diagnosing and planning urban economic resilience.

3. METHODOLOGY

3.1. Data used in the analysis

This paper uses the data from the above joint UN project and the author's own research. The project had a special focus on economic and financial recovery in the urban context and was implemented in 16 partner cities around the world: Accra (Ghana), Alexandria (Egypt), Beirut (Lebanon), Bishkek (Kyrgyzstan), Guayaquil (Ecuador), Harare (Zimbabwe), Hoi An (Vietnam), Kharkiv (Ukraine), Kuwait (Kuwait), Lima (Peru), Pune (India), Santo Domingo (Dominican Republic), Subang Jaya (Malaysia), Suva (Fiji), Tirana (Albania), and Yaoundé (Cameroon).

The data of particular importance from this project include the performance ratings of individual cities in each resilience area. These data were supplied by the cities themselves based on local socio-economic data and qualitative assessments as specified in the performance assessment guidelines. For this study, ratings were collapsed into two categories, low and high, with the cut-off value for the low level of performance at C. Performance at C+ and above was categorised as high.

The study also uses certain socio-economic data from the project, such as the population, Gross City Product (GCP), city economic diversity, and some others. In addition, the paper relies on several other publicly available datasets to triangulate and complement the project data, such as the UN-Habitat City Prosperity Index (UN-Habitat, 2016), which contains data for 333 cities and urban areas on 25 indicators. To control for the differences in the COVID-19 restrictions, the paper uses the Oxford COVID-19 Government Response Tracker (Hale et al., 2021), which includes the stringency index indicating the duration and intensity of COVID-19 response measures.

3.2. Research approach and methods

This paper uses OSR as the aggregate indicator of resilience and examines the determinants of urban resilience, using empirical data from 16 project cities and relevant external sources. The resilience performance areas and the financial resilience indicators are considered the determinants of urban economic resilience. The analysis treats these cities as a unique population, without generalising beyond them.

3.3. Outcome variable

The UN economic resilience assessment framework highlights the relationship between economic resilience and a city's economic performance across four dimensions: GCP growth, per capita revenue, labour force participation rate, and income inequality (UNCDF, 2021). For validation purposes, changes in GCP would be an ideal outcome variable. This approach aligns with existing research that has used GCP or related metrics to measure the impact of COVID-19 and its associated responses on city-level economies (Brada et al., 2021; Gajewski, 2022; Wu et al., 2023).

Unfortunately, post-COVID-19 data on GCP were not available for the participating cities at the time of the project's completion, even where such data were expected to be collected. Consequently, OSR was used as a proxy for economic output. According to the UN framework, OSR includes taxes, fees, and service charges that cities are authorised to impose and regulate independently, with or without central government consent (UNCDF, 2021). Evidence suggests that OSR is highly elastic in relation to local economic activity, much more so than other sources of revenue (Bahl & Bird, 2018). In many local governments, tax-elastic revenues – those sensitive to economic conditions – dominate the revenue structure. While the share of tax-inelastic revenues tends to be low in Africa and other developing countries (Fjeldstad & Heggstad, 2011), even developed economies have shifted toward revenue sources that are more income-elastic, as Bartle et al., (2011) argue.

For this analysis, we used the percentage change in OSR as the dependent variable. This approach ensures comparability across participating cities that operate in different national currencies. Depending on the timing of data collection, the change reflects OSR collected over nine to twelve months in 2020 (three to four quarters) compared to the same period in 2019.

As outlined in the introduction, the main hypothesis (**H1**) posits that higher performance in each dimension has a positive impact on a city's resilience, as measured by OSR change. Specifically, we expect a positive relationship between performance levels and OSR outcomes, with higher performance mitigating OSR losses.

3.4. Control variables

As discussed in the next section, the participating cities exhibited significant variation in their characteristics. To account for this heterogeneity, the analysis includes the following control variables:

Economic Development. The level of economic development, measured by pre-pandemic GCP per capita in PPP US dollars, may indicate a city's capacity to cope with shocks. More prosperous cities tend to have greater fiscal space and better-developed soft and hard infrastructure, as suggested by existing research

(Hennebry, 2020). Therefore, we hypothesise that wealthier cities demonstrate greater resilience and experience smaller OSR losses (**H2**).

Population Size. Population size is important because larger cities often require greater mobility (Wu et al., 2023), are typically more integrated into international value chains (United Nations Economic Commission for Africa [UNECA], 2020), and may therefore suffer more during pandemics. The negative impact of the disruptions in global value chains on urban economies during COVID-19 is well documented (Gajewski, 2022; Kang et al., 2020). Additionally, numerous studies highlight differences in OSR structures between smaller and larger urban settlements. Larger cities tend to have a higher share of income-elastic revenues linked to economic activities. For instance, they derive a significant portion of their OSR from volatile revenue sources such as taxes on high-value sectors (e.g., tourism, real estate, and corporate activities), which are disproportionately affected during crises (Chernick et al., 2011). Larger cities also collect more revenue through service charges, as their public service infrastructure is better developed and accounts for a greater share of revenues than that of smaller urban areas (Bartle et al., 2011; Bowman, 1981; Kim, 2019).

However, during COVID-19, many larger cities (e.g., Bishkek, Lima, and Tirana) waived or deferred payments for public utilities, rentals for municipal properties, market fees, and other service charges (Pozhidaev, 2022). Under normal circumstances, a diversified OSR structure is advantageous. However, during short-term shocks targeting high-value sectors, such as the COVID-19 pandemic, this diversification can become a disadvantage and result in higher revenue volatility (Carroll, 2009). Therefore, we hypothesise an inverse relationship between city size and OSR performance, with smaller cities performing better than larger cities (**H3**).

COVID-19 Restrictions. The participating cities varied in the duration and strictness of internal COVID-19 restrictions, measured using a composite stringency index from the Oxford COVID-19 Government Response Tracker (Hale et al., 2021). The literature recognises the duration and strictness of response measures as major determinants of economic activity and output levels (Ascani et al., 2021; Wu et al., 2023). Accordingly, we hypothesise that OSR

changes are positively related to the intensity of lockdowns, with longer and stricter lockdowns leading to greater OSR losses (**H4**).

3.5. Regression model specifications

In this analysis, we employ robust regression using iteratively reweighted least squares (IRLS) due to several critical characteristics of the dataset and modelling requirements that make it a more suitable choice than standard ordinary least squares (OLS) regression. This method iteratively assigns weights to observations based on their residuals, reducing the influence of extreme values on the regression estimates (Fox, 2015).

The basic specification for urban economic resilience takes the form:

$$OSR_i = \alpha + \beta_1 BE_i + \beta_2 LM_i + \beta_3 FS_i + \beta_4 EG_i + \beta_5 BIC_i + \varepsilon_i , \quad (1)$$

where α and $\beta_1 \ldots \beta_5$ refer to the population parameters, OSR_i is the percentage change in OSR in city *i* under COVID-19 and *BEi, LMi, FSi, EGi,* and *BICi* are dummy variables denoting high resilience performance score in city$_i$ in each of the five resilience areas: business environment, labour market, financial system, economic governance, and basic infrastructure and connectivity. High performance is defined as the score C+ and above. In line with the main hypothesis, we expect positive coefficients for all terms.

The expanded specification form for urban economic resilience includes three additional dummy variables: *income* (1 for upper- and middle-income cities and 0 otherwise), *size* (1 for cities with a population of 1 million or less and 0 otherwise), and *lockdown* (1 if the city experienced an intense lockdown of more than 6 months and 0 otherwise).

$$OSRi = \alpha + \beta_1 BE_i + \beta_2 LM_i + \beta_3 FS_i + \beta_4 EG_i + \beta_5 BIC_i + \beta_6 income_i - \beta_7 citysize_i - \beta_8 lockdown_i + \varepsilon_i \quad (2)$$

In line with the auxiliary hypothesis, we expect positive coefficients for income and negative coefficients for city size and lockdown.

3.6. Data limitations

The UN diagnostic tool was applied to a small number of cities globally (16). No specific sampling framework was used to select the participating cities; rather, the selection depended on the availability of resources and the prior cooperation experience with the cities. This type of sample is defined as a convenience sample. It belongs to the class of non-probability samples, which cannot be used for unbiased estimates of population parameters (Levy & Lemeshow, 2008).

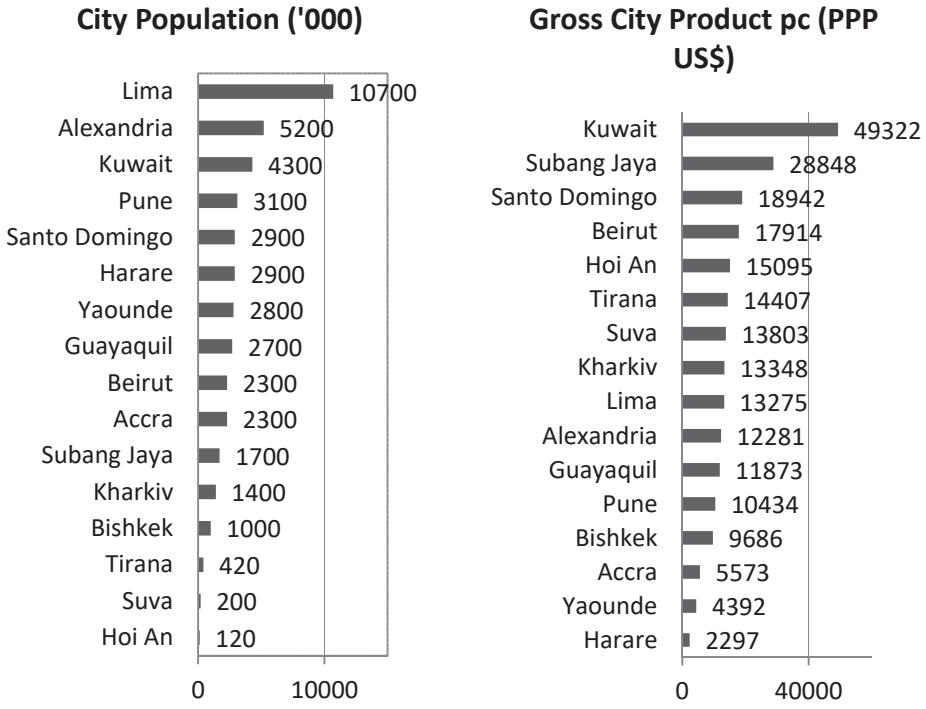
Hence, the subsequent analysis focuses on the cities that participated in the UN joint project. These cities are considered as a population in their own right, and the findings cannot be generalised to the entire global population of cities. In the context of statistical analysis applied to an entire population (as opposed to a sample), statistical significance tests are less about making inferences about a broader population and more about understanding the variability or strength of relationships within the population itself. In this case, the focus shifts to describing the population's characteristics and emphasising the practical significance and policy implications of the findings. Even if a coefficient or relationship is not statistically significant, it may still be of practical importance if the magnitude of the effect is meaningful. These practical implications should be highlighted, regardless of statistical significance, to inform policy and decision-making.

4. EMPIRICAL RESULTS AND DISCUSSION

4.1. Summary statistics

The UN project cities differed greatly in terms of their population, economic and financial potential, and other characteristics (Figure 1). They included very populous cities with a population of more than 10 million, such as Lima, as well as small cities, such as Hoi An in Vietnam with a population of only approximately 120,000. In terms of income status, the participating cities included nine cities with low middle-income status and seven cities with upper middle-income and high-income (Kuwait) status. Their wealth varied considerably, from about US$50,000 in PPP terms for Kuwait City to US$2,296 for Harare. The median population is about 2.5 million, and the median GCP per capita is approximately US$13,300.

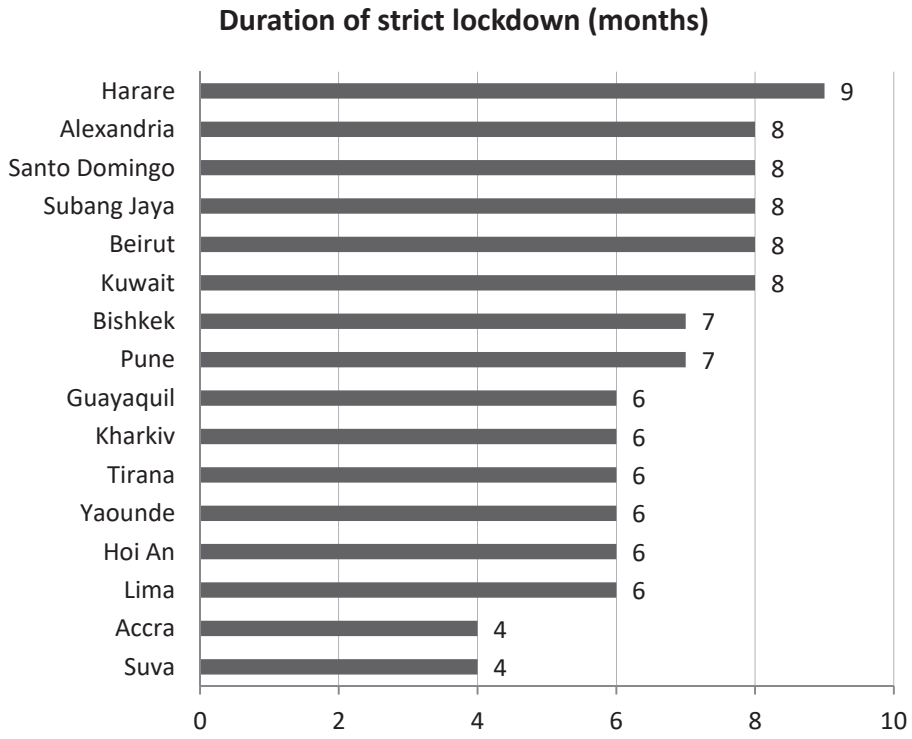
Figure 1: Project cities' population and gross product



Source: Author's presentation based on the UN project data

The response of the cities to COVID-19 also differed in duration and intensity (Figure 2). Some cities, such as Harare, saw longer periods of strict lockdowns of up to 9 months, whereas Suva and Accra imposed strict lockdowns for only 4 months in 2021 (when the data were collected). The median duration of strict lockdowns across the sample was 6.5 months.

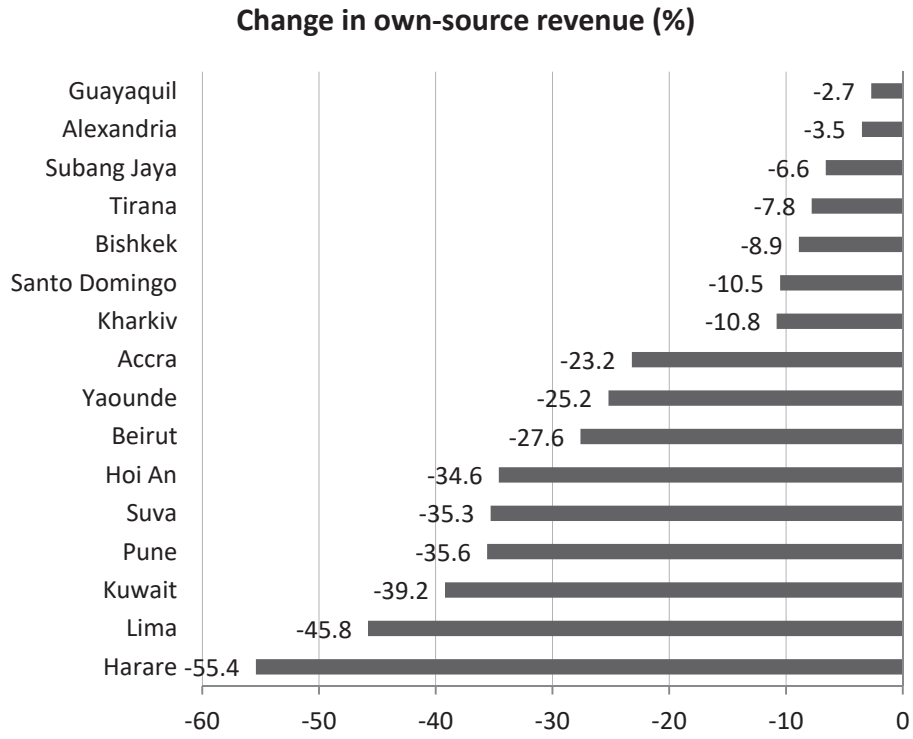
Figure 2: Duration of strict lockdown, months



Source: Author's calculation based on the Oxford COVID-19 Government Response Tracker

The project cities recorded a significant variation in the change in their OSRs (Figure 3) over the COVID-19 period in 2020 (used as an outcome variable to test the validity of the performance assessment framework and the diagnostic tool). The best-performing city, Guayaquil, recorded a 2.7% drop in revenues, whereas OSRs in Harare declined by 55.4%. The median decrease in the project cities was approximately 24%. The low middle-income cities experienced a larger drop in OSR, indicating a potential correlation between the city income and its OSR performance during COVID-19 (Figure 3).

Figure 3: Change in own-source revenues in project cities



Source: Author's presentation based on the UN project data

Unsurprisingly, the resilience performance results of the project cities also differed significantly. Table 2 presents the summary statistics for the five resilience performance areas. The ratings for the performance areas (originally absent in the assessment methodology) have been assigned using the same conversion table as the one used for rating the indicators.

Table 2: Summary descriptive statistics of resilience performance areas

Dimension and indicator	Median	Min.	Max.
Business environment resilience	C	D+	B
Labour market resilience	C	D	B
Financial system resilience	C	D+	B
Economic governance resilience	C	D	B
Resilience of basic infrastructure and connectivity	C+	D+	B+

Note: The interpretation of the scores is as follows:

- 'A' denotes performance associated with a very strong capacity to ensure economic and financial resilience. A very strong capacity ensures minimum impact while also allowing for a rapid recovery.
- 'B' represents sound performance associated with a healthy capacity but a rung below the best performing cities. Such a capacity guarantees a low to moderate impact and a relatively rapid recovery.
- 'C' means an average performance when the city's capacity to mitigate the crisis suffices to achieve low to moderate levels of impact and a somewhat longer recovery period.
- 'D' denotes a weak performance associated with a capacity that falls considerably below the best performers. At this level of capacity, a city experiences a strong impact and has a long recovery period.
- 'F' indicates essentially a lack of resilience capacity, such that without very substantial support from the central government, a city would experience a very strong shock (possibly economic collapse) and a prolonged recovery period.

Source: Author's calculation based on the UN project data

To sum up, there are no clear winners or losers among the performance areas, which tend to converge around rating C, indicating that most entities functioned at an average level without significant strengths or weaknesses. The ranges highlight variability, with the lowest-performing entities scoring D or D+ in all dimensions, suggesting areas that require significant improvement. The highest-performing entities score between B and B+, indicating room for growth to reach the highest resilience levels (A or A+). The resilience of basic infrastructure and connectivity shows the highest median (C+) and maximum (B+), suggesting it is relatively stronger compared to other dimensions. The lower bounds of the ranges (D or D+) suggest specific entities are highly vulnerable, particularly in labour market resilience and economic governance resilience, which might require targeted interventions.

4.2. Descriptive analysis

The descriptive analysis in this study is used to estimate the relationship between the outcome variable and resilience performance across the performance resilience areas (Table 3). The Kruskal–Wallis H test was chosen as the most appropriate method for analysing OSR changes across resilience categories due to its ability to provide robust comparisons where parametric tests like ANOVA or *t*-tests would not be valid or reliable. While the Kruskal–Wallis statistics are provided for reference, it is important to note that their inclusion is not intended for the generalisation of the results, as the study considers each of the 16 participating cities as a population in its own right.

To complement this analysis, Table 4 presents the Spearman's rank correlation coefficients between OSR change and the performance in the resilience areas. This matrix offers a broader view of the relationships, emphasising the significance and strength of associations across the entire dataset, particularly given concerns over normality revealed by the Shapiro–Wilk test. However, as with the Kruskal–Wallis H test, the non-random nature of the convenience sample and the treatment of the dataset as a population mean that the correlation results should not be interpreted as inferential or generalisable. Both analyses serve as supplementary descriptive tools, providing insights into patterns within the dataset rather than conclusive statistical evidence.

