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Social Protection Benefits Compatibility and Evaluation Criteria: the Case of Lithuania

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Abstract. In general, the social protection (SP) system consists of two main blocks: social insurance (SI) and social assistance (SA). The main idea of SP is to leave no one behind, support in times of social risks. However, SI and SA systems are usually developed and improved separately. Organization for Economic Cooperation and Development (OECD) and European Commission (EC) often emphasise that expenditure on the SP system in Lithuania is scarce, income poverty and inequality are critical, not improving. This raises the question of whether both elements of SP in Lithuania are based on the same criteria to achieve consolidated SP and avoid its gaps. This paper aims to identify evaluation criteria, look at the Lithuanian SP system through its main benefits, and identify whether people are protected. The analysis consists of a literature review, which helps identify evaluation criteria for the SP system, and Lithuanian analysis based on evaluation criteria for 2018–2022 policy years. Three main criteria for SP benefits evaluation are identified: coverage, adequacy, and incentives to work. To make an in-depth analysis of the SP system in Lithuania, the tax-benefit microsimulation model EUROMOD is used to analyse different households' poverty and unemployment traps and test whether the current SP system contributes to them. It was expected that this research would help to shed a light on how well Lithuanian SI and SA function simultaneously. Results show that SP system compatibility in Lithuania is above average, the weakest part is coverage.
Keywords: social protection system consolidation, evaluation, coverage, adequacy, incentives to work

1. Introduction

While countries' economies are growing, their populations' quality of life is also improving. However, poverty and income protection are still an issue in modern society. Rawl's (1999) Theory of Justice states that despite a person's primary goods, equality and justice should be ensured for all, with no one left behind. One way to solve those problems would be state intervention in redistributing income through the social protection (SP) system.

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State intervention through SP helps to ensure that individuals are secured from potential risks and supported when loss of job, sickness, childcare, etc. do occur. The concept of SP varies widely between different researchers and organisations (Devereux, 2021a; Hanna and Karlan, 2017; Johnson and Muthoora, 2021; Gataūlinas and Zabarauskaitė, 2014; Robalino et al., 2012; World Bank, 2022), but it can be seen as a general concept: SP refers to the intervention of the state through various institutions and programs with the common goal of safeguarding the income of the population when faced with particular risks (e.g., unemployment) and when already in poverty.

The EC (2019) and OECD (2022) have noticed that Lithuania has recently extended SP system. Despite efforts to address income inequality and poverty, they are not decreasing, and there is a lack of funds allocated towards improving the system. The latest official statistics show that the at-risk-of-poverty rate in Lithuania in 2022 was 20.9%, income inequality (S80/S20) was 6.4, while the European Union (EU) average for poverty was 16.5%, and the S80/S20 was 4.7 (Eurostat, 2023a; Eurostat, 2023b). In the aftermath of a pandemic and in times of inflation, the SP system sustainability and compatibility question takes on even greater significance. It is worth studying the ways to improve the Lithuanian SP system and identify why the anticipated outcomes have not been achieved despite system expansion.

Two main SP components are crucial to mitigate poverty and inequality: social insurance (SI) system and social assistance (SA) one. These two systems should be analysed based on the same criteria. Coordination between SI and SA systems can help to create adequate support and income protection for individuals participating (or previously participating) in the labour market through SI and the rest through the SA system. Various authors analyse SI and SA systems (Aaron, 2011; Addati, 2015; Navicke, 2015; Marx et al., 2016; Vliet & Wang, 2019) and their redistributive effect on population income, but no consolidated evaluation criteria for these programs have been suggested.

This paper aims to identify evaluation criteria for the SP system (SI and SA), look at the Lithuanian SP system through its main benefits, and identify to what extent people are protected.