Table 3: Comparison of OSR changes across resilience areas by performance

Resilience area	Mean OSR change, %		Kruskal–Wallis H
	Weak resilience performance	Strong resilience performance	
Business environment	-28.38	-18.20	2.16 (0.2318)
Labour market	-32.14	-11.91	4.70*** (0.0071)
Financial system	-28.99	-10.76	3.93*** (0.0093)
Economic governance	-26.73	-15.72	1.69 (0.1944)
Basic infrastructure	-22.60	-23.52	0.014 (0.2282)

Notes: *, **, and *** represent 1%, 5%, and 10% significance levels, respectively.
Source: Author's calculation

Table 4: Correlation matrix

Variable	OSR change	Business environment	Labour market	Financial system	Econ. gov.	Basic infrastr.
OSR change	1					
Business environment	0.3183 (0.2296)	1				
Labour market	0.6271*** (0.0093)	0.1260 (0.6420)	1			
Financial system	0.5280** (0.0355)	0.4045 (0.1202)	0.2208 (0.4111)	1		
Economic governance	0.3191 (0.2284)	0.4045 (0.1202)	0.2208 (0.4111)	0.7091**** (0.0021)	1	
Basic infrastructure	-0.0250 (0.9267)	0.5774** (0.0192)	-0.0727 (0.7744)	0.0778 (0.7744)	0.3892 (0.1362)	1

Notes: *, **, and *** represent 1%, 5%, and 10% significance levels, respectively.
Source: Author's calculation

The 'strong' categories across all resilience areas (except for basic infrastructure) consistently show better OSR changes compared to the 'weak' categories, supporting theoretical expectations that resilience improvements drive better economic and financial performance. This pattern is further reinforced by the correlation analysis, which reveals a strong positive (albeit statistically insignificant) relationship between the labour market strength (ρ=0.6271, p=0.0093) and OSR changes, as well as a moderate positive relationship for the fiscal system strength (ρ=0.5280, p=0.0355). These findings emphasise the importance of labour market and financial system resilience in influencing OSR changes, as further discussed in the regression analysis section.

For business environment and economic governance, while the trends align with theoretical expectations, the Kruskal–Wallis test results are not statistically significant, and the correlations with OSR change are weaker (ρ=0.3183, p=0.2296 and ρ=0.3191, p=0.2284, respectively). Nonetheless, high resilience performance in these areas reduces the average OSR loss by about 10 percentage points, highlighting their potential secondary role in mitigating economic losses.

The resilience area basic infrastructure and connectivity is an exception, showing virtually no influence on OSR changes in both the mean comparison (H=0.014) and the correlation analysis (ρ=0.0313, p=0.9080). This lack of association is

consistent with the results of the regression analysis, as discussed in the next section.

By combining insights from both the mean comparison and correlation analysis, the descriptive results set the stage for the regression analysis that follows.

4.3. Regression analysis

As mentioned before, we employ a robust regression using iteratively reweighted least squares (IRLS) for this analysis. With only 16 observations, the sample size is relatively small, which can amplify the effects of outliers and increase the variability of coefficient estimates in a standard OLS regression. In small samples, the assumptions of OLS regression (e.g., homoscedasticity and normality of residuals) are more likely to be violated, leading to unreliable estimates. Robust regression mitigates these issues by down-weighting the influence of outliers and providing more reliable parameter estimates in small-sample contexts.

A preliminary examination of the dataset indicated the presence of influential observations that could disproportionately affect the OLS regression results. Outliers may distort both the direction and magnitude of coefficients and inflate standard errors. Robust regression addresses this issue by ensuring that the regression estimates are less sensitive to outliers and better reflect the central trends in the data.

The outcome variable, OSR change, exhibits a left-tailed (negatively skewed) distribution, with most observations clustering near the higher end and a long tail extending toward smaller values. This non-normality violates one of the key assumptions of OLS regression, potentially leading to biased estimates and invalid significance tests. Robust regression provides an alternative that preserves the interpretability of the original variable. In addition, small samples and the non-normal distribution of OSR change increase the likelihood of heteroscedasticity. Robust regression is designed to handle heteroscedasticity by providing robust standard errors, ensuring valid hypothesis testing even when the assumption of constant variance is violated.

While robust regression is effective in addressing heavy-tailed error distributions and mitigating the influence of outliers, it does not correct for potential

nonlinearity. To ensure that multicollinearity did not distort the regression results, a standard variance inflation factors (VIF) test was applied. The test results show that there is no significant multicollinearity issue, as all VIF values are well below the commonly accepted threshold of 10, and even below the more conservative threshold of 5 (the maximum value for a variable is 2.74). The mean VIF value of 2.11 thus confirms that multicollinearity is not a major concern.

Robust regression, particularly when using IRLS, does not provide goodness-of-fit statistics, such as R or R^2, as part of its output. This is because robust regression minimises a weighted sum of residuals rather than the standard sum of squared residuals (as in OLS). Importantly, the F-statistic is provided for reference because this sample is treated as a population in its own right. The analysis does not seek to generalise results to the global population of cities. Given the dataset includes only 16 cities chosen through convenience sampling, it would indeed be inappropriate – and extremely unwise – to extrapolate findings to the entire population of world cities, numbering in the hundreds of thousands. Instead, the results are intended to provide insights specific to the cities included in the sample.

The results of the regression analysis for urban economic resilience are presented in Table 5. The table provides statistics for the baseline scenario with the five resilience dimensions and three additional scenarios with one control variable added consecutively.

Table 5: OLS regression results

Variable	**(1) OSR change**	**(2) OSR change**	**(3) OSR change**	**(4) OSR change**
Explanatory variables				
Business environment	-2.01 (0.864)	5.87 (0.574)	14.90* (0.082)	17.53*** (0.000)
Labour market	23.71** (0.021)	18.75** (0.036)	13.67** (0.053)	14.04*** (0.000)
Financial system	10.90 (0.295)	15.14** (0.085)	9.03** (0.083)	3.29** (0.049)
Economic governance	-7.31 (0.321)	-8.74* (0.075)	-13.17** (0.066)	-10.07*** (0.000)
Basic infrastructure and connectivity	0.46 (0.970)	-0.92 (0.939)	-2.59 (0.781)	-3.04** (0.043)
Control variables				
Income (high and medium)		-4.30 (0.590)	-1.79 (0.782)	-3.57*** (0.001)
City size (population > 3m)	-		-11.06* (0.071)	-8.71*** (0.000)
Lockdown	-	-		8.38***
Constant	-34.28*** (0.003)	-33.68*** (0.004)	-28.04*** (0.005)	-31.81*** (0.000)
Observations	16	16	16	16
***F*-statistic**	2.97*	1.91	2.81*	176.88***
Prob > *F*	0.0808	0.1831	0.0853	0.0000

Notes: *, **, and *** represent 1%, 5%, and 10% significance levels, respectively.
Source: Author's calculation

In the baseline model, the coefficient for the business environment is slightly negative (-2.01) and insignificant, indicating a weak negative relationship with OSR changes. However, introducing control variables reverses this to a positive and significant relationship in Models (3) and (4) (14.90 and 17.53, respectively). This suggests that improvements in the business environment may help mitigate OSR losses. Notably, this dimension incorporates indicators that may

demonstrate opposing directions of correlation, such as local economy diversity, openness and external markets integration, entrepreneurship and innovation, and productivity, economic and financial capacity. COVID-19 research has demonstrated that local economic diversity and openness are often (albeit not always) negatively correlated with economic resilience (Gajewski, 2022; Hu et al., 2022; Tuysuz et al., 2022). At the same time, a strand of COVID-19 research stresses the adaptive and innovative capacity of local economies, including localisation of supply chains and introduction of digital technologies (Akberdina, 2022; Grabner & Tsvetkova, 2022). Due to the internal construction of this dimension, the results reflect the peculiarities of the sample, where, on average, the positive impact of some indicators outweighs the negative impact of others.

The labour market consistently emerges as a strong predictor of reduced OSR losses across all models. In the baseline model, the coefficient is 23.71, indicating a significant positive relationship. As controls are added, the coefficient decreases to 18.75 in Model (2), decreasing further to 13.67 and 14.34 in Models (3) and (4), respectively, but remains strongly positive, reaffirming the importance of the labour market in cushioning the financial effects of short-term shocks, such as the COVID-19 pandemic. At the same time, the results indicate that labour market resilience alone does not explain the outcomes and should be considered in the context of structural factors, such as income and city size and intensity of lockdown.

Research on COVID-19 highlights the critical role of labour market flexibility and mobility (measured as employment diversity, occupational and geographic labour mobility, and some other indicators) in helping businesses survive and retain workers, facilitating alternative employment opportunities and employability support for those out of work, and providing protections for individuals who lose their jobs (Carranza et al., 2020). The evidence demonstrates that the negative impact on output and employment was significantly less pronounced in regions with adaptable labour markets that offered re-skilling opportunities, new employment prospects (Marek et al., 2020), the introduction of new technologies, and flexible working arrangements, such as remote work and adjustable hours (Acciarini et al., 2021; Shekarian et al., 2023). Furthermore, regions with robust labour market policies and social safety nets were better

positioned to absorb the economic shock, maintaining employment levels and supporting household incomes during the crisis (Hu et al., 2022).

The financial system also demonstrates a consistently positive and evolving impact across models. In the baseline model, the coefficient is 10.90, suggesting that improvements in the financial system reduce OSR losses. This effect strengthens moderately to 15.14 in Model (2) before declining to 9.03 and 3.09 in Models (3) and (4), respectively. COVID-19 research indicates that cities and regions with lower fiscal capacity suffered more (Wu et al., 2023). These results highlight the role of local financial systems in ensuring liquidity and facilitating fiscal adjustments during economic disruptions (Pozhidaev, 2022; Steffensen, 2020). However, the declining significance of the financial system in later models reflects the influence of additional factors, such as city size and lockdown intensity. A robust financial system may cushion some negative economic impacts but is unlikely to have much impact on OSR collection.

The coefficient for economic governance is consistently negative across all models, revealing a counterintuitive relationship. In the baseline model, the coefficient is -7.31, suggesting that better governance correlates with greater OSR losses. This negative association intensifies in later models, reaching a statistically significant -10.07 in Model (4). While this finding contradicts theoretical expectations and previous research emphasising the positive role of governance during COVID-19 (Janssen & Van der Voort, 2020; McGuirk et al., 2021; Wright, 2020), it can be explained by the characteristics of the participating cities. Larger cities, which tend to perform poorly in economic governance metrics, also experienced worse economic outcomes, with a mean OSR loss of -31.03% compared to -20.72% for smaller cities. This finding is not unique to this study. Other researchers also note the greater vulnerability and worse performance of larger cities during COVID-19 (Feyen et al., 2021; Hu et al., 2022; Marcu, 2021). In addition, smaller cities in the sample demonstrate better economic governance than larger cities, potentially indicating the challenges of economic governance and coordination in large conurbations, particularly in developing countries, as discussed by Stren (2007). This suggests that city size, rather than governance itself, drives the observed relationship.

The resilience area basic infrastructure and connectivity shows minimal impact across models. In the baseline model, the coefficient is 0.46, indicating a negligible positive relationship. This effect turns negative in Model (2) (-0.92) and stabilises at around -1.02 in Model (4). These results suggest that while infrastructure is vital for general economic activity, its role in mitigating short-term OSR losses during crises is limited, consistent with previous studies emphasising infrastructure's enabling role rather than its direct influence during shocks (Arimah, 2017; Sun & Cui, 2018; Taghizadeh-Hesary et al., 2019). COVID-19 research also notes a limited impact of infrastructure on economic activities under COVID-19 restrictions which included reduction or closure of public transport options and limitations on physical activity and access to public space (Rojas-Rueda & Morales-Zamora, 2021).

The control variables provide additional insights. Income levels (high and medium) have a weakly negative but insignificant impact on OSR losses across models. In Model (2), the coefficient is -4.30, stabilising at -3.57 in Model (4). Wealthier cities appear to experience slightly greater OSR losses, likely due to their integration into global value chains, which were disproportionately affected by the pandemic. This is in line with research highlighting the economic vulnerability of larger cities but challenges earlier findings linking strict lockdowns to economic recessions (Caselli et al., 2020; Wu et al., 2023). Being a prosperous city does not spare a city from experiencing economic shocks, but neither does it significantly exacerbate the impact. The results emphasise that factors such as labour market conditions and the business environment play a more direct and significant role in shaping resilience to economic disruptions than income level alone.

City size, introduced in Models (3) and (4), has a consistently negative and significant impact, with coefficients of -11.06 and -8.71, respectively. This is unsurprising, considering the earlier discussion of the greater vulnerability of large cities during COVID-19.

The results for lockdown measures, included only in Model (4), present a surprising positive coefficient of 8.38. This contradicts theoretical expectations and earlier studies linking stricter lockdowns to poorer economic performance (Teachout & Zipfel, 2020; Wu et al., 2023). However, 75% of cities with strict

lockdowns in this sample were smaller cities, which performed better overall in terms of OSR losses. This again suggests that city size, rather than lockdown measures alone, influenced the observed outcomes. Lockdown measures, while impactful in other areas, do not independently explain variations in OSR losses during the period analysed.

The explanatory power of the models improves significantly as additional variables are introduced. The *F*-statistic evolves from marginal significance in Model (1) (2.97, p=0.0808) to high significance in Model (4) (176.88, p<0.001). This progression highlights the importance of incorporating such structural factors as city size and income into the analysis.

Overall, the business environment, labour market, and, to a lesser extent, the financial system emerge as key determinants of OSR changes. Meanwhile, the limited role of infrastructure and the unexpected negative relationship between governance and OSR losses underscore the need for contextual interpretation. These findings emphasise the complexity of urban economic resilience and the necessity of tailored approaches in addressing short-term economic shocks.

5. CONCLUSION AND POLICY SUGGESTIONS

Although the results of this study are not representative due to the small and non-random sample of 16 cities, they nevertheless provide valuable insights into the factors influencing urban economic resilience during the COVID-19 pandemic.

The main hypothesis (H1) posited that high performance across the five resilience dimensions would correlate with improved OSR performance, and this was partially confirmed. Labour markets and business environments emerged as key drivers (determinants) of resilience, consistently demonstrating their critical role in helping cities withstand and recover from economic shocks. The financial system also contributed positively, although its influence weakened as additional structural factors were considered.

However, other dimensions diverged from expectations. Economic governance showed a surprising negative relationship with OSR performance, likely reflecting the structural vulnerabilities of larger cities rather than inherent governance issues. Basic infrastructure had minimal or even slightly negative effects,

underscoring its limited role in addressing short-term economic shocks despite its broader importance.

The auxiliary hypotheses revealed mixed results. Higher-income cities (H2) did not fare better; instead, their deeper integration into global value chains made them more vulnerable to shocks. Larger cities (H3) proved more susceptible to OSR losses due to their reliance on complex financial and economic systems. Surprisingly, stricter lockdowns (H4) were associated with better OSR performance, a finding influenced by the strong performance of smaller cities in the sample.

These findings highlight the complex interplay of institutional arrangements and structural factors, which are unique to each city. No single factor inevitably dooms a city to an unconditional economic shock. For instance, being poorer or having a less diversified revenue structure does not necessarily result in greater shocks. What may be an advantage during 'normal' times – such as integration into global value chains or reliance on income-elastic revenues – can turn into a vulnerability under particular stresses, such as those induced by the COVID-19 pandemic. Conversely, perceived disadvantages in stable conditions can become resilience strengths during crises. These insights underscore the complexity of resilience dynamics and the need for tailored approaches to enhance urban economic resilience in the face of future crises.

The findings offer several actionable policy recommendations to enhance local economic resilience:

1. *Strengthen labour markets and business environments*. Policymakers should prioritise measures to improve labour market conditions and the overall business environment, as these factors consistently demonstrated strong positive effects on OSR performance. Investments in workforce development, access to finance, and support for small and medium-sized enterprises (SMEs) can enhance resilience by enabling local economies to adapt and recover more effectively from shocks.
2. *Address the vulnerabilities of larger cities*. Given the inverse relationship between city size and OSR performance, targeted policies are needed to mitigate the vulnerabilities of larger cities. These could include diversifying revenue sources, reducing reliance on income-elastic revenues, and

strengthening local governance to manage economic disruptions more effectively.

3. *Reassess the role of infrastructure investments*. The negligible impact of basic infrastructure on OSR performance during the pandemic suggests the need to re-evaluate infrastructure priorities. Policymakers should focus on infrastructure that directly enhances economic adaptability and resilience, such as digital infrastructure and logistical networks, rather than purely physical infrastructure.
4. *Promote context-sensitive governance strategies*. The unexpected negative relationship between governance and OSR performance underscores the importance of tailoring governance strategies to the unique characteristics of cities, particularly larger ones. Enhancing governance frameworks to address the specific challenges of urban areas, including revenue diversification and fiscal autonomy, can strengthen resilience.
5. *Account for structural factors in policy design*. The results highlight the critical role of structural factors, such as city size and integration into global value chains, in shaping OSR resilience. Policymakers should adopt a holistic approach that accounts for these factors when designing resilience strategies, ensuring that policies are well suited to the specific contexts of different cities.
6. *Enhance data collection and model specification*. The complexity of the relationships observed in this study highlights the need for improved data collection and model specification to capture the nuances of urban resilience. The UN project revealed a dearth of relevant socio-economic data in many cities as they struggled to supply the data for their performance assessment. Governments and researchers should invest in better data systems to inform evidence-based policymaking.

The findings reinforce the importance of context-specific approaches to urban resilience, emphasising labour markets, business environments, and such structural factors as city size as key determinants of OSR performance. While certain results, such as the role of governance and lockdowns, may appear counterintuitive, they highlight the complexity of urban systems and the necessity of nuanced, tailored policy responses. By addressing these insights, policymakers can strengthen urban resilience and enhance cities' ability to withstand and recover from future economic shocks.

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INTERACTIVE BEHAVIOUR BETWEEN CURRENCY SPECULATORS, MONETARY AND FISCAL ACTORS TO MINIMISE SOCIAL LOSS: A GAME THEORETIC ANALYSIS

ABSTRACT: *In this study, using game theory and the cooperative Stackelberg game model, the extent of social loss resulting from various interactive behaviours among monetary policymakers, fiscal policymakers, and currency speculators was assessed using economic parameters from Iran over ten years (2013–2022). Three strategies for each player (government, central bank, and currency market participants) were defined by their objectives, and through optimisation, the reaction function for each player was determined. This approach helped to identify the optimal interactive strategy among these players to minimise social loss. The findings of this research indicate that in a cooperative game between the government and the central bank, more favourable outcomes are achieved when the government assumes the role of the leader, as opposed to when the central bank leads. Furthermore, prioritising the exchange rate gap over other economic variables improves outcomes when the central bank acts as the leader. Specifically, these results suggest that for fiscal policymakers, the importance of budget balance outweighs the significance of the interest rate and exchange rate gaps. Under such circumstances, the social loss during the examined period is lower than that in other scenarios, signifying the optimality of this approach in terms of minimising social loss.*

KEY WORDS: *social loss, currency speculators, monetary policy, fiscal policy, cooperative game.*

JEL CLASSIFICATION: E52, E62, C71, C79.

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1. INTRODUCTION

Game theory is recognised as a valuable tool for analysing and modelling strategic interactions among various stakeholders in the economic decision-making process. This theory, beyond merely processing human interactions and decisions in interactive situations, provides a comprehensive theoretical framework for effectively analysing economic issues. By emphasising the strategic interactions between two or more agents, game theory has become an important analytical tool for economists, instilling confidence in its problem-solving capabilities to address economic challenges (Sherlin, 2012).

One of the fundamental challenges in economic policymaking is the independent actions of monetary and fiscal authorities, which may conflict with each other's interests. Game theory can be employed as a practical framework to analyse and resolve these conflicts, as its primary objective is to determine actors' optimal behaviour in conflict or competition situations (Bosnjak & Perić, 2017).

Classical economic policy studies emphasise that inconsistent policies between monetary and fiscal authorities can lead to economic instability. Sargent and Wallace (1981) argued that an undisciplined fiscal policy prevents the formation of disciplined monetary policies. Consequently, a lack of coordination between the monetary and fiscal authorities can hinder the achievement of optimal economic objectives. This finding aligns with multiple studies, including Simons (1936), Friedman (1995), Kydland and Prescott (1977), and Barro and Gordon (2019). These economists sought to answer the question of which policies and strategies between the government and central bank could create paths for achieving stable macroeconomic variables and desirable economic growth. They posited that rule-based monetary policy could yield favourable economic outcomes instead of discretionary monetary policy. In line with the objective of our research, *game theory* is one of the approaches for deriving rule-based policies by the main economic actors to minimise social loss.

Given the significance of exchange rate fluctuations in the Iranian economy and the increasing motivation for speculation in recent years, the necessity to examine the interaction between monetary and fiscal policymakers has become even more pressing. As a result, this group of actors is considered in our study.

Given the fluctuations in exchange rates in the Iranian economy and the increased motivation for speculation, speculators are also considered as actors in this study. Studies such as Pérez and Santos (2010), Fujimoto (2014), and Lopez-Suarez and Razo-Garcia (2017) have demonstrated that game theory can aid the understanding of decision-making processes in the currency market. Applying game theory to exchange rate speculation can significantly help explain speculators' behaviour and exchange rate dynamics. Game theory provides a framework for analysing strategic interactions between market participants, including dealers, and can help understand their decision-making processes in the currency market (Fujimoto, 2014).

Compared to other studies, this study's innovation lies in the critical role assigned to currency market speculators as third players in the analysis of strategic interactions. Unlike previous studies, which mainly focused on bilateral interactions between fiscal and monetary authorities, this study offers a more comprehensive view of economic dynamics by including exchange rate actors, leading to more effective solutions for reducing social loss and improving economic outcomes.

This study aims to design a strategic game among the government, central bank, and currency speculators to provide an optimal solution for coordinating monetary and fiscal policies and the behaviour of speculators. The model used in this study is based on Stackelberg game theory (leader-follower structure), with fiscal authorities acting as leaders (or followers), monetary authorities as followers (or leaders) and speculators as followers (see also Lambertini & Rovelli, 2003).

This study aims to present a theoretical framework using game theory to analyse and optimise economic policies. This framework assists policymakers in selecting the best strategies for achieving desirable economic goals and minimising social losses. The following sections delineate the theoretical foundations of the topic of the study, culminating in game design by specifying objective functions for each player to calculate the social loss associated with each defined behaviour.

The remainder of this paper is structured as follows: Section 2 reviews the relevant literature on the interactions between monetary and fiscal authorities and exchange rate speculators. Section 3 outlines the theoretical framework, including

the objective functions and constraints of each actor as well as the formulation of the cooperative game model based on the Stackelberg approach. Section 4 presents the data, estimation of key parameters, and the results of the model under different scenarios. Finally, Section 5 concludes the study by summarising the key findings and their policy implications.

2. LITERATURE REVIEW

The interaction between currency speculators, monetary policymakers, and fiscal policymakers within an economy is a complex and dynamic process. Monetary policy involves the management of money supply and interest rates by central banks, whereas the government controls fiscal policy, which involves taxation and government spending. Both policies can significantly impact economic activities, and governments can influence their economies' performance through monetary and fiscal policies (Canzoneri et al., 2010). The relationship between exchange rates and domestic financial conditions can create challenging trade-offs for monetary policy, thus complicating its implementation. The interaction among these stakeholders is crucial in shaping the economic environment, affecting factors such as inflation, interest rates, and overall economic stability (Carstens, 2019).

The interplay between fiscal and monetary policies is essential for determining the trajectory of the macroeconomic variables. These interactions can be categorised into four primary scenarios:

1. Both the government and central bank operate according to predetermined rules.
2. The central bank operates according to the rules, whereas the government operates at its own discretion.
3. Conversely, the government operates according to rules, whereas the central bank operates at its own discretion.
4. Both institutions operate at their own discretion.

Moreover, the government and the central bank can either collaborate to implement their policies or operate independently (Lambertini & Rovelli, 2003). Barro and Gordon (2019) and Rogoff (1985) suggest that monetary policy should be delegated to an independent and appropriately conservative central bank.

Government oversight of the economy can lead to crises (Carfì & Musolino, 2011).

Changes in the central bank's policies and their interactions with the government have been observed in Iran. The central bank's independence and the effectiveness of its policy tools can only be evaluated by considering its economic structure and national objectives. An independent central bank should have complete control over monetary policy instruments, and a conservative central bank should aim to keep production and inflation targets within the socially optimal level (Dixit & Lambertini, 2003). Ultimately, crucial issues such as time inconsistency and debt sustainability play a vital role in the interaction between monetary and fiscal policies and speculators and must be carefully examined. Analytical approaches, including game theory, offer critical insights into understanding these interactions.

Findings from researchers in this field often focus on the interaction between monetary and fiscal authorities as the primary actors. As previously noted, our study incorporated speculators into our model due to their current significant influence on fluctuations and commodity prices in the Iranian economy. Therefore, our analysis proceeded with three actors to examine their reciprocal behaviour. Nevertheless, examples of existing research in this domain include the following.

Saulo Bezerra dos Santos (2010) applies the Stackelberg model to investigate the interaction between monetary and fiscal authorities. His findings demonstrate that coordination between these two policies is crucial because decisions made by one entity may harm the other, reducing overall societal welfare. His study identified optimal monetary and fiscal policies within three coordination frameworks: the first, where each institution independently minimises welfare loss as a Nash equilibrium of a standard game; the second, where one institution moves first, followed by the other (known as the Stackelberg solution); and the third, where institutions pursue common objectives. The results indicate that the smallest welfare loss occurs under the Stackelberg solution, with monetary policymakers acting as leaders and fiscal policymakers as followers.

Anevlavis et al. (2019) showed that cooperation between central banks and the government results in faster debt adjustment and reduced social loss. Sargent and

Wallace (1981), within the framework of the Stackelberg model, demonstrated that a monetary policymaker cannot exert permanent control over inflation when fiscal policy dominates monetary policy.

Welburn and Hausken (2015) examined financial frictions using a game consisting of five players – countries, central banks, banks, corporations, and households. Their results indicate that global financial crises expose the systemic risk transmitted through economic contagion. Due to the interconnected nature of national and global economies, adverse effects are disseminated across countries. Within this framework, Welburn and Hausken (2015) modelled strategic choices, conducted sensitivity analyses, and examined the impacts of random shocks. The main findings of their study suggest that contagion through credit channels and trade channels, or general macroeconomic conditions without contagion can lead to crises, even if all actors in the model behave rationally.

Dixit (2001) constructed several European Monetary Union and European Central Bank models to analyse the interactions between monetary and fiscal policies in selected countries. He found that attention should be paid to the perilous role of unrestrained fiscal policies, as they can undermine the commitment to the central bank's monetary policy. Kirsanova et al. (2005) examined the interaction of monetary and fiscal policies through three types of games (cooperative, non-cooperative, and the Stackelberg model, where the fiscal actor is the leader and the monetary actor is the follower, and vice versa). Their results indicate that if both policymakers are benevolent and cooperate, allowing the fiscal policymaker to enable the monetary policymaker to play a significant role in responding to economic shocks, the lowest possible level of social loss can be achieved.

According to the studies by Tanner and Ramos (2003), Fialho and Portugal (2005), and Gadelha and Divino (2008), the central bank acting as a leader in the Stackelberg model results in minor welfare loss for society. This response also indicates a strong reaction from monetary authorities to inflationary pressure. Additionally, an inflationary effect stems from fiscal shocks, reinforcing the crucial role of the monetary authority in stabilising the economy.

Research indicates that game theory can be employed to model speculative attacks on exchange rates, in which speculators make decisions based on their expectations of other market participants' actions and the potential outcomes of their actions over different periods (Chamley, 2003). Furthermore, game theory is used to analyse the proportion of agents involved in currency sales; this factor serves as a measure of speculative pressure and can influence exchange rate dynamics (Fujimoto, 2014). By considering the strategic interactions and heterogeneous expectations of market participants, game theory can provide insights into the potential for speculative attacks and the dynamics of exchange rate movements.

Additionally, the role of game theory in understanding speculator behaviour in the foreign exchange market and its implications for exchange rate stability has been a significant area of interest for researchers (Krugman, 1989). With its focus on strategic interactions and varied participant expectations, game theory offers valuable perspectives on the likelihood of speculative attacks and the resulting exchange rate dynamics. In summary, game theory can influence speculators by providing a framework for modelling strategic behaviour and its impact on exchange rate dynamics (Fujimoto, 2014).

Based on the research, the reciprocal decisions of the central bank, government, and foreign exchange market participants can have direct and indirect effects on these three actors. In this context, understanding the interactions between the central bank, government, and currency speculators is crucial, as these interactions not only influence domestic variables but can also impact the foreign exchange market. This understanding can serve as a tool for policymakers and macroeconomic strategists. This is particularly significant in countries such as Iran, where a substantial portion of government revenue is derived from foreign exchange earnings from the export of natural raw materials. Therefore, considering the impact of the interaction between monetary and fiscal policies on social welfare loss, the implementation or non-implementation of government directives by the central bank is a crucial subject that warrants examination, particularly with the acknowledgment of the role and presence of foreign exchange market traders.

We subsequently explored the necessary elements for designing a game among these three players, introducing the role and strategy of each player according to their objectives.

3. FRAMEWORK

This study examines the interactions between the three principal actors in Iran's economic landscape:

1. The Iranian government: Acting as the implementer of fiscal policies.
2. The Central Bank of Iran: Serving as an executor of monetary policy.
3. Currency speculators: banks, companies, investment funds, and other market participants.

It is crucial to understand that each actor operates within a complex framework and faces specific constraints when utilising their tools and mechanisms. In our models, the objective of both monetary and fiscal authorities and foreign exchange market participants is to minimise their respective loss functions, which involves dealing with complex constraints on aggregate demand and aggregate supply in the economy.

In the models under consideration, each actor uses controllable instruments to manage their target variables. Thus, the government's budget, the interest rate, and the amount of foreign currency demanded by speculators are considered the target variables for the government, the central bank, and speculators, respectively.

The stages of the study are as follows:

In the first stage, we conduct a process known as 'constrained optimisation' to determine the actors' best response functions. This process involves maximising or minimising a function while satisfying constraints. We consider the possible strategies and relevant constraints for each actor, and this process is performed using MAPLE mathematics software.

In the second stage, the interactions between the actors are designed in the Stackelberg model. According to the definition in game theory, the primary entity

in all theoretical models is the player, who may be an individual, a group, or a government facing decision-making. We have a non-cooperative Nash equilibrium model if the players act independently in a game. In the Stackelberg model, one of the players chooses their strategy first, and for this type of decision-making issue, a subgame perfect equilibrium (SPE) is determined. This decision-making process is derived from Stackelberg's work. In this model, the player who chooses their strategy first is called the leader, and the other player who responds to the leader's strategy is called the follower. Such games can involve multiple leaders and followers and multiple decision-making processes (Başar & Olsder, 1999).

Using the Stackelberg model, two scenarios are examined:

- Scenario one: The government is the leader, and the central bank is the follower.
- Scenario two: The central bank is the leader, and the government is the follower.

The third stage involves meticulously calculating the social loss resulting from each scenario. Subsequent sections provide a detailed breakdown of all computations, underscoring the thoroughness of our analysis.

Furthermore, Lagrangian techniques from Woodford and Walsh (2005) and Lambertini and Rovelli (2003) are employed to introduce loss functions and optimal reaction functions for each actor.

3.1. Objective functions of financial actors

In this context, we assume the quadratic equation of the government's loss function, which defines the preferences of both society and the government:

$$LS = (\pi - \pi_1)^2 + \mu(i - \pi_1 - R)^2 + (y - y_1)^2 + \gamma f^2 + \omega(e - e_1)^2 \qquad (1)$$

In Equation 1, y denotes the actual national output, y_1 is the potential output, π is the current inflation rate, π_1 is the inflation target, f represents government spending, which is one of the government's policy instruments used to minimise its social loss function, i is the nominal interest rate, and R is the long-term (target) interest rate. Each term captures a deviation from its respective target or potential level, contributing to the overall social loss. γf^2 represents the

government's loss due to the exchange rate gap. The government suffers more loss when the difference between the market and official exchange rates increases. The parameter γ reflects how sensitive the government is to this gap. $\omega(e - e_1)^2$ represents the central bank's loss from the deviation between the market exchange rate and the official exchange rate**.** The larger the gap between the market rate e and official rate e_1, the more it harms the central bank's objectives. The parameter ω indicates how much weight the central bank places on this issue.

In Equation 1, variables cause disruptions and inefficiencies in the economic system, resulting in losses for producers and consumers. In this study, we assume that in the absence of shocks, and when current national output equals potential national output ($y = y_1$) and current inflation equals the monetary authority's target inflation ($\pi = \pi_1$), social loss is minimised. Therefore, under these optimal conditions, a neutral policy stance should be adopted, which includes $f = 0$ and $i = \pi_1 - R$; otherwise, any deviation from the target values is considered an appropriate measure of loss, as deviations from a target rate, whether above or below, result in a positive value for the loss function. Consequently, what is included in the loss function is the product of their weights and the square of the deviation from the target value. $(e - e_1)$ represents the exchange rate gap. The reason for including this variable in the government's objective function is the regulated exchange rate system in Iran, which is determined by the government and considered one of the influential variables in the government's response.

It is important to note that these weights represent the significance of the variables and indicate how crucial stabilising these variables is for society. These weights were incorporated as coefficients of the variables in the loss function. For example, suppose the loss function includes both output and inflation rates, and the central bank considers the inflation rate target more critical than the output target. In this case, a greater weight is assigned to the inflation rate. Thus, a more significant coefficient is considered. Once the target values are established, any deviation from these targets (positive or negative) is undesirable and considered a loss.

Note on the exchange rate regime in Iran: In the government's loss function, the inclusion of the exchange rate gap reflects the institutional structure of Iran's exchange rate policy, which is not fully floating but rather a managed or dual

exchange rate system. In this system, the government or central bank sets an official exchange rate, while a market-based rate emerges in parallel markets. The deviation between these two rates introduces economic distortions, such as arbitrage opportunities, rent-seeking behaviour, and misallocation of resources, especially in trade and capital flows. Therefore, minimising this gap is not merely about enforcing a fixed regime, but about reducing inefficiencies and social costs arising from the dual exchange rate environment.

The loss function of the central bank is considered in Equation 2:

$$LM = (\pi - \pi_1)^2 + \mu(i - \pi_1 - R)^2 + \omega(e - e_1)^2 \quad (2)$$

In the central bank's loss function, the first term, $(\pi - \pi_1)$, represents inflation targeting; the second term, $(i - \pi_1 - R)$, captures the central bank's effort to control the real interest rate; and the third term, $(e - e_1)$, reflects the importance of minimising the exchange rate gap . The parameters μ and ω denote the relative importance assigned to the interest rate and exchange rate deviations, respectively. In this context, the monetary actor seeks to adopt a monetary rule to find guidelines for setting the interest rate. Therefore, the interest rate in the central bank's loss function is considered the tool for this actor. Another critical point is that, according to this loss function, from the perspective of the monetary policymaker, any positive or negative deviation from the target interest rate is viewed as undesirable.

Speculators, the third actor in this context, are primarily involved in the buying and selling of foreign currency. Their goal is to minimise the loss function, which is a function of the inflation gap, interest rate gap, output gap, and the gap between the real and nominal exchange rates. This function, as per the details mentioned earlier, is specified in Equation 3:

$$LE = (\pi - \pi_1)^2 + \mu(i - \pi_1 - R)^2 \quad (3)$$

Speculators' losses, as a function of the aforementioned variables, follow the logic that any operational bias in the macroeconomic environment, specifically in terms of inflation, interest rates, and economic growth (output gap) relative to the expected values set by economic policymakers, can introduce errors in the

calculations of active market players. This underscores the significant role of economic policymakers in setting the expected values, which can lead to losses for market participants due to their buying or non-buying decisions at the beginning of the period.

It is worth noting that, although the exchange rate gap does not explicitly appear as a separate term in the speculators' loss function, it is implicitly embedded through the exchange rate variable *e*, which affects their decisions and market expectations. Speculators incur loss when their forecasts of exchange rate movements (including divergence from the official rate) deviate from actual outcomes. Thus, the gap indirectly influences their loss via inflation, interest rate, and output deviations.

3.1.1. Rationale behind the weight structure

Before moving to the aggregate demand and supply constraints, it is important to clarify the rationale behind the weighting structure used in the loss functions. In the loss functions of each actor, we assume that the weights associated with inflation and output gaps are normalised to 1, i.e., these gaps are equally important baseline components of social loss. The use of explicit weights (γ, μ, ω) for variables such as government spending, interest rate, and exchange rate gaps reflects their relative importance in comparison to inflation and output. This approach simplifies the analysis by setting inflation and output as reference variables with standard priority, while allowing flexibility in how sensitive each actor is to the additional variables. The weights (γ, μ, ω) are assumed to be positive real numbers. Their specific values or ranges (e.g., 0.5 to 1.5) are selected in the sensitivity analysis section to reflect different policy priorities of each actor, such as more emphasis on budget discipline, interest rate stability, or exchange rate control.

3.1.2. Aggregate demand and supply constraints

The constraint functions must be considered by mathematical programming based on the same variables in the objective function. The present model defines two constraints: aggregate supply and aggregate demand. The IS curve represents aggregate demand, and the Phillips curve depicts aggregate supply. The aggregate demand relationship is formulated on the idea that, in the short term, a positive value of the output gap may result from an expansionary monetary policy (which

causes the short-term real interest rate to fall below its long-term equilibrium value), an expansionary fiscal policy, or an unexpected positive shock from the demand side. In other words, the behaviour of aggregate demand in this economy can be described as:

$$AD: y = y_1 - \alpha(i - \pi_1 - R) + \eta f + \theta(e - e_1) + \varepsilon_1 \quad (4)$$

In Equation 4, y denotes actual national output and y_1 is potential output. The term $\alpha\ (i - \pi_1 - R)$ captures the deviation of the real interest rate from its long-term value, with i as the nominal interest rate, π_1 the target inflation rate, and R the long-term equilibrium interest rate. The parameter α reflects the sensitivity of aggregate demand to real interest rate changes. The term $\theta\ (e - e_1)$ accounts for the structural and expectation-driven effects of the exchange rate gap, where e is the market exchange rate and e_1 is the official exchange rate set by monetary authorities. This term captures how exchange rate misalignments affect consumption, investment, and net exports through market channels and inflationary expectations. In contrast, the term ηf represents the direct influence of fiscal or administrative exchange rate policies on aggregate demand. Here, $f = e - e_1$ is defined explicitly to represent the exchange rate gap from the perspective of fiscal authorities, such as the government. By modelling f as a separate input in the aggregate demand function, the model allows for a clear distinction between the monetary and fiscal interpretations of exchange rate misalignments. This distinction is particularly relevant in economies with dual exchange rate regimes or heavy government intervention in the foreign exchange market. Finally, ε_1 denotes a demand-side shock that may reflect unforeseen variations in consumption, investment, or government spending unrelated to policy instruments.

Equation 5 represents another constraint in the study, the Phillips curve, which reflects the limitations of the economy's supply function. According to the Phillips curve, the inflation rate increases (decreases) in response to a positive (negative) gap in output. Additionally, unexpected positive or negative supply shocks can alter the inflation rates. Notably, without these shocks, the inflation rate equals its expected value.

$$AS: \pi = \pi_1 + \beta(y - y_1) + \varepsilon_2 \quad (5)$$

In Equation 5, π denotes the current inflation rate, π_1 is the target (expected) inflation rate, y is the current output, y_1 is the potential output, and ε_2 represents unexpected supply shocks in the economy. Additionally, β, the parameter (coefficient), indicates the impact of the output gap on the current inflation rate. ε_1 and ε_2 are assumed to be independently and identically distributed (i.i.d) with a mean of zero and constant variance. In line with standard macroeconomic modelling, the random shocks ε_1 and ε_2, representing demand-side and supply-side disturbances respectively, are assumed to be i.i.d. with zero mean. Economic agents do not observe the realised values of these shocks at the time of decision-making. Therefore, their expectations are formed based on the mean, which is set to zero. This allows the optimisation process to proceed using expected rather than realised shock values, preserving both tractability and economic realism.

It is important to note that the determination of constraints depends on the variables in the social loss function. In this context, two scenarios are considered. In the first scenario, where only inflation and output variables are present in the loss function, the sole constraint is the aggregate supply function. This is because the curve reflects the relationship between the fluctuations and the sensitivity of the two variables over time. In the second scenario, where inflation, output, and interest rate variables are included in the loss function, the problem is examined with two constraints: the aggregate supply function and the aggregate demand function. Given the monetary transmission mechanism, it is crucial to consider this mechanism in any monetary policy. If the interest rate is the central bank's policy tool, then the related constraints will also include the interest rate. In other words, changes in the interest rate, and consequently its effect on investment, lead to changes in output (via the IS curve), and changes in output affect inflation through the aggregate supply curve.

The design of the monetary transmission mechanism depends on two factors. The variables in the loss function and the country's economic conditions determine the variables in the loss function, the number of constraints, and which functions should be utilised.

In the current study, the output gap, the difference between actual GDP and potential GDP, is regarded as a significant real variable influencing inflation. This gap serves as an effective indicator for measuring economic fluctuations and is a

valuable tool in the short term for assessing inflationary pressures in the goods and services market. When the actual level exceeds the potential level, it signals inflationary pressures that necessitate contractionary policies. Conversely, when the actual level falls below the potential level, it signifies recessionary conditions that call for expansionary policies.