The object of this study is SP system benefits. In this paper, literature review helps to identify main components for evaluating SP system benefits. It shows that three main elements should be kept together when analysing the social protection system: coverage, adequacy, and incentives to work. To evaluate the Lithuanian SP system, SP compatibility (SPC) evaluation index is constructed based on the literature review and partly on the Human Development Index methodology. For SPC Index results, legislative information, statistical information is used from 2018 to 2022. The SPC index is applied to SI and SA systems and for consolidated SP system. The SPC Index helps to identify which elements in the index are stronger/weaker. The poverty and unemployment trap methodology is presented to make a deeper analysis of SP benefit compatibility. Poverty and unemployment traps are calculated using the tax-benefit microsimulation model EUROMOD and additional components for Lithuania developed by the Ministry of Social Security and Labour of the Republic of Lithuania and the Hypothetical Household Tool (HHT). The use

of microsimulation helps to include the most recent changes in fiscal policy in the analysis and to see how or if the SP system protects families from poverty and unemployment traps.

The paper is developed as follows: literature review is provided in section 2, section 3 presents methodology for evaluating SP benefits compatibility, section 4 analyses results from SPC index and poverty and unemployment traps and the last section provides conclusions, recommendations, and further improvements.

2. Literature review

The SP system consists of formal public programs: SI, SA programs, and passive and active labour market policy (ALMP) programs (Hanna and Karlan, 2017; Dutzler et al., 2021). Each of it has different aim: SI programs are fundamentally linked to protecting income and consumption in case of specific shocks such as illness, unemployment, disability, and old age, e.g., income support and income redistribution in the event of risks; SA programs protect against poverty by providing benefits to people experiencing this risk or helps to reduce additional cost for specific needs; passive and ALMP measures focus on the aim to improve income opportunities and help individuals function effectively in the labour market (Robalino et al., 2012; Nguyen et al., 2023). Usually, the latter measures are included in SA system as a condition for receiving benefit.

Income protection, poverty and additional costs reduction can be ensured through social benefits. There are three benefit schemes in SP system: SI benefits, categorical (universal) benefits, and means-tested benefits (Nelson, 2007; Lazutka et al., 2013). Social benefits can either be universal or targeted, or the balance between the two (Cremer and Pastieau, 2003). To better understand SP system, SI and SA systems benefits are presented further. Passive and ALMP systems are not discussed here as a separate part since they are included in previous systems to ensure participation in the labour market. SI and SA systems analysis can help to identify main evaluation criteria for both systems that later could be applied to overall SP system.

SI benefits include SI benefit schemes. SI benefits can be evaluated according to their characteristics and principles. According to Aaron (2011), SI benefits must have the following characteristics: benefits are combined with other existing benefits (e.g., old-age and disability pensions, widow's pensions, can be paid simultaneously); redistributive benefit formula; indexation for inflation. Therefore, SI benefits must ensure income replacement in the event of a specific risk. The relationship between the replacement rate of the benefit and former income, protection against poverty must be assessed. At the same time, it must ensure that the benefits provided are progressive, linked to past income (benefits are higher for those who received higher working income) and benefits should not be determined by age. If the conditions for receiving the benefit are met (e.g., required insurance period), regardless of age, the person is entitled to receive the full benefit or pension. These benefits must not depreciate over time and their purchasing power must be maintained, but also it should ensure that work incentives are kept (Aaron, 2011; O'Donoghue, 2011). Benefit amount should be adequate to protect against poverty, but its amount should not be higher

than work income. SI benefits are generally evaluated based on their coverage, adequacy (income replacement rate in relation to protect against poverty) and incentives to work.

SA benefits include both universal (categorical) and means-tested schemes. SA is provided regardless of whether the person participated in the labour market. It is used as a last-resort source of income for those who are not entitled to unemployment protection (SI benefit) or who need additional state support (Garland, 2014; Lorentzen et al., 2014; Goedemé and Marchal, 2016). SA programs can be called the guaranteed minimum income (Bergmark and Stranz, 2023). SA usually consists of basic cash benefits for daily living expenses and housing costs (means-tested benefits). It also includes additional support to cover the household's special needs (categorical benefits) (Lorentzen et al., 2014). SA benefits are generally smaller than SI (Addati, 2015). This aims to maintain the distinction between SI and SA systems and encourage people, receiving SA benefits, to join the labour market eventually.