Changes in national output, driven by the effects of aggregate supply or aggregate demand policies, are always associated with fluctuations in unemployment and inflation. During economic booms, characterised by growing national output, unemployment decreases while inflation increases. Conversely, during recessions, the opposite effects are observed. A flourishing economy under these conditions typically exhibits two fundamental characteristics: first, the actual output is close to the potential output; and second, the natural output growth rate is rapid yet steady.

The government seeks to establish a rule for its expenditures. Therefore, in the loss function, government expenditure serves as the tool for the government. Like the central bank, the government is concerned with inflation and the underutilisation of potential economic capacities. The financial actor's loss function is minimised concerning aggregate supply and demand constraints. Using the Lagrange method and MAPLE software, the optimal reaction function for the government's financial tool (i.e., government expenditure) is derived in Equation 6.

It is worth noting that, although ε_1 and ε_2 appear explicitly in the first-order conditions (Equations 6–14), agents optimise their strategies based on expected values, with $E[\varepsilon_1]=E[\varepsilon_2]=0$. Therefore, the equilibrium decisions are not influenced by the realisation of these shocks at the time of decision-making.

$$L: (\pi - \pi_1)^2 + \mu(i - \pi_1 - R)^2 + (y - y_1)^2 + \gamma f^2 + \omega(e - e_1)^2 + \lambda_1[(y - y_1 + \alpha(i - \pi_1 - R) - \eta f - \theta(e - e_1) - \varepsilon_1] + \lambda_2[\pi - \pi_1 - \beta(y - y_1) - \varepsilon_2] \quad (6)$$

To minimise the above function, the partial derivatives of the function with respect to its endogenous variables must be set equal to zero, as shown in the system of equations in Equation7.

$$\frac{\partial \mathrm{L}}{\partial \pi} = 2\pi - 2\pi_1 + \lambda_2 = 0$$

$$\frac{\partial \mathrm{L}}{\partial \mathrm{y}} = 2y - 2y_1 + \lambda_1 + \lambda_2\beta = 0$$

$$\frac{\partial \mathrm{L}}{\partial \mathrm{f}} = 2\gamma f - \lambda_1\eta = 0 \qquad (7)$$

$$\frac{\partial \mathrm{L}}{\partial \lambda_1} = y - y_1 + \alpha(i - \pi_1 - R) - \eta f - \theta(e - e_1) - \varepsilon_1 = 0$$

$$\frac{\partial \mathrm{L}}{\partial \lambda_2} = \pi - \pi_1 - \beta(y - y_1) - \varepsilon_2 = 0$$

The government's optimal reaction function, derived by solving the above system of equations in terms of the model's parameters and exogenous variables, is presented in Equation 8.

$$f_{br} = -\frac{\eta(R\alpha\beta^2 - \alpha\beta^2 i + \alpha\beta^2\pi_1 + \beta^2 e\theta - \beta^2 e_1\theta + \beta^2\varepsilon_1 + \alpha R - \alpha i + \alpha\pi_1 + \beta\varepsilon_2 + \theta e - \theta e_1 + \varepsilon_1)}{\beta^2\eta^2 + \eta^2 + \gamma}$$

$$\frac{\partial \mathrm{f}_{br}}{\partial \mathrm{e}_1} = \frac{-\eta(-\beta^2\theta - \theta)}{\beta^2\eta^2 + \eta^2 + \gamma} = \frac{\eta(\beta^2\theta + \theta)}{\beta^2\eta^2 + \eta^2 + \gamma} > 0$$

$$\frac{\partial \mathrm{f}_{br}}{\partial \mathrm{i}} = \frac{-\eta(-\alpha\beta^2 - \alpha)}{\beta^2\eta^2 + \eta^2 + \gamma} = \frac{\eta(\alpha\beta^2 + \alpha)}{\beta^2\eta^2 + \eta^2 + \gamma} > 0 \qquad (8)$$

The above function effectively represents the government's optimal response to the decision-making processes of the central bank and foreign exchange speculators. Specifically, according to this function, if speculators exhibit high demand for foreign currency and the independent central bank aims to increase the nominal interest rate, the government's best response would be to allow a more significant deviation of government spending from a balanced budget condition.

As shown in Equation (8), f_{br} represents the government's deviation from the balanced budget, that is, its adjustment in government spending. Comparative

statics reveal that an increase in the exchange rate gap $(e-e_1)$, interpreted as a larger divergence between the market and official rates, prompts the government to increase its expenditures. This reflects the government's effort to offset the contractionary effects of exchange rate misalignments on aggregate demand.

Similarly, when the nominal interest rate i rises, leading to higher real interest rates, the government optimally reduces its expenditures. Higher interest rates dampen investment and consumption, and thus the government adjusts its fiscal stance by reducing spending to stabilise output and inflation. These results are derived directly from Equation (8) and align with the theoretical expectations regarding fiscal policy reactions to monetary and exchange rate conditions.

Similarly, the central bank, like the fiscal actor, seeks to minimise its social loss function given the complex economic constraints. The structure for this problem is presented in Equation (9):

$$L: (\pi-\pi_1)^2+\mu(i-\pi_1-R)^2+\omega(e-e)^2+\lambda_1[(y-y_1+\alpha(i-\pi_1-R)-\eta f-\theta(e-e)-\varepsilon_1]+\lambda_2[\pi-\pi_1-\beta(y-y_1)-\varepsilon_2] \quad (9)$$

Additionally, the partial derivatives of the mentioned function with respect to the model's endogenous variables are expressed by the following system of equations in Equation 10.

$$\frac{\partial \mathrm{L}}{\partial \pi}=2\pi-2\pi_1+\lambda_2=0$$

$$\frac{\partial \mathrm{L}}{\partial \mathrm{y}}=\lambda_1-\lambda_2\beta=0$$

$$\frac{\partial \mathrm{L}}{\partial i}=2\mu(i-\pi_1-R)+\lambda_1\alpha=0$$

$$\frac{\partial \mathrm{L}}{\partial \lambda_1}=y-y_1+\alpha(i-\pi_1-R)-\eta f-\theta(e-e)-\varepsilon_1=0 \quad (10)$$

$$\frac{\partial \mathrm{L}}{\partial \lambda_2}=\pi-\pi_1-\beta(y-y_1)-\varepsilon_2=0$$

By solving the above system of equations in terms of the model's parameters and exogenous variables using MAPLE software, the optimal reaction function for the nominal interest rate is derived as follows. This function effectively represents the central bank's best response to the decision-making processes of the government and currency speculators. Specifically, according to this function, if speculators decide to increase their demand for currency, the central bank's best response would be to lower the nominal interest rate. Conversely, if the government intends to increase its spending, the central bank's optimal reaction would be to raise the nominal interest rate according to Equation 11.

$$i_{br} = \frac{R\alpha^2\beta^2 + \alpha^2\beta^2\pi_1 + \alpha\beta^2 e\theta - \alpha\beta^2 e_1\theta + \alpha\beta^2\eta f + \alpha\beta^2\varepsilon_1 + \alpha\beta\varepsilon_2 + \mu R + \mu\pi_1}{\alpha^2\beta^2 + \mu}$$

$$\frac{\partial i_{br}}{\partial e_1} = \frac{-\alpha\beta^2\theta}{\alpha^2\beta^2 + \mu} < 0$$

$$\frac{\partial i_{br}}{\partial f} = \frac{\alpha\beta^2\eta}{\alpha^2\beta^2+\mu} > 0 \qquad (11)$$

The optimal reaction function of speculators for the level of foreign currency demand is derived in Equation 12.

$$L: (\pi - \pi_1)^2 + \mu(i - \pi_1 - R)^2 + \lambda_1[(y - y_1 + \alpha(i - \pi_1 - R) - \eta f - \theta(e - e_1) - \varepsilon_1] + \lambda_2[\pi - \pi_1 - \beta(y - y_1) - \varepsilon_2] \qquad (12)$$

Additionally, the following equations in Equation 13 represent the partial derivatives of the mentioned function concerning the model's endogenous variables.

$$\frac{\partial L}{\partial \pi} = 2\pi - 2\pi_1 + \lambda_2 = 0$$

$$\frac{\partial L}{\partial y} = \lambda_1 - \lambda_2\beta = 0$$

$$\frac{\partial L}{\partial e_1} = +\theta\lambda_1 = 0$$

$$\frac{\partial L}{\partial \lambda_1} = y - y_1 + \alpha(i - \pi_1 - R) - \eta f - \theta(e - e_1) - \varepsilon_1 = 0$$

$$\frac{\partial L}{\partial \lambda_2} = \pi - \pi_1 - \beta(y - y_1) - \varepsilon_2 = 0 \tag{13}$$

The best response of the speculators is derived in Equation 14:

$$e_{1_{br}} = \frac{R\alpha\beta - \alpha\beta i + \alpha\beta\pi_1 + \beta b\theta + \beta\eta f + \beta\varepsilon_1 + \varepsilon_2}{\beta\theta}$$

$$\frac{\partial e_{1_{br}}}{\partial f} = \frac{\beta\eta}{\beta\theta} > 0$$

$$\frac{\partial e_{1_{br}}}{\partial i} = \frac{-\alpha\beta}{\beta^2\theta^2 + \omega} < 0 \tag{14}$$

The above function represents the optimal response of speculators to the decisions made by the government and the central bank. According to this function, if the government decides to increase its expenditures, the optimal reaction of the speculators would be to demand more foreign currency. Conversely, if the central bank intends to raise the nominal interest rate, the optimal response from the speculators would be to demand less foreign currency.

3.2. Optimisation of the model under the cooperative game (Stackelberg)

The Stackelberg model is examined in the following two scenarios: In the first scenario, when the fiscal expert moves first, they predict a response from monetary policy as the Stackelberg leader. In the second scenario, when the monetary expert moves first, they anticipate a response from fiscal policy as the Stackelberg leader.

In this section, we delve into the complexity of the Stackelberg model. Based on the objective functions in the basic model, defined constraints, and Lagrangian techniques from Woodford (2003) and Lambertini and Rovelli (2003), the optimal reaction functions of the aforementioned players are derived under

dynamic play by minimising each player's loss function while adhering to the constraints. Subsequently, the loss functions are calculated with respect to three constraints, one demand constraint, one supply function, and the best response function of the opposing player, to obtain the Stackelberg equilibrium.

To derive the equilibrium in the Stackelberg model in this study, which involves three key players – the government, the central bank, and speculators, the problem is solved by initially substituting the third player's reaction function into the optimisation process of the second player's objective function, followed by the substitution of the second player's reaction function into the optimisation process of the first player's objective function. The interactions between these players are analysed within the Stackelberg model framework under the following two scenarios. It is worth noting that the resulting equilibrium is a subgame perfect Nash equilibrium (SPE), obtained through backward induction and reflecting optimal strategies for all players at every stage of the game.

It is important to note that in the computational process of both methods, foreign exchange market speculators are considered followers since they do not actively participate but only aim to maximise their utility.

3.2.1. First scenario: Stackelberg equilibrium when the government is the leader and the central bank acts as the follower

In this scenario, we analyse a case where the government selects f before the monetary authority decides on the size of i. Here, the central bank acts as the follower by minimising LM with respect to f while considering a specified interest rate. In this situation, the fiscal player is the leader and initiator of the game. Within the Stackelberg model framework, the optimal f is first determined.

Subsequently, the fiscal authority minimises its cost function under the given constraints, using the best response functions provided by the central bank and the speculators. This process involves minimising the government's cost function subject to the demand and supply constraints and the best reaction functions of the other two players, the central bank and the speculators. Therefore, the government's objective is to minimise the following subject to the mentioned constraint, which is expressed in Equation 15.

It is worth noting that although ε_1 and ε_2 appear explicitly in the intermediate derivations for completeness, during the optimisation stage agents only consider their expected values, which are zero. Thus, the equilibrium strategies are based on the assumption that ε_1 and ε_2 have an expected value of zero at the time of decision, and their realised values influence only the realised outcomes, not the chosen strategies:

$$LS = (\pi - \pi_1)^2 + \mu(i - \pi_1 - R)^2 + (y - y_1)^2 + \gamma f^2 + \omega(e - e_1)^2$$

S.t:

$$1)\ AD: y = y_1 - \alpha(i - \pi_1 - R) + \eta f + \theta(e - e_1) + \varepsilon_1$$

$$2)\ AS: \pi = \pi_1 + \beta(y - y_1) + \varepsilon_2$$

$$3)\ i_{br} = \frac{R\alpha^2\beta^2 + \alpha^2\beta^2\pi_1 + \alpha\beta^2 e\theta - \alpha\beta^2 e_1\theta + \alpha\beta^2\mu f + \alpha\beta^2\varepsilon_1 + \alpha\beta\varepsilon_2 + \mu R + \mu\pi_1}{\alpha^2\beta^2 + \mu}$$

$$4)\ e_{1_{br}} = \frac{R\alpha\beta - \alpha\beta i + \alpha\beta\pi_1 + \beta e\theta + \beta\eta f + \beta\varepsilon_1 + \varepsilon_2}{\beta\theta}$$

$$LL: (\pi - \pi_1)^2 + \mu(i - \pi_1 - R)^2 + (y - y_1)^2 + \gamma f^2 + \omega(e - e_1)^2 + \lambda_1[(y - y_1 + \alpha(i - \pi_1 - R) - \eta f - \theta(e - e_1) - \varepsilon_1] + \lambda_2[\pi - \pi_1 - \beta(y - y_1) - \varepsilon_2] + \lambda_3\left[i - \frac{R\alpha^2\beta^2 + \alpha^2\beta^2\pi_1 + \alpha\beta^2 e\theta - \alpha\beta^2 e_1\theta + \alpha\beta^2\mu f + \alpha\beta^2\varepsilon_1 + \alpha\beta\varepsilon_2 + \mu R + \mu\pi_1}{\alpha^2\beta^2 + \mu}\right] + \lambda_4\left[e_1 - \frac{R\alpha\beta - \alpha\beta i + \alpha\beta\pi_1 + \beta e\theta + \beta\eta f + \beta\varepsilon_1 + \varepsilon_2}{\beta\theta}\right] \quad (15)$$

Solving the above L function in MAPLE software yields the government's optimal response under the Stackelberg game in Equation 16.

$$f_s^g = -\frac{\theta^2\omega\mu^2\eta(\beta\varepsilon_1 + \varepsilon_2)}{\beta(\alpha^4\gamma\omega^2 + 2\alpha^2\gamma\mu\omega\theta^2 + \eta^2\mu^2\omega\theta^2 + \gamma\mu^2\theta^4)}$$

$$f_s^g = -\frac{\theta^2\omega\mu^2\eta(\beta\varepsilon_1+\varepsilon_2)}{\beta(\alpha^4\gamma\omega^2+2\alpha^2\gamma\mu\omega\theta^2+\eta^2\mu^2\omega\theta^2+\gamma\mu^2\theta^4)} \quad (16)$$

In Equation 16, f_s represents the extent of the government's budget deviation from the balanced budget within the framework of the Stackelberg game when the government assumes the role of the leader. Given the equilibrium budget deviation for the government under the Stackelberg game, other players can also determine the equilibrium responses for the interest rate and the demand for foreign currency. Equation 18 illustrates these equilibrium values, which the respective players establish.

$$i_s^g = \frac{1}{\beta(\alpha^4\gamma\omega^2 + \mu\theta^2(2\alpha^2\gamma + \eta^2\mu)\omega + \gamma\mu^2\theta^4)}[(\beta(R+\pi_1)\alpha + \beta\varepsilon_1 + \varepsilon_2)\gamma\alpha^3\omega^2 + \mu\theta^2\left(\eta^2\beta(R+\pi_1)\mu + 2\left(\beta(R+\pi_1)\alpha + \frac{\beta\varepsilon_1}{2} + \frac{\varepsilon_2}{2}\right)\gamma\alpha\right)\omega + \mu^2\beta\gamma\theta^4(R+\pi_1)]$$

$$e_1{}_s^g = \frac{(e\mu\beta\theta^2 + \mu(\beta\varepsilon_1+\varepsilon_2)\theta + e\beta\alpha^2\omega)(\omega\alpha^2+\mu\theta^2)\gamma + e\beta\eta^2\mu^2\omega\theta^2}{((\omega\alpha^2+\mu\theta^2)^2\gamma+\eta^2\mu^2\omega\theta^2)\beta} \quad (18)$$

Given each player's equilibrium values in the Stackelberg game, the loss for each player can be calculated. The following equations represent the loss functions of each player in terms of the study's parameters.

1. The loss function of the government with the government as the leader in Equation 19:

$$LS_s^g = \frac{1}{((\omega\alpha^2+\mu\theta^2)^2\gamma+\eta^2\mu^2\omega\theta^2)^2\beta}(\left(((\beta\varepsilon_1+\varepsilon_2)^2\mu + \alpha^2\varepsilon_2^2)\omega + \theta^2\varepsilon_2^2\mu\right)(\omega\alpha^2 + \mu\theta^2)^3\gamma^2 + \eta^2(2\alpha^4\omega^2\varepsilon_2^2 + \mu\theta^2((\beta\varepsilon_1+\varepsilon_2)^2\mu + 4\alpha^2\varepsilon_2^2)\omega + 2\mu^2\theta^4\varepsilon_2^2)\mu^2\theta^2\omega\gamma + \eta^4\mu^4\omega^2\theta^4\varepsilon_2^2) \quad (19)$$

2. The loss function of central bank with the government as the leader in Equation 20:

$$LM_S^g = \frac{\mu\gamma^2\omega(\beta\varepsilon_1+\varepsilon_2)^2(\omega\alpha^2+\mu\theta^2)^3}{((\omega\alpha^2+\mu\theta^2)^2\gamma+\eta^2\mu^2\omega\theta^2)^2\beta^2} \quad (20)$$

3. The loss function of the speculators with the government as the leader in Equation 21:

$$LP_s^g = \frac{\mu\gamma^2\alpha^2\omega(\beta\varepsilon_1+\varepsilon_2)^2(\omega\alpha^2+\mu\theta^2)^2}{((\omega\alpha^2+\mu\theta^2)^2\gamma+\eta^2\mu^2\omega\theta^2)^2\beta^2} \quad (21)$$

In the above equations, LS_s^g, LM_S^g, and LP_s^g represent the loss functions of the fiscal player (government), the monetary player (central bank), and the currency speculators, respectively, within the Stackelberg model under the government's leadership.

3.2.2. Second scenario: Stackelberg equilibrium when the central bank is the leader and the government acts as the follower

Using Equation 22, we examine a scenario where the central bank selects i before the fiscal authority decides on the value of f; in this context, the government, acting as a follower, minimises LS with respect to i given a specified interest rate. In this case, the monetary player acts as the leader and initiates the Stackelberg game by first determining the optimal i. Subsequently, the monetary authority minimises its cost function subject to the best response functions of the government and foreign exchange speculators. In other words, the central bank minimises its cost function under the constraints of demand and supply and the optimal response functions of the other two players.