Although means-tested benefits are considered an adequate measure of helping the poorest, it has drawbacks. Means-tested benefits can create a stigma for recipients and lead to a low level of benefit take-up (Garland, 2014; Marx et al., 2016; Gabnytė et al., 2020; Roelen, 2020). Any system that attempts to detect those individuals who unlawfully receive benefit, might make errors, and unintentionally neglect those who genuinely require the assistance (Sen, 1992). To avoid Type II error (including noneligible with eligible), excluding those who need the most help, can lead to Type I errors. This creates an even greater stigma, as those entitled to benefits are more closely monitored. The stigma associated with receiving benefits, coupled with the intrusive monitoring of individuals and their households to determine eligibility, can discourage people from seeking assistance, even if they require it. Also, means-tested benefits are expensive regarding their administration since a monitoring mechanism must constantly operate. Means-tested benefits can create unemployment and poverty traps; it must be assessed whether the amount of the benefit provided is adequate to ensure the satisfaction of living needs and, at the same time, whether it is sufficiently motivating to leave the SA system. Means-tested benefits should be evaluated through coverage, adequacy, and through incentives to work (exit SA system and participate in the labour market).

Another part of SA benefits is categorical benefits. These benefits are programs where eligibility is based on universal criteria such as citizenship, age. Categorical targeting in SA means that it reaches groups most in need of income protection and support, they are not means-tested (Devereux, 2021b). These types of benefits take a large part of the share of total social costs, i.e., due to their universality, they are expensive, and the payment amounts are standardized and flat (Lazutka et al., 2013; Schüring, 2021), but they are simpler to administer and avoid Type I and II errors since the target group is easy to identify. This benefit can be and is combined with other benefits. For example, if means-tested benefits are provided, universal benefits are generally not included in the income-test list. The purpose of universal benefit is to contribute to mitigating additional costs incurred by the target group. The adequacy and coverage of the benefit remains essential. Adequacy here means that the payment contributes at least partially to mitigat-

ing the additional costs incurred; it is not directed to reduce poverty. The assessment of coverage is based on whether all eligible individuals are receiving the benefit. Also, there is no goal to increase incentives to work through these benefits, since they are paid to the most vulnerable groups to relief part of the additional expenses due to their situation. The criteria for categorical SA benefits evaluation are coverage and adequacy.

Both SI and SA programs aim to protect household income from income loss shocks and poverty (Vliet and Wang, 2019; Spies-Butcher et al., 2020). However, SI covers only those who have accumulated sufficient working experience, i.e., only those who participated in the labour market for a certain period. Those who cannot apply for SI benefits, can rely on the SA system. Coordination of SI and SA benefits is important to ensure that the entire population is protected (Bierbaum and Wodsak, 2021). This means that those, who can participate in the SI system, participate in it, whether by entering the labour market, receiving benefits, or by participating in employment programs. The SA system ensures basic income protection for all residents, regardless of whether a person participates in the labour market or not. These programs are universal (e.g., health care), categorical (e.g., child benefits) or means-tested (e.g., the cash SA benefit). The balance of the two systems' benefits and their amounts is essential: if SI programs offer benefits that are marginally higher than SA programs, this creates low incentives to work, or may even lead individuals to work in the informal economy. The amounts of SI benefits must be higher than SA benefits. Such a distinction from SA payments would encourage individuals to participate in the labour market transparently while ensuring they meet their basic needs (Bierbaum and Wodsak, 2021).

To ensure adequate minimum income in the European Union, European Commission released Council Recommendation 2023/C 41/01 of 30 January 2023 on the adequate minimum income ensuring active inclusion (Council Recommendation, 2023). This recommendation states that minimum income should be adequate, the eligibility requirements should be simplified to reach all target groups and benefits should be encouraging enough to participate in the labour market. Even though these criteria are proposed for the minimum income protection, these criteria are relevant for the overall SP system. Adequacy, coverage, and incentives to work are interconnected and should be analysed together. Coverage and adequacy are essential to the SI and SA systems. At the same time, incentives to work are significant to the SI system and a part of the SA system (means-tested benefits).

3. Methodology for evaluating SP benefits compatibility

SP system compatibility index (SPC Index). From the literature analysis, three main evaluation criteria can be distinguished: coverage, adequacy, and incentives to work. We evaluate SI, SA and coordination between these systems (SP overall). The SA system is analysed by considering both means-tested and categorical benefits. SI system evaluation is presented for the minimum benefit amounts to make it comparable with SA system and to see if there is a difference between minimum SI benefits and SA benefits. An explanation of each criteria in the Index is presented below.

Coverage is the proportion of the population entitled to the benefit to all individuals receiving the benefit. For example, in the case of SI unemployment benefits, the actual coverage is how many unemployed receive unemployment SI benefit. The coverage of means-tested benefits can be measured by the proportion of individuals who receive benefit to all persons below the poverty line (or other established national thresholds (NT)). Categorical SA benefits are assessed through the reach of the target group. For example, in the case of child benefit – all children should receive it.

Adequacy refers to the benefit amount that ensures protection against poverty or meets the minimum needs determined by the country's NT. For this case, we are using the same NT for both systems – minimum consumption needs basket (MCNB). SI benefits are evaluated using their minimum amounts in relation to MCNB.

In general, both the SI and the SA (means-tested) systems must ensure a horizontal principle – incentives to work. The benefits provided cannot exceed the potential working income. To make comparisons between SI, SA and SP more consistent, we are using the same threshold – net minimum monthly salary (MMS): benefits are compared in relation to net MMS. SI benefits are evaluated using their minimum amounts in relation to MMS. For the incentives to work, old-age pensions and categorical benefits are excluded from the analysis, since their goal is not to incentivize to return to labour market.

Table 1 summarises MCNB and net MMS amounts during 2018–2022 and Table 2 summarises which questions are answered by SI and SA systems and overall SP coordination.

Table 1. Minimum consumption needs basket and net minimum monthly salary in Lithuania in 2018–2022, EUR.

	2018	**2019**	**2020**	**2021**	**2022**
MCNB	245	251	257	260	267
Net MMS	361	395.8	447.2	468.4	549.7

Table 2. Questions of social insurance and social assistance systems and their coordination by evaluation criteria.

Criteria	**Social insurance**	**Means-tested social assistance**	**Categorical social assistance**	**Coordination of systems**
Coverage	What proportion of individuals are receiving benefit in relation to target group?			Are all residents protected through SI and SA systems?
Adequacy	Does benefits ensure minimum consumption needs?		Is the benefit sufficient to cover the additional costs incurred by the target group?	Do benefits ensure minimum consumption needs? Are SI benefits greater than SA?
Incentives to work	Are minimum benefits lower than net minimum monthly salary?			Are minimum benefits lower than net minimum monthly salary?

We evaluate each system separately and together based on these criteria to identify which components need improvement for a more coordinated and compatible SP system. The Lithuanian SP system has been evaluated for the 2018–2022 period. A meta-document analysis of the laws governing the SP system has been conducted to identify the rules governing the main benefits. Next, we use administrative data and official statistics to evaluate those benefits' coverage, adequacy, and incentives to work. The results of meta-document analysis and administrative data are presented in Annex 1. Table 3 shows the benefits that are included in the analysis.

Table 3. Social insurance and social assistance benefits in SPC Index.

System	Benefits
Social insurance	Old-age contributory pension, sickness benefit, maternity benefit, paternity benefit, childcare benefit, unemployment benefit.
Means-tested and categorical social assistance	Cash social assistance, additional child benefit, child benefit, pregnancy grant, student's childcare benefit, old-age assistance pension.

Later, SP system compatibility is evaluated on the constructed index (SPC Index) based partly on the Human Development index methodology (Sen and Anand, 1994). All initial values are expressed as percentages (see Annex 1 Tables 2–4). These values are normalised using categorical scales (OECD/European Union/EC-JRC, 2008), which gives a maximum value of 10 and a minimum value of 0. For the coverage and adequacy criteria – the higher the value, the higher the category – while in the incentives to work criteria, value categories are in reverse order (i.e., the higher the value, the lower category). Table 4 shows categories for SPC Index criteria.