It is worth noting that although ε_1 and ε_2 appear explicitly in the intermediate derivations for completeness, during the optimisation stage agents only consider their expected values, which are zero. Thus, equilibrium strategies are based on the assumption that ε_1 and ε_2 have the expected value of zero at the time of decision, and their realised values influence only the realised outcomes, not the chosen strategies. Therefore, the central bank's objective is to minimise:

$$LM = (\pi - \pi_1)^2 + \mu(i - \pi_1 - R)^2 + \omega(e - e_1)^2$$

S.t:

$$1)\ AD: y = y_1 - \alpha(i - \pi_1 - R) + \eta f + \theta(e - e_1) + \varepsilon_1$$

$$2)\ AS: \pi = \pi_1 + \beta(y - y_1) + \varepsilon_2$$

$$3)\ f_{br} = -\frac{\eta(R\alpha\beta^2 - \alpha\beta^2 i + \alpha\beta^2\pi_1 + \beta^2 e\theta - \beta^2 e_1\theta + \beta^2\varepsilon_1 + \alpha R - \alpha i + \alpha\pi_1 + \beta\varepsilon_2 + \theta e - \theta e_1 + \varepsilon_1)}{\beta^2\eta^2 + \eta^2 + \gamma}$$

$$4)\ e_{1_{br}} = \frac{R\alpha\beta - \alpha\beta i + \alpha\beta\pi_1 + \beta e\theta + \beta\eta f + \beta\varepsilon_1 + \varepsilon_2}{\beta\theta}$$

$$LM_S: (\pi - \pi_1)^2 + \mu(i - \pi_1 - R)^2 + \omega(e - e_1)^2 + \lambda_1[(y - y_1 + \alpha(i - \pi_1 - R) - \eta f - \theta(e - e_1) - \varepsilon_1] + \lambda_2[\pi - \pi_1 - \beta(y - y_1) - \varepsilon_2] + \lambda_3\left[f - \frac{\eta(R\alpha\beta^2 - \alpha\beta^2 i + \alpha\beta^2\pi_1 + \beta^2 e\theta - \beta^2 e_1\theta + \beta^2\varepsilon_1 + \alpha R - \alpha i + \alpha\pi_1 + \beta\varepsilon_2 + \theta e - \theta e_1 + \varepsilon_1)}{\beta^2\eta^2 + \eta^2 + \gamma}\right] + \lambda_4\left[e_1 - \frac{R\alpha\beta - \alpha\beta i + \alpha\beta\pi_1 + \beta e\theta + \beta\eta f + \beta\varepsilon_1 + \varepsilon_2}{\beta\theta}\right]. \quad (22)$$

By solving the above Lagrange function using MAPLE software, the government's optimal response in the Stackelberg game is obtained, as presented in Equation 23.

$$i_S^m = \frac{1}{\beta((\mu\theta^4 + \alpha^2\theta^2)\gamma^2 - 2\eta^2\omega(\mu\theta^2 + \alpha^2)\gamma + \eta^4\mu\omega^2)}(\theta^2\left(\left((R + \pi_1)\alpha^2 + \varepsilon_1\alpha + \mu\theta^2(R + \pi_1)\right)\beta + \varepsilon_2\alpha\right)\gamma^2 - 2\left(\left((R + \pi_1)\alpha^2 + \varepsilon_1\alpha + \mu\theta^2(R + \pi_1)\right)\omega\beta + \varepsilon_2\alpha(-\theta^2 + \omega)\right)\eta^2\gamma + \omega\eta^4(\mu\omega(R + \pi_1)\beta - 4\varepsilon_2\alpha) \quad (23)$$

In the above equation, i_S^m represents the equilibrium nominal interest rate when the central bank is the leader in the game between fiscal authorities and foreign exchange speculators. Given the equilibrium nominal interest rate in the Stackelberg game, one can determine the equilibrium responses of the other players, including the government's deviation from a balanced budget and the level of foreign exchange demand. Equation 24 reflects these equilibrium values as adopted by the respective players.

$$f_s^m = -\frac{(\mu\eta^2(\beta\varepsilon_1 + \varepsilon_2)\omega^2 + \left(2\left(\left(-\frac{\beta\varepsilon_1}{2} - \frac{\varepsilon_2}{2}\right)\gamma + \eta^2\varepsilon_2\right)\theta^2\mu + 4\eta^2\alpha^2\varepsilon_2\right)\omega - 2\gamma\theta^2\varepsilon_2(\mu\theta^2 + \alpha^2))\eta}{\beta(\eta^4\mu\omega^2 - 2\eta^2\omega(\mu\theta^2 + \alpha^2)\gamma + \gamma^2\theta^2(\mu\theta^2 + \alpha^2))}$$

$$b_{1_S}^{\ m} = \frac{1}{\beta((\theta^4\mu + \theta^2\alpha^2)\gamma^2 - 2\eta^2\omega(\mu\theta^2 + \alpha^2)\gamma + \eta^4\mu\omega^2)}(\theta^2(e\mu\beta\theta^2 + \mu(\beta\varepsilon_1 + \varepsilon_2)\theta + e\beta\alpha^2)\gamma^2 - 2\left(-\mu\theta^3\varepsilon_2 + e\mu\beta\omega\theta^2 + \frac{\mu\omega(\beta\varepsilon_1 + \varepsilon_2)\theta}{2} + e\beta\alpha^2\omega\right)\eta^2\gamma + \mu\eta^4\omega(e\beta\omega - 2\theta\varepsilon_2)) \quad (24)$$

Given each player's equilibrium values in the Stackelberg game, the loss incurred by each player can be calculated. The following equations represent the loss functions of each player in terms of the study's parameters.

1. The loss function of government with the central bank as the leader in Equation 25:

$$LS_S^m = \frac{16(\eta^2\varepsilon_2+\frac{(\beta\varepsilon_1+\varepsilon_2)\gamma}{2})^2(\eta^2\omega-\frac{\gamma\theta^2}{2})^2\mu\alpha^2}{\beta^2((\eta^2\omega-\gamma\theta^2)^2\mu-2\left(\eta^2\omega-\frac{\gamma\theta^2}{2}\right)\gamma\alpha^2)^2}+\frac{\varepsilon_2^2}{\beta^2}+$$
$$\frac{\eta^2\gamma((\omega(\beta\varepsilon_1+\varepsilon_2)+2\theta^2\varepsilon_2)(\eta^2\omega-\gamma\theta^2)\mu+4\left(\eta^2\omega-\frac{\gamma\theta^2}{2}\right)\varepsilon_2\alpha^2)^2}{\beta((\eta\omega-\gamma\theta)\mu-2\left(\eta\omega-\frac{\gamma\theta}{2}\right)\gamma\alpha)}+$$
$$\frac{4(\left(\frac{\beta\varepsilon_1}{2}+\frac{\varepsilon_2}{2}\right)\gamma+\eta^2\varepsilon_2)^2\theta^2\omega\mu^2(\eta^2\omega-\gamma\theta^2)^2}{\beta^2((\theta^2\mu+\theta^2\alpha^2)\gamma^2-2\eta^2\omega(\mu\theta^2+\alpha^2)\gamma+\eta^4\mu\omega^2)^2} \quad (25)$$

2. The loss function of central bank with the central bank as the leader in Equation 26:

$$LM_S^m = \frac{\mu(\beta\varepsilon_1\gamma+2\eta^2\varepsilon_2+\varepsilon_2\gamma)^2(\eta^4\mu\omega^3\theta^2-2\eta^2\gamma\mu\omega^2\theta^4+\gamma^2\mu\omega\theta^6+4\alpha^2\eta^4\omega^2-4\alpha^2\eta^2\gamma\omega\theta^2+\alpha^2\gamma^2\theta^4)}{\beta^2(\eta^4\mu\omega^2-2\eta^2\gamma\mu\omega\theta^2+\gamma^2\mu\theta^4-2\alpha^2\eta^2\gamma\omega+\alpha^2\gamma^2\theta^2)} \quad (26)$$

3. The loss function of speculators with the central bank as the leader in Equation 27:

$$LP_s^m = \frac{\alpha^2\mu(2\eta^2\omega-\gamma\theta^2)^2(\beta\gamma\varepsilon_1+2\eta^2\varepsilon_2+\gamma\varepsilon_2)^2}{\beta^2((\mu\theta^4+\alpha^2\theta^2)\gamma^2-2\eta^2\omega(\mu\theta^2+\alpha^2)\gamma+\eta^4\mu\omega^2)^2} \quad (27)$$

In the above equations, LS_S^m, LM_S^m, and LP_s^m, the loss functions of the fiscal player (the government), the monetary player (the central bank), and the speculators in the Stackelberg model, under the leadership of the central bank, are presented sequentially.

3.3. Comparison of equilibrium outcomes

The two equilibrium concepts derived in this section offer different insights into the strategic interactions between players. The Stackelberg frameworks model hierarchical decision-making. When the government acts as the leader (SPE-1), it internalises the reactions of the central bank and speculators, potentially achieving greater control over macroeconomic targets. Conversely, when the

central bank leads (SPE-2), monetary policy takes precedence, possibly resulting in better inflation or interest rate management but less coordination with fiscal objectives. These distinctions highlight the institutional importance of leadership structure in economic policy design.

4. EXPERIMENTAL RESULTS

Here, using the results from the designed models above and the estimated parameters based on data extracted from the Central Bank of Iran's information databases, we calculate the minimum losses for the monetary authority (central bank), the fiscal authority (government), and foreign exchange speculators.

It is important to note that regression methods and EViews software were employed to estimate the parameters related to the study's constraint functions. The results obtained from the MAPLE software calculations were used to calculate the minimum losses of the government, the central bank, and speculators within the framework of the Stackelberg game.

In addition to the estimated parameters, the model includes several exogenous coefficients, specifically γ, μ, and ω, which represent the sensitivity of the government's and central bank's loss functions to key economic gaps. These gaps include the exchange rate gap, the interest rate gap, and the government expenditure gap. Given their critical role, evaluating different scenarios for these parameters is essential to analysing the outcomes of the model. Calculating the minimum losses under various parameter scenarios is feasible. This involves examining the importance of these coefficients and their influence on the values of the players' losses and allows the determination of which of these three coefficients has the most significant impact on the results. This depends on the degree of the central bank's independence – greater independence corresponds to less government intervention, while limited independence reflects more government intervention. Accordingly, a higher value of the ω coefficient suggests the central bank uses this parameter to enhance the effectiveness of its policies, indicating greater independence. Conversely, higher values of the other coefficients reflect a lack of central bank independence.

Similarly, the higher the γ coefficient, the more the government uses its authority to implement policies, indicating lower central bank independence. Conversely,

a lower γ implies that the government considers the central bank's independence in its policy implementations. Additionally, it is noteworthy that adopting different scenarios for the coefficients in relation to the interest rate gap and the production gap is based on the premise that for the central bank, stabilising the interest rate and, consequently, stabilising prices is frequently more critical than stabilising production. In contrast, the primary focus of fiscal policymakers is stabilising production, such that governments pursue increased production through expansionary fiscal policies, even at the cost of rising inflation.

The results, which include the estimation of some intrinsic model parameters and the potential output of Iran, are achieved using the Hodrick–Prescott filter (Hodrick & Prescott, 1997), a crucial tool in economic analysis.

In this section, the statistical data for the variables used in the analysis include official and market exchange rates, short-term and long-term nominal interest rates, actual and target inflation rates, GDP, and corresponding data sources. The interest rates in the Iranian economy, a key aspect of our study, are managed by the Central Bank of Iran. This institution plays a pivotal role in determining interest rates according to the supply and demand for money in the free market. The Central Bank of Iran does not have a specific inflation target because the fundamental principle in target-setting policy (whether for inflation or any other economic variable) is the principle of announcement. Accordingly, the policymaker publicly declares the explicit value of the targeted variable to shape the expectations of economic agents. In Iran, inflation and certain other macroeconomic targets can only be found in development plans, although there is practically no commitment or obligation to achieve these targets. Nevertheless, in the text of the Fifth Development Plan, the monetary policymakers set an inflation target of 9 percent, and in the Sixth Development Plan, the inflation target was set at 8.8 percent. For official and market exchange rates, data from the Central Bank of Iran have been utilised. In this study, as mentioned, the Hodrick-Prescott filter is used to calculate the potential national output of our country, which is one of the common methods for estimating this unobservable variable. The filter's basis for calculating potential national output is to separate the long-term trend of national output from its short-term cycles.

4.1. Estimation of parameters of the supply and demand functions in the Iranian economy during the study period

Estimates of the required parameters (α, η, θ, and β) for the study are essential to calculate the loss functions for each of the actors. Therefore, the following parameters are estimated using the data presented in the previous section and employing econometric models within the EViews software.

$$log(y_i) = log(y_{1i}) - \alpha(i_i - \pi_{1i} - R_i) + \eta \log(f_i) + \theta[log(e_i) - log(e_{1i})] + \varepsilon_{1i} \quad (28)$$

$$\pi_i = \pi_{1i} + \beta[\log(y_i) - \log(y_{1i})] + \varepsilon_{2i} \quad (29)$$

Table1: Parameter estimation results for the Iranian economy in the period (2013–2022)

Parameter	α	η	θ	β
Estimated value	*0.01*	*0.003*	*0.02*	*105.7*

4.2. Estimation of parameters

It should be noted that calculating the minimum losses is feasible by considering various scenarios for the exogenous parameters of the model (γ, μ, and ω). The values assigned to these different parameters depend on their significance and the level of intervention by the fiscal authority (government) in the monetary authority's affairs (central bank's instrumental independence). Given that the parameter represents the exchange rate gap and the interest rate gap, it must be determined which of these two parameters is more significant in reducing the central bank's costs.

On the other hand, a higher coefficient indicates that the central bank leverages this parameter to enhance the effectiveness of its policies, thereby achieving greater independence. To evaluate the significance of these coefficients and their impact on costs, various scenarios for these coefficients should be analysed. Therefore, different scenarios can be employed to calculate the social loss functions for each actor. In this section, the results are derived from two considered scenarios.

The first scenario focuses on the central bank's policy instrument parameter.

Table 2: Possible states for importance of central bank policy instruments – first scenario

External parameters	Political tool of the monetary authority		Policy tool of the financial authority
	The importance of interest rates (μ)	Importance of exchange rate speculators (ω)	Importance of government spending (γ)
The first mode	1	1	1
The second mode	1.5	0.5	1
The third mode	0.5	1.5	1

Source: Authors' calculations

The second scenario focuses on the government expenditure coefficient parameter.

Table 3: Possible states for importance of government policy instruments – second scenario

	Political tool of the monetary authority		Policy tool of the financial authority
External parameters	The importance of interest rates (μ)	Importance of exchange rate speculators (ω)	Importance of government spending (γ)
The first mode	1	1	1
The second mode	1	1	0.5
The third mode	1	1	1.5

Source: Authors' calculations

Given that the coefficient of government expenditures plays a significant role in the government's objective function, this coefficient, along with others, is examined under different conditions in the second scenario. Therefore, in this second scenario, both the interest rate gap and the exchange rate gap coefficients in the social loss function of the monetary and fiscal actors are set to 1. Meanwhile, the coefficient of government expenditures (γ) in the fiscal actor's social loss function is considered at 1, 0.5, and 1.5. In this context, adopting a higher coefficient for government expenditures indicates a greater emphasis on budget balance from the fiscal policymaker's perspective.

Table 4: Social loss (total loss of three actors) over entire study period (2013–2022) in different states in order of amount of loss.

Type of game	Description of the situation	γ	ω	μ	Losses of exchange rate speculators	Loss of the central bank	Loss of the government	Total social loss
Stackelberg equilibrium government leadership	Equality of policy instruments	1	1	1	0.14	29.5	92.3	121.94
	Greater importance of balancing the government's budget	1.5	1	1	0.04	9.8	61.1	70.94
	Less importance of balancing the government's budget	0.5	1	1	0.3	56.7	123.5	180.5
Stackelberg balance of central bank leadership	Equality of policy instruments	1	1	1	9.10	301.1	823.5	1133.7
	Greater importance of the exchange rate gap	1	1.5	1	1.2	111.2	432.5	544.9
	Less importance of the exchange rate gap	1	0.5	1	95235	101520	101952	298.707

Source: Authors' calculations

Based on the results presented in the above table, it can be asserted that the lowest social loss within the dynamic-cooperative game framework (Stackelberg model) occurs when fiscal and monetary actors cooperate, with the fiscal actor taking on the role of leader and the monetary actor acting as the follower. Under these conditions, the total social loss amounts to 70.94 units, the lowest among all scenarios. The second lowest social loss is observed when the government and the central bank cooperate with the government as the leader and give equal importance to all factors, namely the budget balance, interest, and exchange rate gaps in the policymaking process. In this scenario, the total social loss is 121.94 units.

From the table, it is evident that the scenario in which the government and the central bank behave cooperatively – with the central bank as the leader and the exchange rate gap given more importance than the other two policy tools (government budget balance and central bank interest rate gap) – results in a social loss of 544.9 units. This loss is higher than the scenario where the government and the central bank cooperate with the central bank as the leader but assign equal importance to all policy factors or give less importance to the exchange rate gap than the other two tools.

Of the two equilibrium structures analysed in this study – Stackelberg with the government as leader (SPE1) and Stackelberg with the central bank as leader (SPE2) – the former seems most consistent with the institutional setting of Iran. In practice, fiscal policy tends to dominate the macroeconomic environment in Iran, particularly through large public expenditures, subsidies, and off-budget spending. Therefore, the Stackelberg equilibrium with the government as leader better reflects the strategic dominance of fiscal authorities over monetary institutions. In contrast, in countries with independent and credible central banks, such as the European Union or Canada, monetary leadership (SPE2) is more realistic. In some well-coordinated systems, the Nash equilibrium may better capture the balanced interplay of fiscal and monetary policies. This comparison highlights the institutional differences that shape equilibrium dynamics across countries.

Our results regarding the influence of exchange rate movements on economic performance are consistent with recent findings in the literature. For example,

Ješić (2023) highlights the critical drivers of GDP growth in selected European countries, emphasising the role of macroeconomic policy coordination. Similarly, Odionye and Chukwu (2023) demonstrate that exchange rate shocks have asymmetric effects on stock prices and industrial output, further supporting the need for coordinated fiscal and monetary responses to stabilise economic activity. These studies reinforce the importance of minimising social loss through strategic policy interactions as modelled in our framework.

5. CONCLUSION

This study employed a game-theoretic framework to analyse the strategic interactions between the government, the central bank, and foreign exchange market participants. Using the Stackelberg model, we considered two distinct leadership structures to evaluate their implications for macroeconomic coordination and social welfare. In the first scenario, the government acts as the leader, while the central bank and speculators are followers. In the second scenario, the central bank assumes the leadership role. For each case, we derived the optimal reaction functions of the players and calculated the social loss over a ten-year period.

The main finding of the study is that when the fiscal and monetary authorities behave cooperatively, with the government taking the lead, the overall social loss is minimised. In this setup, the government effectively anticipates the reactions of the central bank and foreign exchange market participants and adjusts its fiscal policy accordingly. The strategic advantage of leadership allows for better alignment of fiscal actions with macroeconomic stabilisation goals, particularly in terms of inflation control, output gap minimisation, and management of the exchange rate gap. The model shows that when the government prioritises budget discipline and coordinates with the central bank, the economy achieves the highest level of social welfare.

In contrast, when the central bank leads the game, the results are less favourable. Although the monetary authority may better control inflation or interest rate deviations in this role, the lack of fiscal alignment can increase social loss. Particularly in economies where fiscal policy has a dominant role – as is the case in Iran – central bank leadership without fiscal coordination may result in policy conflicts and inefficiencies. The findings suggest that in such institutional

environments, fiscal leadership supported by a responsive central bank is a more effective governance model.

The model also highlights the critical role of exchange rate management. In countries that operate under a dual or managed exchange rate regime, such as Iran, the gap between market and official rates – captured in the model as an explicit component of the loss function – can significantly affect macroeconomic outcomes. Government leadership in this context allows for more direct intervention in the currency market, helping to stabilise exchange rate expectations and reduce speculative pressures. Through tools such as currency interventions, capital flow regulations, and fiscal targeting, the government can play a central role in narrowing the exchange rate gap and reducing the associated distortions.

Although the model offers valuable insights, several limitations should be acknowledged. First, the framework is static, representing a one-period game without considering the temporal evolution of policy interactions. In reality, macroeconomic policy is dynamic, and agents operate under intertemporal constraints and expectations. A dynamic extension of the model would allow for an analysis of credibility, reputation, and learning.

Second, the model abstracts from external shocks and international linkages, such as oil price fluctuations, sanctions, and capital mobility – all of which are particularly important in Iran's economy. Including these factors in future extensions would provide a more comprehensive view of the policy environment.

Third, the model assumes rational and fully informed agents. However, in many real-world settings, information is incomplete, and decision-makers may operate under bounded rationality or political constraints. Behavioural extensions of the model could account for cognitive biases, delayed responses, or institutional frictions that often affect policy outcomes in practice.

Despite these limitations, the proposed framework can be adapted to other countries with similar structural characteristics. For instance, in countries where fiscal dominance is prevalent or where exchange rate distortions are severe, such as Venezuela, Egypt, or Argentina, the model's assumption of fiscal leadership reflects the actual policy structure. In contrast, in more developed or

institutionally balanced economies, where central banks have greater independence and credibility, the reverse leadership structure may be more applicable.

Future research could develop a dynamic, multi-period version of the model that allows for shock persistence, forward-looking expectations, and real-time policy adjustments. Empirical calibration using time-series data from Iran or similar economies would also enhance the model's practical value. Furthermore, incorporating global financial conditions or spillover effects could enrich the understanding of exchange rate dynamics in open economies.

In conclusion, this paper provides a theoretical foundation for understanding the role of leadership in macroeconomic policy coordination. By modelling the government and central bank as strategic players interacting with speculative market participants, the analysis reveals how institutional structure and leadership sequencing affect macroeconomic stability. The evidence from the model suggests that in economies such as Iran, government leadership with coordinated monetary support offers the most effective path for reducing social loss and enhancing overall welfare.