Table 4. SPC Index criteria values and categories.

Categories	Coverage/adequacy	Incentives to work
0	(-∞;10%)	[100%; +∞)
1	[10%; 20%)	[90%; 100%)
2	[20%; 30%)	[80%; 90%)
3	[30%; 40%)	[70%; 80%)
4	[40%; 50%)	[60%; 70%)
5	[50%; 60%)	[50%; 60%)
6	[60%; 70%)	[40%; 50%)
7	[70%; 80%)	[30%; 40%)
8	[80%; 90%)	[20%; 30%)
9	[90%; 100%)	[10%; 20%)
10	[100%; +∞)	(-∞; 10%)

Next, for each criteria (coverage, adequacy, incentives to work) in the index, the arithmetic mean (AM) is calculated:

$$\overline{X_c} = \frac{\sum_{i=1}^{n} X_i}{N},$$

where $\bar{X}_c$ is the AM of each criteria, X_i is the sum of observations values (benefit values), N is the total number of observations in particular criteria. Detailed description of benefits used in each criteria are presented in Annex 1 Table 1.

SPC Index is calculated as a geometric mean of coverage, adequacy, and incentives to work since the criteria weight in the SPC Index is equal. Indicator weights within each criteria are also distributed equally, but weight for each indicators depends on the number of indicators within each criteria. Detailed weight distribution is presented in Annex 1 Table 1. The SPC Index is calculated for SI, SA, and consolidated SP systems:

$$SPC\ Index = \sqrt[3]{\bar{X}_{coverage} * \bar{X}_{adequacy} * \bar{X}_{incentives\ to\ work}}$$

where $\bar{X}_{coverage}$ is AM of benefits in coverage criteria, $\bar{X}_{adequacy}$ is AM of benefits in adequacy criteria and $\bar{X}_{incentives\ to\ work}$ is AM of benefits in incentives to work criteria.

The SPC Index is calculated for aggregated benefit groups for the consolidated SP system: old-age, childcare/sickness, and poverty/unemployment. These groups are aggregated from SI and SA systems evaluations.

Since SPC Index calculations are based on the minimum SI benefits amounts (to make it more consistent with the SA benefits), to better show incentives to work, poverty and unemployment traps are calculated if one person of the household starts working for MMS and average monthly salary (AMS).

Poverty and unemployment traps calculation. Poverty and unemployment traps are calculated using the tax-benefit microsimulation model EUROMOD and its additional component of the Hypothetical Household Tool (HHT) for 2018–2022. The application of microsimulations is a useful analytical tool to analyse tax-benefit policy reforms in light of societal socioeconomic changes and how these affect income distribution and redistribution (Herault and Azpitarte, 2016). EUROMOD is a static microsimulation model of the EU. This model links statutory tax and social benefit rules with representative survey micro-level data on households and their income structure (Sutherland and Figari, 2013). The static nature of the model means that the first-order effect is analysed, i.e. what would be the effect of a specific policy before people's behaviour changes. EUROMOD analyses taxes, SI contributions, and cash payments and how all these components affect each other. HHT allows generating hypothetical households based on various conditions: household members, age, educational attainment, employment situation, and employment income. HHT generates data (input data) for simulations based on the household type, which is later used with the basic EUROMOD model. This allows to analyse how countries' tax-benefit policies affect hypothetical households: for what benefits they are entitled to or not.

The poverty trap shows whether it is worthwhile for nonworking recipients of cash SA in households of different compositions to start working and at what wage. Poverty trap calculations were performed for seven hypothetical household types: single person, two adults without children, a lone parent with 1 child, a lone parent with 2 children, 2 adults with 1 child, 2 adults with 2 children, 2 adults with 3 children. The poverty trap reflects the percentage of household income received from the cash SA system compared to income when one person from the household is employed for MMS and AMS. The higher this ratio, the greater the poverty trap and the lower the incentives to work. Adults are not eligible for unemployment SI benefit in the unemployment situation. Indicators of poverty trap are calculated after evaluating the procedure for providing cash SA and the additional support provided after employment.