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BIBLIOMETRIC ANALYSIS OF PORTFOLIO DIVERSIFICATION FOCUSING ON ALTERNATIVE INVESTMENTS

ABSTRACT: *Portfolio diversification, a key investment management strategy, traditionally involved stocks, bonds, and cash. However, the growing complexity of financial markets has led to increased interest in alternative investments such as hedge funds, private equity, real estate, commodities, and cryptocurrencies due to their low correlations with traditional assets. This study aims to explore the evolving role of alternative investments in portfolio diversification by conducting a bibliometric analysis of 405 articles from the Web of Science database. The analysis provides insights into the most frequently cited articles, journals, co-author teams, individual authors, organisations, and countries. Additionally, it includes sentiment analysis of abstracts, followed by keyword co-occurrence, bibliographic coupling, and co-citation analysis. The findings reveal a marked increase in research activity on alternative investments over the past five years, peaking in 2019. Key themes identified include portfolio optimisation, asset allocation, and the integration of traditional and alternative investments, underscoring the growing significance of alternative assets in modern investment strategies. These findings have implications for both the academic community and practitioners, enhancing the understanding of alternative investments in portfolio diversification and informing future research and investment strategies.*

KEY WORDS: *portfolio diversification, alternative investments, bibliometric analysis, data visualisation and analysis*

JEL CLASSIFICATION: G11, G15, C88, F36

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1. INTRODUCTION

In the realm of finance, portfolio diversification has long been recognised as a fundamental strategy for risk management and performance enhancement. Traditionally, diversification strategies have predominantly focused on a mix of equities, bonds, and other conventional financial instruments. However, the evolving financial landscape has ushered in a growing interest in alternative investments, which include assets such as real estate, private equity, hedge funds, commodities, and digital currencies. These alternative investments are increasingly being considered for their potential to enhance portfolio returns and mitigate risks, prompting a surge in scholarly research dedicated to their role in diversified portfolios (Ang et al., 2009; Baur & Lucey, 2010;).

The traditional approach to portfolio diversification, grounded in modern portfolio theory (MPT) proposed by Markowitz (1952), emphasises the balance of risk and return through the allocation of investments across various asset classes with low correlations. While equities and bonds have historically formed the core components of diversified portfolios, the financial crises and market volatilities of the past few decades have highlighted the limitations of relying solely on these traditional assets (Campbell et al., 2013; Longstaff & Schwartz, 1995). Consequently, investors and researchers have turned their attention to alternative investments, seeking additional avenues for risk mitigation and return enhancement (Fabozzi et al., 2002).

Alternative investments are characterised by their distinct asset classes and investment strategies, which often exhibit low correlations with traditional assets (Kat & Miffre, 2008; Schneeweis et al., 2010). This unique characteristic positions them as valuable components in a diversified portfolio, potentially reducing overall portfolio volatility and enhancing returns (Swensen, 2000). Despite their growing popularity, the academic literature on the integration of alternative investments into diversified portfolios remains fragmented, necessitating a comprehensive analysis to synthesise existing findings and identify research gaps (Amenc & Martellini, 2002).

To the best of our knowledge, no bibliometric analysis has been performed on portfolio diversification with a specific focus on alternative investments. A closely related study is 'A bibliometric review of portfolio diversification literature' by

Migliavacca et al. (2023), which focuses on portfolio diversification in general. Our study extends this work by specifically addressing the integration of alternative investments into diversified portfolios. Another related piece of research is Patel et al. (2022), which conducts a bibliometric analysis focused on financial markets integration. However, there is no content overlap between the studies, as market integration is only one of the numerous factors that have influenced portfolio diversification over the last decades.

By providing a targeted analysis of alternative investments, our study offers novel insights that are highly relevant for contemporary portfolio management. The increasing complexity of financial markets and the emergence of new asset classes necessitate an updated understanding of diversification strategies. Our findings can inform educators updating curricula, researchers identifying new areas of inquiry, and practitioners seeking to enhance portfolio performance through the inclusion of alternative assets.

This analysis provides a review of the evolution of portfolio diversification literature over the last fifty years. Bibliometric investigation, firmly established as a scientific approach and integral to research evaluation (Ellegaard & Wallin, 2015), allows for a quantitative and qualitative review of the portfolio diversification literature. By examining the contributions of various types of alternative investments, this analysis aims to deepen the understanding of their impact on portfolio performance and risk management. Considering this, our article addresses several research questions (RQs):

RQ1: What are the influential aspects of this stream of literature in terms of top journals, authors, most studied and least studied countries, influential and trending articles/topics?

RQ2: What are the key research streams in portfolio diversification literature?

RQ3: What are the trends in research on alternative investments in portfolio diversification over the last two decades?

RQ4: What are the main themes and findings in the literature regarding alternative investments and portfolio diversification?

Adopting the guidelines provided by Donthu et al. (2021), Øyna and Alon (2018), and Zott et al. (2011), this study performs bibliometric analysis of portfolio diversification articles published between January 1974 and January 2023 in the Web of Science (WoS) database. This descriptive part of the analysis identifies influential journals, authors, and articles, while the content analysis maps out key research streams and trends within the portfolio diversification literature (Ellegaard & Wallin, 2015).

Our contribution to the extant literature lies in our methodological approach, which uniquely focuses on alternative investments. We adopt a holistic research design that utilises both descriptive analysis and content analysis tools to organise research streams on portfolio diversification that include alternative assets, such as real estate, private equity, hedge funds, commodities, and digital currencies. This comprehensive framework allows us to provide a thorough assessment of portfolio diversification, starting from defining its broad domain and identifying the most influential articles, journals, and research groups specifically in the context of alternative investments. We then map portfolio diversification research avenues, visualising focus areas and trends related to these non-traditional assets and finally propose future research questions that may further expand the extant literature on alternative investments (Goodell & Goutte, 2021; Guesmi et al., 2019).

Thus, this study not only advances academic knowledge by synthesising and structuring the existing literature but also offers practical implications for investment professionals. By highlighting the growing importance of alternative investments in portfolio diversification, we provide insights that can aid in the development of more resilient and optimised investment strategies in today's dynamic financial markets.

The remainder of this paper is organised as follows: Section 2 provides an in-depth description of the methodological approach adopted. Section 3 presents the results of the bibliometric analysis, including descriptive analysis and the analysis of keywords, bibliographic coupling of articles, authors, and countries, as well as co-citation of references. Section 4 discusses the findings, while Section 5 suggests directions for future research. Finally, Section 6 concludes the paper.

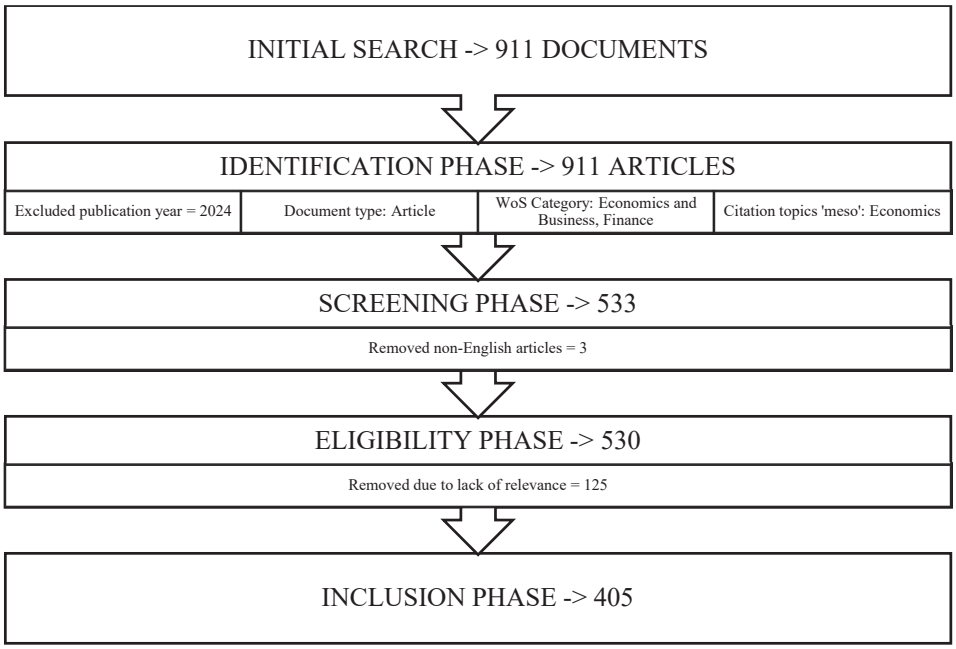
2. METHODOLOGY

A bibliometric review or bibliometric analysis serves as a research approach to examine the evolutionary development of scientific literature over time, shedding light on the intellectual relationships and diversity of knowledge within a field. For this study, we conducted a bibliometric analysis using data downloaded from the WoS database. The metadata was retrieved using a comprehensive search query based on terms such as: alternative assets, alternative investments, asset allocation, Bitcoin, commodities, digital currency, diversification, equity, hedge funds, portfolio, private equity, real estate, REITs, and virtual currency. This initial search produced a total of 911 documents. See the Appendix for details on the search query.

Furthermore, we utilised the PRISMA methodology to sift through the relevant articles. We applied specific filters to the WoS database in the initial identification phase. Initially, we excluded the year 2024 since it was ongoing, leaving us with 886 documents. Subsequently, we focused solely on articles as document types, reducing the count to 758. Further refinement was made by narrowing the categories to Economics and Business as well as Finance,–which reduced the number to 601 articles. To further narrow the selection, we included only those articles classified under the citation topics 'meso' for Economics, resulting in 533 articles.

During the screening phase, we focused on articles written in English, a common language in academic research, which resulted in a selection of 530 articles. In the subsequent eligibility phase, we applied rigorous criteria to narrow down the articles, carefully reviewing the abstracts and ensuring that each selected article was relevant to our study. This meticulous process excluded 125 articles, leaving us with a high-quality set of 405 articles for our analysis (Figure 1).

Figure 1: Visualisation of the PRISMA protocol



Source: Authors' compilation

3. RESULTS AND DISCUSSION

Our analysis began with a descriptive examination of the articles, in which we identified the most cited articles and annual publication trends as well as the most cited articles, author groups, individual authors, organisations, and countries. Additionally, we performed a sentiment analysis of the abstracts to gauge the general tone and sentiment expressed in the literature.

After conducting a descriptive analysis, we performed a more advanced bibliometric analysis using VOSViewer software (van Eck & Waltman, 2014). This included keyword co-occurrence analysis to uncover the relationships and common themes within the articles. Additionally, we carried out a bibliographic coupling of articles, authors, and countries to gain insights into the field's intellectual structure and collaboration patterns. Lastly, we conducted a co-citation analysis of references to pinpoint the most influential works and authors in portfolio diversification. This comprehensive approach gave us a profound

understanding of the current state and trends in the literature on portfolio diversification and alternative investments.

3.1. Descriptive analysis

Building upon the previous discussion, a detailed examination of the most frequently cited articles (Table 1) reveals several notable trends and focal points within portfolio diversification and alternative investments. One prominent area of interest is the study of home bias, in which investors prefer domestic equities over foreign ones. This is underscored by several highly cited papers, highlighting a significant interest in comprehending investors' inclination towards local investments despite the potential advantages of international diversification. Home bias can potentially hinder optimal portfolio performance by constraining the opportunities for risk mitigation through diversification across global markets.

An important area of focus pertains to the advantages and mechanisms of international diversification. Various highly regarded articles delve into how investors can optimise their portfolios by incorporating international equities, which allows for risk diversification and potential improvement of returns. This topic is essential for individual and institutional investors seeking to offset risks linked to local market declines. The concept of asymmetric correlations, wherein equity correlations fluctuate under different market conditions, is also a significant study area. Understanding these correlations is crucial for portfolio management as it enables investors to foresee and handle risks, especially during market declines when correlations among assets tend to rise, thereby diminishing the benefits of diversification.

The increasing attention towards alternative assets, including hedge funds, commodities, and digital currencies, represents a significant trend. Studies on these assets underscore their potential for enhancing portfolio diversification strategies. For instance, incorporating hedge funds and commodities can provide diversification advantages owing to their minimal correlation with conventional equity markets. Similarly, digital currencies such as Bitcoin are being examined for their ability to hedge against conventional market fluctuations (Table 1).

Table 1: The ten most cited articles

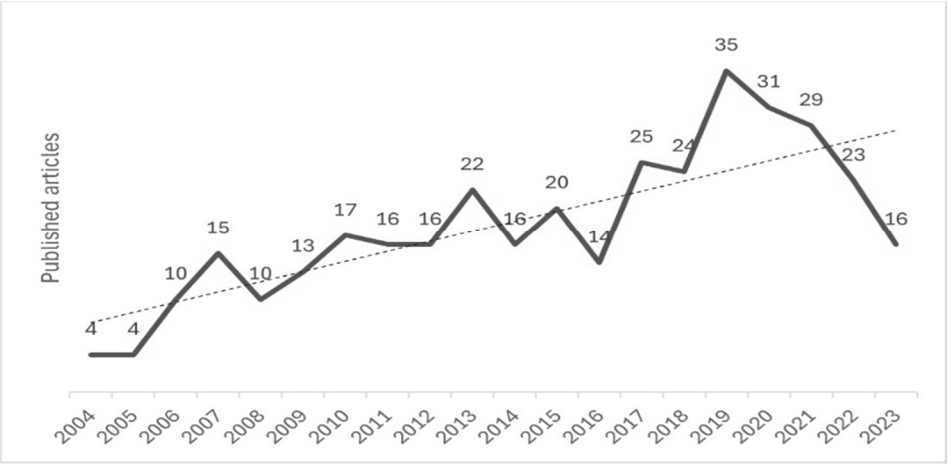
Article	Journal	Authors	Year	All databases' citations	WoS Core citations
Home bias at home: Local equity preference in domestic portfolios	The Journal of Finance	Coval, J. D.; Moskowitz, T. J.	1999	1493	1246
Investor diversification and international equity markets	The American Economic Review	French, K. R.; Poterba, J. M.	1991	1225	1056
Asymmetric correlations of equity portfolios	Journal of Financial Economics	Ang, A.; Chen, J.	2002	845	738
Why is there a home bias? An analysis of foreign portfolio equity ownership in Japan	Journal of Financial Economics	Kang, J. K.; Stulz, R. M.	1997	744	662
Risks and portfolio decisions involving hedge funds	The Review of Financial Studies	Agarwal, V.; Naik, N.Y.	2004	587	509
Equity portfolio diversification	Review of Finance	Goetzmann, W. N.; Kumar, A.	2008	566	498
Portfolio diversification with virtual currency: Evidence from Bitcoin	International Review of Financial Analysis	Guesmi, K.; Saadi, S.; Abid, I.; Ftiti, Z.	2019	362	355
Home bias in equity portfolios, inflation hedging, and international capital-market equilibrium	The Review of Financial Studies	Cooper, I.; Kaplanis, E.	1994	334	284
Should investors include commodities in their portfolios after all? New evidence	Journal of Banking & Finance	Daskalaki, C.; Skiadopoulos, G.	2011	234	210
US equity investment in foreign markets: Portfolio rebalancing or return chasing?	The American Economic Review	Bohn, H.; Tesar, L. L.	1996	223	204

Source: WoS database.

In addition, Figure 2 illustrates the annual trends in published articles on portfolio diversification focusing on alternative investments from 2004 to 2023. The data

shows a general upward trajectory, indicating growing interest and increased research activity in this area. After a relatively low and stable period from 2004 to 2006, the number of publications began to rise in 2007. Despite some fluctuations, the overall trend continued upwards, peaking at 35 articles in 2019. Although there was a slight decline in subsequent years – with 23 articles in 2022 and preliminary data indicating 16 articles in 2023 – the research output remains significantly higher compared to the early years.

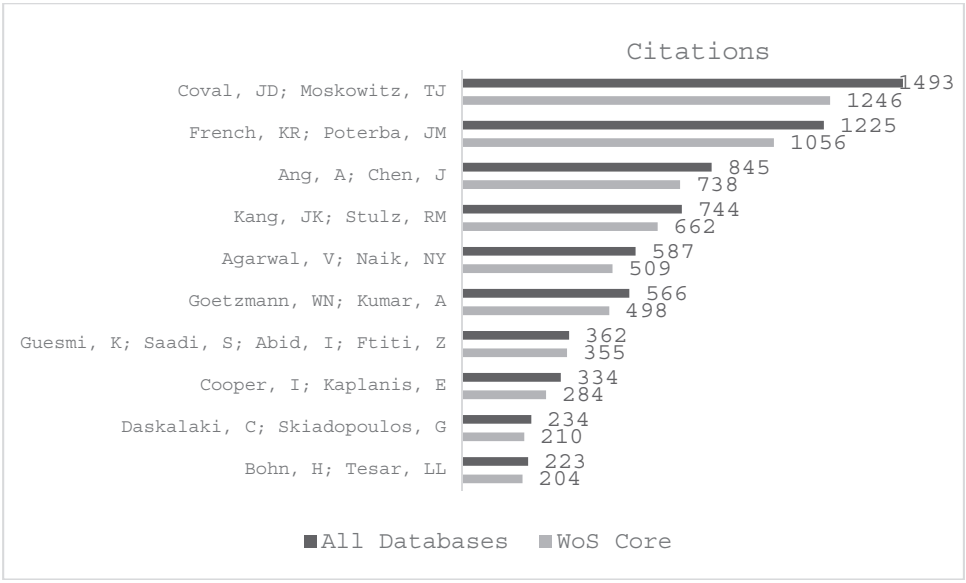
Figure 2: Annual trends of published articles



Source: WoS database.

Furthermore, Figure 3 presents the most cited authors (author groups) in all databases and the WoS database. Collaborative efforts by co-author teams account for 82% of the articles, emphasising the pivotal role of collaboration in producing influential research. This substantial percentage suggests combining diverse expertise and perspectives often leads to more comprehensive and impactful studies. The collaborative approach empowers researchers to tackle complex questions and devise innovative strategies, propelling the field more effectively.

Figure 3: The ten most cited author groups

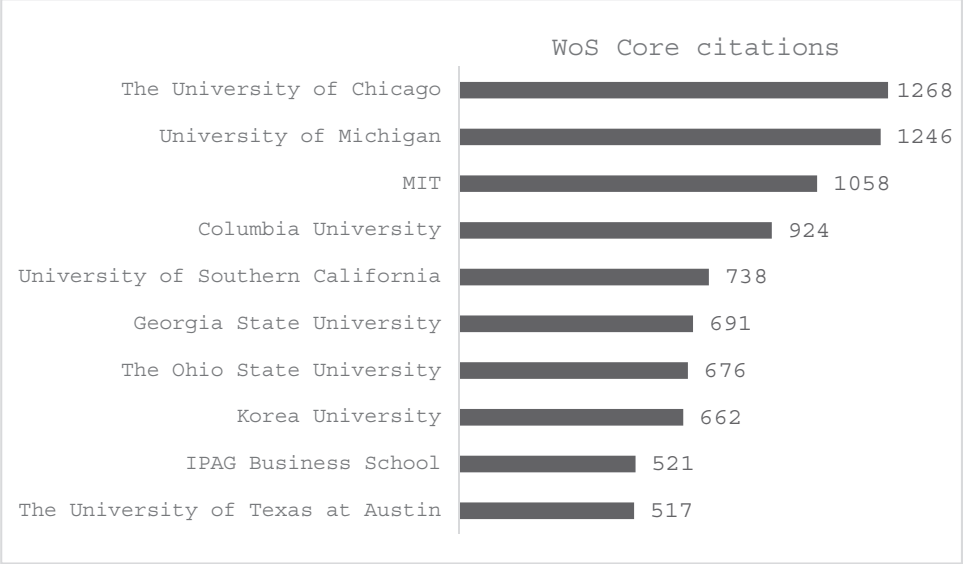


Source: WoS database.

In contrast, only 18% of the articles are authored by individuals. While these individual contributions remain significant, the lower percentage underscores the distinct advantage of teamwork in generating high-quality research. Individual authors often offer foundational insights and innovative ideas, but the scope and impact of their work are frequently amplified through collaborative endeavours.

Moreover, Figures 4 and 5 offer valuable insights into the organisations and countries most frequently cited in portfolio diversification with a focus on alternative investments. Figure 4 displays the top ten most cited organisations based on their WoS Core citations. Esteemed institutions such as the University of Chicago and the University of Michigan lead the list, with 1268 and 1246 citations, respectively. Other notable contributors include MIT, Columbia University, and the University of Southern California. These organisations are lauded for their significant research contributions to portfolio diversification, focusing on alternative investments, underscoring their influential roles in advancing knowledge and shaping the discourse within this field.

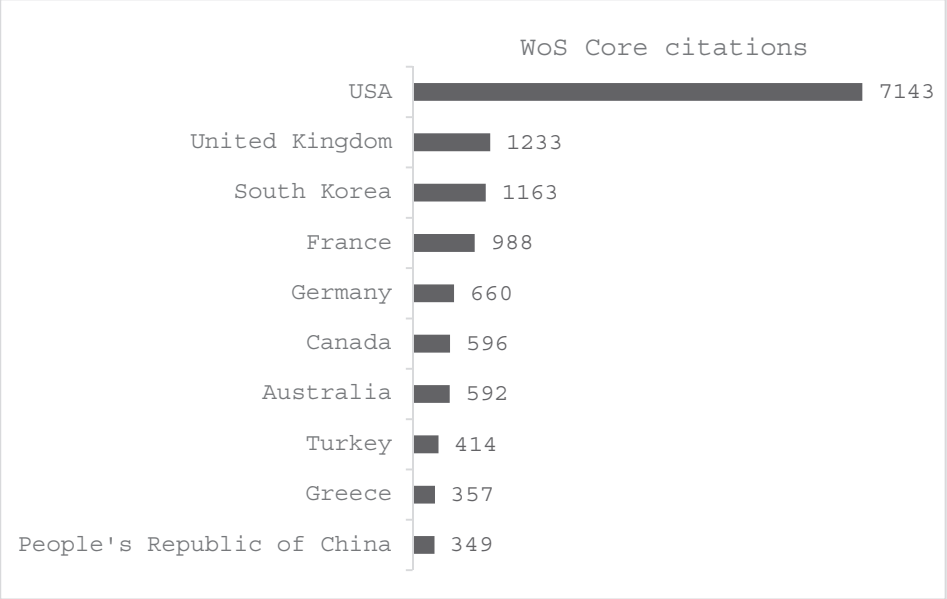
Figure 4: The ten most cited organisations



Source: WoS database.

In Figure 5, the focus shifts to the ten most cited countries, illustrating the global distribution of influential research in portfolio diversification with a focus on alternative investments. The United States leads the list with 7143 citations, firmly establishing its prominence in generating high-impact research. The United Kingdom (UK) and South Korea follow, with 1233 and 1163 citations, respectively, signalling their noteworthy contributions. Countries such as France, Germany, and Canada are also prominently featured, highlighting their active participation in portfolio diversification research. This international diversity underscores the widespread interest and collaboration across different regions in propelling advancements in the field.

Figure 5: The ten most cited countries



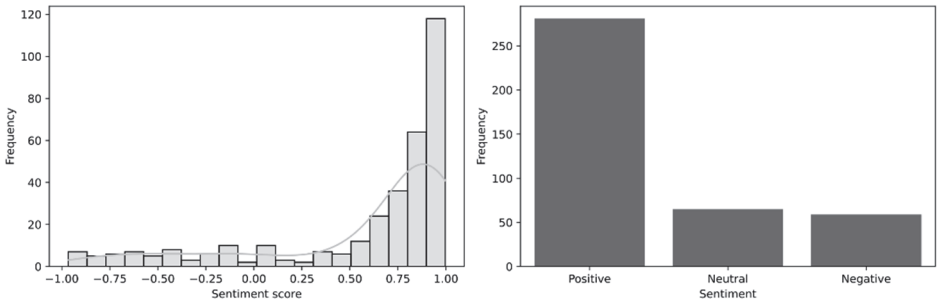
Source: WoS database.

Finally, Figure 6 presents the sentiment analysis of the abstracts, highlighting both the distribution of sentiment scores (ranging from -1.0 to 1.0) and the categorisation into positive, neutral, and negative sentiments. The distribution shows a significant clustering of positive sentiment scores, particularly between 0.75 and 1.0, indicating that the majority of abstracts convey a positive tone. Specifically, approximately 69% of the abstracts are classified as positive, 16% as neutral, and only about 15% as negative.

These findings suggest that the literature on portfolio diversification focusing on alternative investments predominantly reflects optimistic perspectives. This prevalence of positive sentiment may indicate that researchers are reporting favourable outcomes, successful strategies, or the benefits associated with alternative investments in diversification processes. Specifically, the positive sentiment could be attributed to the improved optimisation of portfolio diversification when alternative investments are included. By enhancing risk-adjusted returns and providing diversification benefits due to their lower correlation with traditional assets, alternative investments contribute to more

efficient portfolios. This growing confidence in incorporating alternative investments is likely contributing to the optimistic tone observed in the literature.

Figure 6: Abstracts sentiment distribution and categories



Source: WoS database.

3.2. Analysis of keywords co-occurrence, bibliographic coupling and co-citation

The keyword co-occurrence and clustering analysis in portfolio diversification focusing on alternative investments identifies thirteen critical clusters, with 1008 links connecting these items and a total link strength of 1188, each reflecting significant themes and methodologies within the field. They form a network visualisation map, which is presented in Figure 7. The larger circles and labels on the map indicate greater weight, whereas smaller ones represent smaller weight and, in some cases, may not be presented to avoid overlapping and making the map difficult to follow. Based on how closely connected they are and the topic they correspond to, all items are grouped into clusters, which the map highlights in separate colours. Additionally, the items are connected with lines called links. Thus, the shorter the distance and the deeper the lines are, the stronger the relationship between the terms is.

This analysis focuses on the most important clusters to provide a deeper understanding of their contributions to the evolving landscape of portfolio diversification, particularly emphasising alternative investments. From all clusters, the terms that occur the most are (portfolio) diversification and asset allocation (occurrences: 73, links: 107, total link strength: 148); Bitcoin (occurrences: 20, links: 32, total link strength: 47); portfolio optimisation and portfolio choice (occurrences: 29, links: 47, total link strength: 52); and commodities (commodity futures) (occurrences: 23, links: 36, total link strength:

43). These terms highlight the significant focus on both traditional and alternative investments, underscoring the diverse aspects of portfolio diversification. Following these, terms such as hedge funds, real estate, portfolio construction, and volatility further emphasise the variety of investment strategies and asset classes considered in diversification research.

The first cluster, marked in red, is the most prominent with 71 occurrences and focuses on portfolio optimisation, equity markets, and risk models. This cluster is central because it combines advanced optimisation techniques with traditional equity markets and sophisticated financial risk modelling approaches. Portfolio optimisation involves maximising returns while managing risk, a fundamental aspect of modern portfolio theory. Equity markets provide essential opportunities for growth and income, serving as performance benchmarks, while financial risk models offer robust methods for assessing and mitigating potential financial risks, thereby enhancing the diversification and resilience of traditional portfolios.

The blue cluster, with 59 occurrences, highlights asset allocation, portfolio diversification, and volatility spillover. This cluster is crucial because it addresses the core strategies of distributing investments across various asset classes to balance risk and reward. Effective asset allocation considers factors such as investment horizon, risk tolerance, and market conditions to optimise portfolio performance. Portfolio diversification aims to reduce risk by spreading investments across different assets, industries, and geographies, thereby mitigating unsystematic risk. Understanding volatility spillover, or how volatility in one market or asset can impact others, is essential for maintaining portfolio stability and crafting resilient investment strategies.

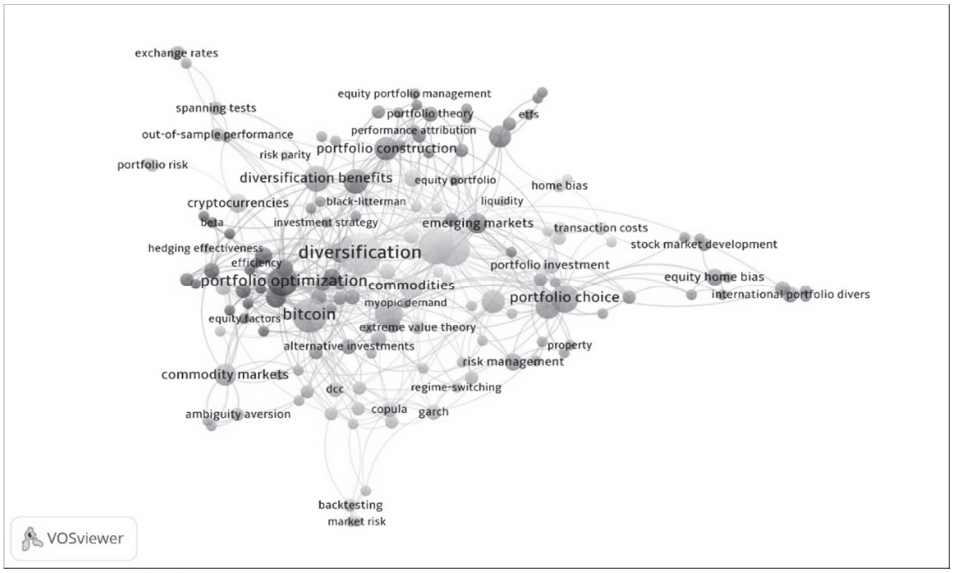
The yellow cluster, with 53 occurrences, focuses on diversification, commodities, and performance evaluation. This cluster emphasises the inclusion of non-traditional assets, such as commodities, in portfolios to provide diversification benefits and hedge against economic uncertainties. Commodities, with their low correlation to traditional stocks and bonds, enhance portfolio diversification and stability. Performance evaluation is critical in this context, as it involves assessing the effectiveness of diversification strategies through metrics such as returns and risk-adjusted returns, ensuring that the portfolio meets its investment objectives.

The green cluster, with 51 occurrences, delves into portfolio management, Islamic equities, and financial crises. This cluster's significance lies in its exploration of effective portfolio management strategies, especially during periods of financial turbulence. Portfolio management encompasses various strategies and practices aimed at achieving investment goals while managing risk. Islamic equities, adhering to Sharia principles, offer ethical investment opportunities and have shown resilience during financial crises. This cluster highlights the importance of understanding how different asset classes perform under stress and how they can be managed to mitigate risks effectively.

Finally, the turquoise cluster, with 50 occurrences, explores Bitcoin, commodity markets, and dynamic conditional correlation. This cluster is notable for its focus on emerging markets and such assets as Bitcoin, which offer unique risk-return profiles. The inclusion of digital currencies and commodities in portfolios represents the evolving nature of asset classes in modern finance. Dynamic conditional correlation models are used to analyse time-varying correlations between asset returns, providing insights into how different assets co-move over time.

Overall, these clusters collectively illustrate the evolving landscape of portfolio diversification research, with a particular focus on alternative investments. The integration of traditional and alternative assets, advanced optimisation techniques, and sophisticated risk management strategies are pivotal for developing robust investment portfolios. By incorporating emerging assets and effectively managing risks, researchers and practitioners can build portfolios capable of navigating diverse market conditions, ultimately contributing to more resilient and optimised investment strategies.

Figure 7: Network visualisation map of keyword co-occurrence



Source: WoS database.

Based on the overlay visualisation map (Figure 8), the focus in the field of portfolio diversification research has shifted over time. Initially, around 2012, the primary focus was on terms such as portfolio choice, portfolio investment, international portfolio diversification, emerging markets, equity home bias, hedge funds, and real estate.

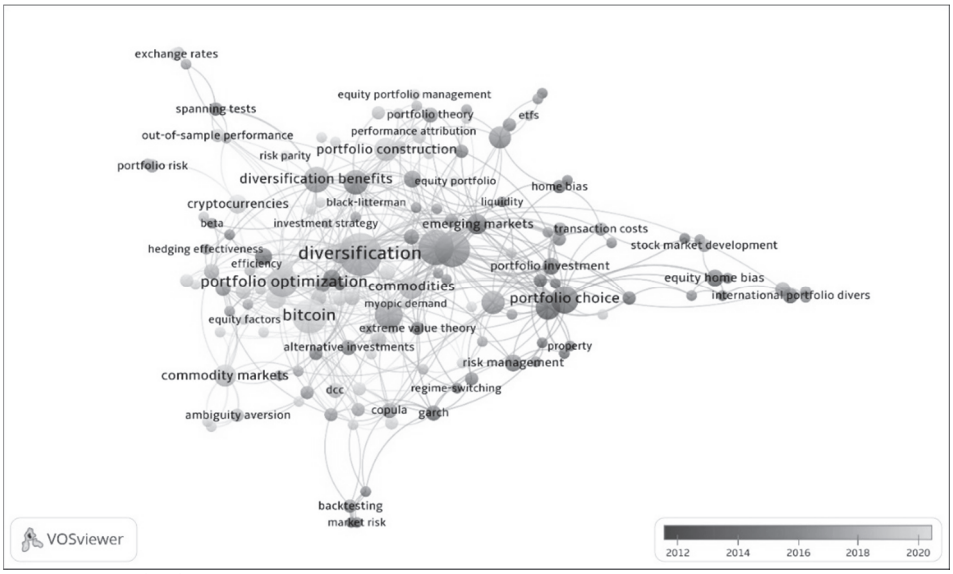
These concepts dominated the research landscape, reflecting a strong focus on optimising returns through established asset classes and mitigating risks associated with global equity markets.

However, more recent research trends, centered around 2020 and beyond, highlight a significant shift towards integrating alternative and innovative assets into diversified portfolios. This is evident from the increased focus on terms like 'Bitcoin', 'cryptocurrencies', 'private equity', and 'digital assets', which have gained prominence as investors seek new avenues for returns amid volatile market conditions. Alongside these, there is a growing interest in the role of 'commodities' and 'commodity markets', driven by their potential to act as hedges against inflation and economic uncertainties.

Further, modern portfolio management now encompasses advanced methodologies, such as 'dynamic conditional correlation' models, which allow for a more sophisticated analysis of time-varying relationships between assets. The focus on 'portfolio optimisation' and 'portfolio construction' remains strong, but it has expanded to include the use of algorithms and data-driven approaches to enhance performance measurement and risk management.

These evolving research trends indicate a critical shift towards embracing alternative investments and leveraging technological advancements for portfolio diversification. Researchers are increasingly exploring the implications of integrating these non-traditional assets, while portfolio managers are looking to optimise their strategies by incorporating such assets as digital currencies, commodities, and Sharia-compliant investments. This diversification is crucial for creating resilient portfolios that can withstand varying market conditions and achieve long-term investment goals.

Figure 8: Overlay visualisation map of keyword co-occurrence



Source: WoS database.

In addition, bibliographic coupling is employed in this study as a method within bibliometric analysis to identify relationships between research articles based on

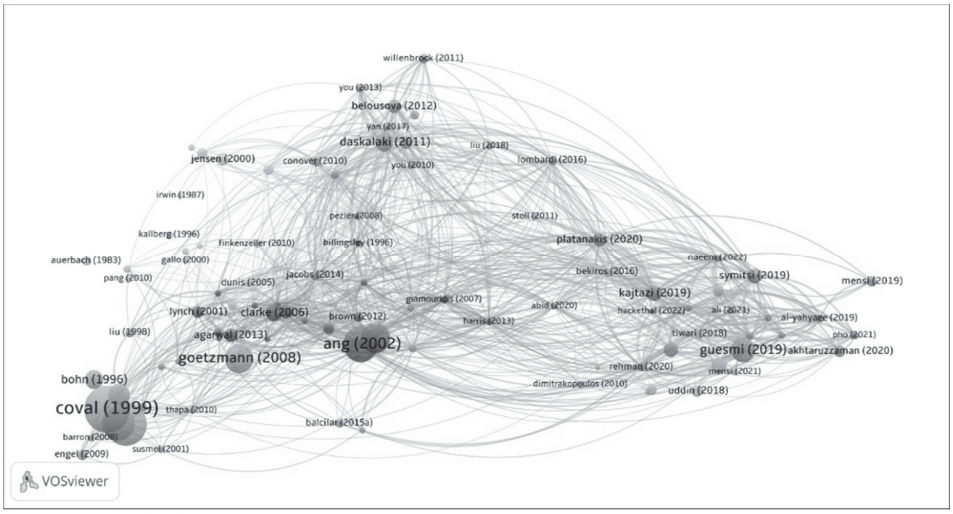
shared references, which helps in mapping the intellectual structure of a research field (Figure 9). This technique involves measuring the similarity between articles by counting the number of references they have in common, creating links between articles that cite the same sources. These links form a network of nodes (articles) and edges (shared references), which can be analysed to identify clusters representing interconnected themes and methodologies. In this study, six critical clusters within the field of portfolio diversification focusing on alternative investments were identified based on the thematic coherence and frequency of shared references among the articles (to enhance readability, only the first author is cited for works with multiple authors).

The first cluster (red) includes key works such as Ang (2002), Agarwal (2004, 2013), Clarke (2006), and Bali (2013), emphasising portfolio optimisation and diversification in equity markets. The second cluster (green) features works by Coval (1999), French (1991), Kang (1997), Goetzmann (2008), Cooper (1994), and Bohn (1996) focusing on portfolio management and equity home bias. The third cluster (blue) explores the integration of emerging assets, such as cryptocurrencies, with influential contributions from Guesmi (2019), Kajtazi (2019), Symitsi (2019), and Platanakis (2020).

Cluster 4 (yellow) emphasises commodities and performance evaluation, highlighted by significant studies from Jensen (2000, 2002), Cheung (2010), and Umar (2017). The fifth cluster (purple) delves into financial integration and international diversification, represented by Daskalaki (2011), Belousova (2012), Bessler (2015), and Willenbrock (2011). Lastly, the sixth cluster (orange) focuses on risk management and the integration of alternative assets, with notable works by Lin (2014), Uddin (2018), Guhathakurta (2020), and Bhatti (2012).

These clusters were identified based on the thematic coherence of the articles, with each cluster representing a distinct area of focus within portfolio diversification. The interconnectedness of research themes in portfolio diversification highlights traditional and alternative assets, advanced optimisation techniques, and sophisticated risk management strategies. This comprehensive and evolving nature of research underscores the importance of integrating diverse assets and effectively managing risks to develop resilient and optimised investment portfolios capable of navigating various market conditions.

Figure 9: Network visualisation map of articles' bibliographic coupling



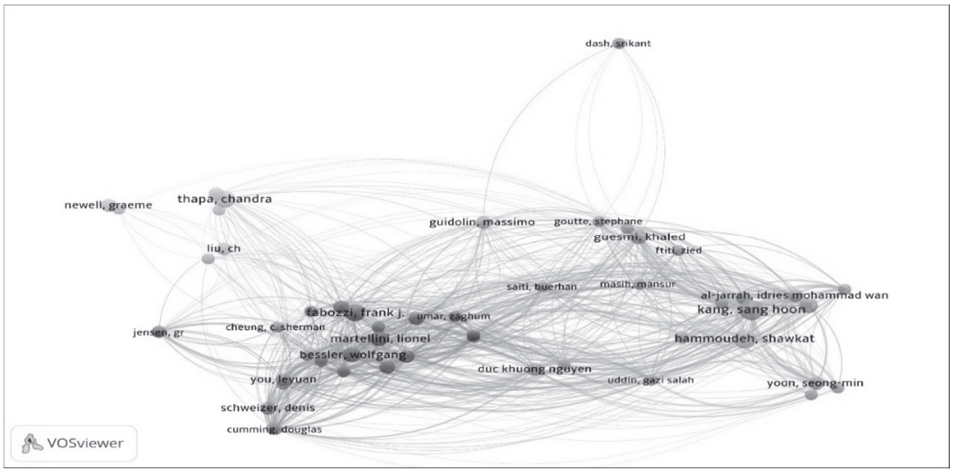
Source: WoS database.

In addition, the bibliographic coupling of authors was analysed to identify key thematic clusters (Figure 10). This analysis identified eight critical clusters also based on the thematic coherence and frequency of shared references among the authors. Cluster one (red) includes prominent authors such as Fabozzi, Platanakis, Bessler, and Sutcliffe. Cluster two (green) comprises notable contributors like Kang, Mensi, and Al-Jarrah. Cluster three (blue) features authors including Cheung, Daskalaki, Skiadopoulos, and You, while cluster four (yellow) includes Thapa, Poshakwale, Liu, Newell, and Ni. Cluster five (purple) features Duc Khuong Nguyen, Sjo, and Yoon, whereas cluster six (turquoise) comprises Hammoudeh, Balcilar, and Demirer. Cluster seven (orange) includes authors such as Guidolin, Dash, and Moran and finally, cluster eight (brown) features Schweizer, Cumming, and Hass.

The clusters identified in red, green, and blue are particularly relevant due to their strong interconnections and the prominence of their authors in the field. This interconnectedness underscores critical facets of contemporary portfolio diversification research, including the integration of diverse asset classes, the application of advanced optimisation techniques, and the implementation of sophisticated risk management strategies.

Moreover, the bibliographic coupling of authors is crucial for generating new ideas, methods, and instruments in the field. By understanding how different researchers are interconnected through their references, it becomes possible to identify emerging trends, foster collaborations, and stimulate innovative approaches in portfolio diversification and alternative investments. This analysis not only maps the current intellectual landscape but also paves the way for future research directions, contributing to the development of more resilient and optimised investment portfolios.

Figure 10: Network visualisation map of authors' bibliographic coupling



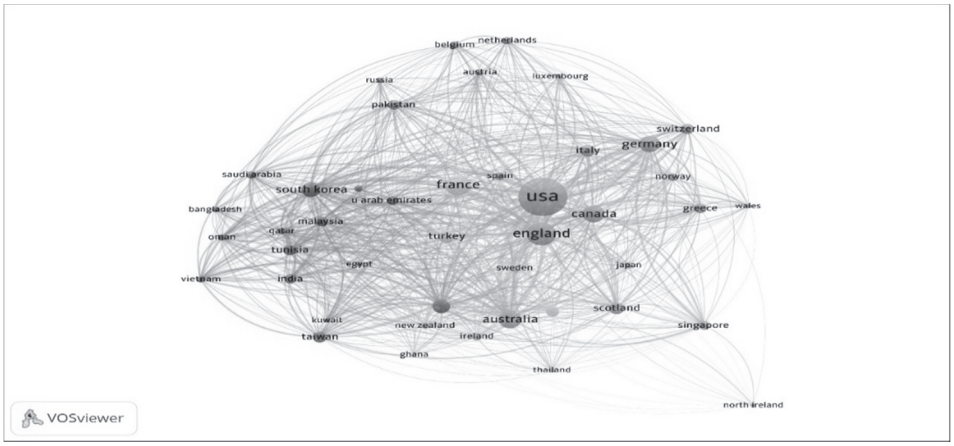
Source: WoS database.

Finally, we analysed the bibliographic coupling of countries, resulting in the identification of six distinct clusters (Figure 11). This analysis reveals how countries are interconnected based on the shared references in their scholarly publications, indicating similarities in research interests and academic focus areas in the field of portfolio diversification with a focus on alternative investments. Cluster one (red), includes South Korea, China, and Tunisia. The bibliographic coupling among these countries suggests that researchers from these nations frequently cite similar literature related to portfolio diversification and alternative investments. While we cannot determine the exact thematic focus without further analysis, the shared references indicate a common interest in specific topics within the field, potentially reflecting collaborative research efforts or parallel academic interests. Cluster two (green), comprising the USA, the UK, Germany,

Canada, and Greece, represents countries with strong research output in finance and economics. This suggests a shared engagement with core theories and methodologies that advance the field, reflecting their contributions to leading global financial research. Cluster three (blue), includes Pakistan, Russia, and the Netherlands. The shared references among these countries point to mutual research interests in portfolio diversification strategies. This suggests that, despite differences in their economic contexts, researchers from these nations engage with similar scholarly works, possibly exploring topics such as risk management, investment in alternative assets, or the dynamics of emerging markets. However, precise themes would require further investigation. Cluster four (yellow), features France, Turkey, and Sweden. While the specific themes cannot be ascertained without deeper analysis, this coupling may reflect shared academic interests or collaborations in certain aspects of alternative investments. Cluster five (purple), encompasses Australia, Singapore, Northern Ireland, and Japan. The shared bibliographic links among these countries suggest a collective engagement with specific topics in portfolio diversification and alternative investments. Researchers may be focusing on areas such as the impact of global trade on investment strategies, the integration of alternative assets into portfolios, or regional financial challenges. Cluster six (turquoise), consists of Ireland, New Zealand, and Thailand. It indicates that researchers cite similar references, pointing to shared interests in innovative portfolio diversification strategies. This may reflect a focus on tailoring investment approaches to their specific market conditions or exploring niche areas within alternative investments.

These clusters underscore the global interconnectedness and collaborative nature of research in portfolio diversification. The bibliographic coupling of countries reveals how scholars across different nations build upon shared foundational literature, leading to collective advancements in understanding and implementing alternative investments within diversified portfolios. While the exact thematic focuses within each cluster require deeper exploration, the coupling highlights significant academic linkages and potential areas for future collaborative research.

Figure 11: Network visualisation map of countries' bibliographic coupling



Source: WoS database.

The co-citation network graphs provide a comprehensive visualisation of the intellectual structure and prominent themes within the same field. Reference co-citation analysis is a bibliometric method that examines how frequently pairs of references are cited together in subsequent publications, thereby revealing the relationships and thematic clusters within a body of literature. This analysis helps identify influential works and emerging trends by highlighting the interconnectedness of scholarly contributions.

In this analysis, the graph (Figure 12) is divided into distinct clusters, each representing a thematic grouping of highly co-cited references. Cluster one (red), centred around Markowitz's seminal 1952 paper in *The Journal of Finance*, highlights foundational works on portfolio theory, as well as the capital asset pricing model and the efficient market hypothesis, including significant contributions by Sharpe (1964) and Fama and French (1993). These works are critical in the development of modern portfolio theory and asset pricing models.

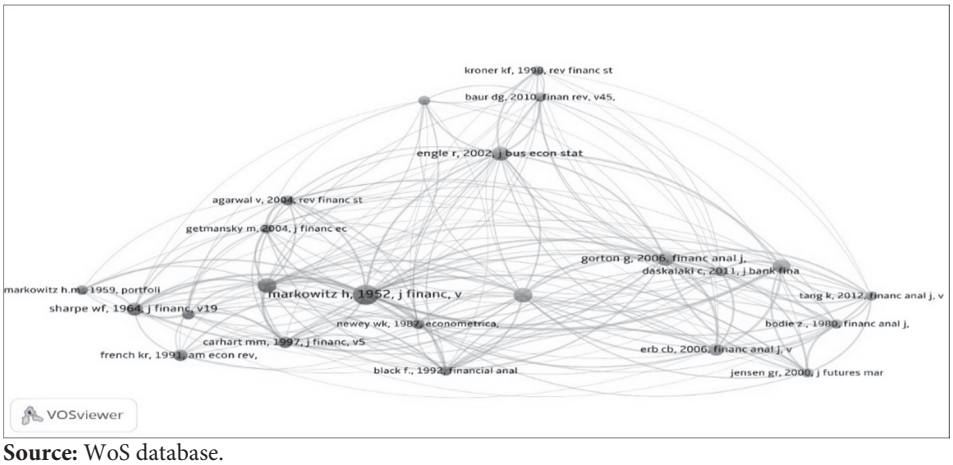
Cluster two (green), prominently featuring the 2009 publication of DeMiguel et al. in *The Review of Financial Studies*, addresses the challenges of estimation errors in portfolio optimisation models, offering insights into the practical limits of theoretical diversification benefits. Additionally, Gorton and Rouwenhorst's 2006 publication contributes significantly to this cluster, highlighting critical analyses of financial instruments and their market behaviours. Additionally, contributions

by Erb and Harvey (2006) and Daskalaki and Skiadopoulos (2011) enrich the cluster's focus on the practical implications and performance of financial instruments, particularly in the context of alternative investments.

Cluster three (blue), with Engle's 2002 work in the *Journal of Business & Economic Statistics*, encapsulates the advancements in econometric models and time-series analysis applied to finance. This cluster features key references, such as Baur and Lucey (2010) and Engle (1982), which have significantly contributed to the understanding of volatility and co-movement in financial markets.

The graph elucidates the interconnectedness of these clusters through co-citation links, demonstrating how foundational theories in finance are built upon and interconnected with empirical research and advanced econometric methods. These works collectively contribute to a nuanced appreciation of the complexities involved in optimising investment portfolios, highlighting both the theoretical advancements and practical challenges inherent in achieving diversification benefits.

Figure 12: Network visualisation map of references co-citation



Source: WoS database.

4. DISCUSSION

The findings from this bibliometric analysis offer a comprehensive overview of the evolving landscape of portfolio diversification, particularly with a focus on

alternative investments. The increasing attention towards alternative assets, as highlighted in this study, underscores the growing importance of these assets in modern investment strategies. The results reveal significant trends, key contributors, and thematic shifts that have shaped the research field over the last five decades.

A primary observation is the significant increase in research activity on alternative investments. This surge reflects broader market movements, where both investors and researchers increasingly recognise alternative assets as effective tools for enhancing portfolio resilience and mitigating risks associated with traditional assets, such as equities and bonds. Due to their distinct characteristics, such as low correlation with conventional assets, alternatives present an attractive option for constructing more resilient portfolios.

Sentiment analysis of abstracts points to a predominantly positive outlook on portfolio diversification involving alternative investments. This favourable tone may reflect the successful outcomes of recent studies, validating the efficacy of innovative strategies with alternative assets. Moreover, keyword co-occurrence and clustering analyses reveal an array of approaches, from portfolio optimisation to the inclusion of cryptocurrencies and digital assets, underscoring the field's dynamic nature. Advanced techniques, including dynamic conditional correlation models, factor-based investing, and other sophisticated optimisation tools, are increasingly employed to enhance portfolio construction. This shift signals an evolution from traditional asset management towards more sophisticated, resilient investment solutions.

For practitioners, the growing emphasis on alternative investments suggests that integrating assets such as cryptocurrencies, commodities, private equity, and digital assets can enhance portfolio diversification. Their unique attributes and low correlations with traditional assets offer potential for reduced overall risk and enhanced returns. Advanced optimisation and risk management tools are essential for creating resilient portfolios. As alternative investments become more integral to diversification strategies, their benefits may be even more pronounced over longer investment horizons. Understanding volatility spillovers can help practitioners craft robust strategies that incorporate alternatives for improved stability, especially during market downturns.

For researchers, these insights open avenues for exploring new dimensions of portfolio diversification, potentially leading to novel theories and models. Educators, too, can leverage these findings to enhance curricula, ensuring students are well-prepared for the evolving financial landscape by exposing them to contemporary topics such as digital assets and advanced risk management.

In conclusion, this bibliometric analysis maps out key research streams, influential contributors, and emerging trends in portfolio diversification with a focus on alternative investments. The study bridges academic insights with actionable strategies, offering value to researchers and practitioners alike. The field is poised to evolve further as financial innovations, methodological advancements, and global dynamics drive research, setting the foundation for more robust and effective diversification strategies in the years to come.

5. DIRECTIONS FOR FUTURE RESEARCH

With the growing complexity and dynamism of financial markets, the role of alternative investments in portfolio diversification has become increasingly significant. This section highlights current trends, challenges, and opportunities for future scientific research in this area. The insights gained from this work will inform the development of more resilient and optimised investment portfolios, particularly as alternative assets continue to evolve in response to market demands. Moreover, we focus on the following aspects and emerging trends expected to shape the landscape of portfolio diversification in the upcoming period:

1. Deeper analysis of understudied keywords: While mainstream keywords such as 'commodities' and 'digital currencies' dominate the literature, future research should focus on less-commonly researched terms such as 'infrastructure investments,' 'blockchain technology,' 'impact investments,' 'intellectual property rights,' and 'sustainable investing.' Analysing the interconnectedness of these keywords and their impact on portfolio performance could provide novel insights into diversification strategies.
2. Expansion of data sources: The majority of studies rely heavily on data from such prominent databases as Web of Science and Scopus. Future research could benefit from incorporating a wider range of databases, including Google Scholar, SSRN, and industry-specific repositories. This broader scope

would not only enhance the analysis but also capture more diverse perspectives and methodologies.

3. Impact of big data and artificial intelligence (AI) on portfolio diversification: The advent of big data and AI presents new opportunities for enhancing portfolio management. Future studies should investigate how these technologies can be integrated with traditional and alternative investments to improve predictive analytics, risk assessment, and decision-making processes. Specifically, exploring the role of machine learning algorithms in optimising diversification strategies could yield significant advancements.
4. Development of hybrid investment models: Combining traditional financial models with alternative investment strategies is a promising area for future research. The development and empirical testing of hybrid models that integrate elements of modern portfolio theory, behavioural finance, and machine learning could lead to more effective and resilient portfolio management frameworks.
5. Longitudinal studies on alternative investments: Conducting longitudinal studies to track the performance and risk characteristics of alternative investments over extended periods can provide a deeper understanding of their long-term benefits and drawbacks. This approach can help identify patterns and trends that are not apparent in short-term analyses.

By addressing these areas, future research can significantly contribute to the evolving landscape of portfolio diversification, offering innovative solutions and practical insights that enhance the effectiveness of investment strategies in a rapidly changing financial environment.

6. CONCLUSION

The objective of this study was to conduct a comprehensive bibliometric analysis of existing research on portfolio diversification, specifically focusing on alternative investments. Utilising data from peer-reviewed articles indexed in the Web of Science database, we provided a detailed citation analysis, identified annual publication trends, highlighted top authors, journals, and countries, and synthesised the findings to pinpoint research hotspots and future trends.

Our analysis reveals a significant rise in scholarly attention towards alternative investments as they relate to portfolio diversification, especially within the last

five years. A peak in publication activity observed in 2019 reflects a heightened recognition of alternative assets – such as cryptocurrencies, commodities, private equity, and digital assets – within both academic and practitioner domains. This shift underscores the expanding role of alternative assets in building diversified, resilient portfolios in a rapidly transforming financial landscape. The unique characteristics of these assets, particularly their low correlation with traditional investments, highlight their potential to mitigate risk and optimise returns, positioning them as essential components in modern investment strategies.

The journals with the most significant impact in this field include the *Journal of Financial Economics*, *The Journal of Finance*, and *The American Economic Review*, reflecting their critical role in disseminating influential research. The United States emerged as the leading country in terms of both the number of publications and citations, followed by the UK and South Korea, highlighting their substantial contributions to the global discourse on portfolio diversification.

Through keyword co-occurrence analysis, our study identifies core thematic areas, such as portfolio optimisation, asset allocation, and the integration of traditional and alternative investments. These themes reflect shifting priorities in the field, underscoring a progressively nuanced understanding of diversification strategies that leverage alternative assets to enhance investment performance. Additionally, bibliographic coupling and co-citation analyses illuminate the intellectual structure and collaborative networks within the research community, revealing distinct clusters focused on various aspects of portfolio diversification. These clusters offer insights into the diverse methodological approaches and theoretical frameworks driving advancements in the field.

Despite the comprehensive nature of our study, it is important to acknowledge its limitations. The dataset was limited to articles indexed in the Web of Science database, which, although extensive, may exclude relevant studies from other databases such as Scopus, Google Scholar, and SSRN. Future research could benefit from incorporating these additional sources to provide a more holistic view of the literature. Furthermore, while VOSviewer provided valuable insights through network visualisations, other bibliometric tools such as Bibliometrix in R, Gephi, and Leximancer offer alternative analytical perspectives that could complement and enhance these insights in subsequent analyses.

In conclusion, this bibliometric study offers a nuanced understanding of portfolio diversification research, with particular attention to the growing role of alternative investments. By mapping influential works, identifying leading contributors, and elucidating thematic trends, the study establishes a foundation for future research aimed at expanding theoretical frameworks and empirical methods. For scholars, the findings emphasise the value of interdisciplinary and collaborative approaches to examining the complex dimensions of diversification. For practitioners, the insights offer actionable guidance on incorporating alternative investments to construct portfolios that are resilient to market volatility and adaptable to an evolving global financial environment. Ultimately, this study bridges academic insights and practical applications, providing a valuable resource for understanding the contributions of alternative investments to robust and diversified investment strategies.

This research is well-positioned to inform and inspire future studies that may explore the nuances of alternative asset classes, refine diversification models, and assess the implications of advanced analytics, such as machine learning in portfolio construction. As the financial landscape continues to evolve, so too will the frameworks and strategies underpinning effective diversification, driven by innovations in both theoretical and practical domains.

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Papers should be prepared as a single file (including text, notes, references, and tables) in MS-Word or .pdf format. Tables and footnotes should be included as they are intended to appear in the final version. Footnotes should be kept to a minimum and numbered as superscripts. Figures should be submitted as separate files in Excel format with the original data included in a separate sheet.

As a rule, submitted articles should not exceed 8,000 words. All pages apart from the first one should be numbered. Subtitles should be concise, clearly marked in bold, and numbered (up to two levels of numbering). No other entries should be bolded. Formulae should be numbered on the right-hand side of the page. In case of long proofs, these should be inserted in a separate Appendix, following the References. Tables and Figures must not use colour, and should be in a format easy to edit, for instance they should take half a page (or a full page) within the indicated margins. They should be clearly labelled at the top, with a legend at the bottom, and should be logically ordered, using Arabic numerals. Sources of the data should be given below tables and figures.

Papers should follow APA style guidelines: https://apastyle.apa.org/style-grammar-guidelines/references/examples#textual-works. Some key points watch out for are as follows. Parenthetic references in the text and in footnotes should be listed by the author surname, with the year of publication in parentheses; in case of more than one author use an ampersand, for instance: (Atkinson, Picketty & Emmanuel, 2011). Narrative citations within the text should use "and" rather than ampersand, for instance: Djankov, Glaeser and La Porta (2003). Use an ampersand in the list of references. When citing works with one or two authors, include the author name(s) in every citation. For works with three or more authors, include the name of only the first author plus "et al." in every citation (even the first citation). Include all author names in the list of references. If the author is unknown, the first few words of the reference should be used; this is usually the title of the source. For example: (*A guide for economy*, 2019). Multiple works by the same author are sorted by date in ascending order; if the works are in the same year they should be ordered alphabetically by title and allocated a letter (a, b, c,…) after the date. Only reference the works that you have cited in your text. Within the text, avoid long strings of citations; cite only those works which are relevant to the text that they inform. Before submitting your paper, check that all references cited in the paper are included in the reference list at the end of the paper, and that all papers included in the reference list have been cited in the text.

References should be left aligned in alphabetical order in the reference list, according to the following formats:

• Article in journals

Author surname(s), initial(s). (Year). Article title. Journal, Volume number (issue or part number, optional), page numbers. DOI.

Rodrik, R., Subramanian, D., & Trebbi, F. (2004). Institutions rule: the primacy of institutions over geography and integration in economic development. *Journal of Economic Growth*, 9(2), 131-165.

https://DOI: 10.1023/B:JOEG.0000031425.72248.85.

• Books

Author surname, initial(s). (Year). *Title*. Publisher location: Publisher

De Grauwe, P. (2020) *Economics of Monetary Union* (13th ed.). Oxford: Oxford University Press.

• Edited Book

Author surname, initial(s). (Ed(s).). (Year). *Title*. Publisher location: Publisher

Baltagi, B.H. (Ed.). (2003). *A Companion to Theoretical Econometrics*. Oxford: Blackwell

• Book with several authors

When there are multiple authors, list them all, with the addition of ampersand (&) before the last surname. If there are more than seven authors, list the first six, then write three full stops (…), and at the end write the last author.

Acemoglu, D., & Robinson, J.A. (2006). *Economic Origins of Dictatorship and Democracy*. Cambridge: Cambridge University Press.

Baumol, W. J., Panzar, J. C., & Willig, R.W. (1982). *Contestable Markets and the Theory of Industry Structure*. New York: Harcourt, Brace, Jovanovich, Inc.

• Chapter in Book

Last name of the chapter author, initial(s). (Year). Chapter title. In editor initial(s), surname (Ed.). *Title* (ed., pp.). Publisher location: Publisher

McMillan J., & Woodruff C. (2003) The central role of entrepreneurs in transition economies. In G. S. Fields, & G. Pfefferman (Eds.). *Pathways Out of Poverty* (pp. 105-121). Dordrecht: Springer. https://doi.org/10.1007/978-94-010-0009-3_6.

• E-Book

Author surname, initial(s). (Year). *Title*. URL

Perry, R.B. (1909). *The Moral Economy*.

https://manybooks.net/book/137844/read#epubcfi(/6/2[id00000]!/4/2[id00000]/1:0)

• Technical Reports or Working Papers

Individual authors

Author surname, initial(s) or corporate name. (Year). *Title*. (Report or Working Paper No.). URL.

Cătuți, M., Kustova, I. and Egenhofer, C. (2020) *Delivering the European Green Deal for Southeast Europe: Do we need a regional approach?* (CEPS Research Report No.2020/1). https://www.ceps.eu/wp-content/uploads/2020/06/RR_2020-01_European-Green-Deal-for-South-Eastern-Europe.pdf.

Corporate authors

American Psychological Association, Task Force on the Interface Between Psychology and Global Climate Change. (2009). *Report of the APA Task Force on the Interface Between Psychology and Global Climate Change*.

http://www.apa.org/science/about/publications/climate-change.aspx

• Newspaper Articles

Author surname, initial(s). (Year, Month Day). Title. *Title of Newspaper*, p. or pp. URL*

*only include if the article is online.

Note: the date includes the year, month and date.

Smialek, J. (2020, May 2). Hotel Group Will Return Tens of Millions in Small Business Loans. *The New York Times*, pp. 10.

https://www.nytimes.com/2020/05/02/business/economy/ashford-hotels-virus-monty-bennett.html

• Website

Author surname, initial(s). (Year, month day). *Title*. URL

Mitchell, J.A. (2017, May 21). *How and when to reference*.

https://www.howandwhentoreference.com