The unemployment trap shows whether unemployed people entitled to unemployment benefits who live in households of different composition pay to start working and at what wages. For unemployment trap, calculations were made for average unemployment traps, i.e., the situation of the unemployed person's family without working for 9 months is compared with the situation if he/she worked during that period (9 months are chosen because in Lithuania, if a person is eligible for unemployment SI benefit, total duration of benefit payment is 9 months). Calculations and comparisons are made if a person is employed for MMS and AMS to a situation if he/she receives the benefit. The same seven households as in the calculation of poverty traps were used. When calculating unemployment trap, there is an assumption that only one adult in the household starts working, and the other one is unemployed and not eligible for the unemployment SI benefit.

4. Analysis and results

Table 5 shows the results of the SPC Index and its components in SI, SA systems, and system coordination for 2018–2022. SPC index components are values in coverage, adequacy, and incentives to work areas. The higher the value of each component, the better its situation.

Table 5. Evaluation criteria values and SPC Index value for social insurance, social assistance, and system coordination in Lithuania in 2018–2022.

	Social insurance system					Social assistance system					System coordination				
	2018	**2019**	**2020**	**2021**	**2022**	**2018**	**2019**	**2020**	**2021**	**2022**	**2018**	**2019**	**2020**	**2021**	**2022**
Coverage	6.0	5.8	6.0	6.5	6.7	4.5	4.0	5.0	5.5	5.8	4.3	4.3	4.7	5.0	5.3
Adequacy	6.0	6.5	6.8	7.0	7.7	3.8	3.8	5.3	5.3	6.2	4.7	5.7	6.3	6.3	7.3
Incentives to work	6.4	6.6	6.6	6.4	7.2	8.5	8.5	8.5	8.5	8.5	7.0	7.0	7.0	7.0	7.0
SPC Index	6.1	6.3	6.5	6.6	7.2	5.3	5.1	6.1	6.3	6.7	5.2	5.6	5.9	6.1	6.5

Source: own calculations

The SPC Index in system coordination has improved during 2018 to 2022: SPC Index value increased by 1.3 points and reached 6.5. Since the maximum value of the Index is 10, we can see that Lithuanian SP system coordination performs better than average. Based on the values of each criteria, the weakest part in the overall system is coverage, followed by incentives to work. Even though the incentives to work are above average and reaches 7 points, there is no improvement during the period.

Monitoring SI and SA systems separately, it is observed that SI system performs better: highest difference is seen in adequacy and incentives to work criteria. Even though results show that SI system better performs in adequacy, some SA benefits are higher: since 2019 contributory minimum maternity, paternity and childcare benefits are lower than SA pregnancy grant or students' childcare benefit, because personal income tax is applied to SI benefits (see Annex 1 Tables 2–3). Incentives to work in SA system performs relatively better. This can be related to very low SA benefits amounts in relation to net MMS. Since SA benefits are very low, incentives to work persist. Coverage is the weakest part in SA system and reaches 5.8 in 2022.

There is an increase in SI, SA systems and system coordination in adequacy criteria between 2021 and 2022: it can be explained by the fact that due to highly rising prices in Lithuania in 2022, there was a government decision to additionally increase social benefit amounts and additionally indexed old-age pensions in the middle of the year. These changes positively impacted on the SA system benefit growth and increased the lowest SI benefits (if floors are applicable). However, most of the minimum benefits in both systems remain relatively low compared to Lithuania's MCNB. Despite the changes in 2022, coverage and adequacy criteria in SA system performs worse than in SI system.

To conclude, SPC Index in Lithuania improved in all criteria during 2018-2022, although overall system SPC Index value remains below 7 points (of maximum 10). We can see that incentives to work criteria could be improved in the SI system, which could allow better SPC Index performance. Although, it should be kept in mind that these changes should not be made at the cost of benefit adequacy. Also, SPC Index evaluates separate benefits, while household (or single person) might receive more than one benefit at a time, depending on household structure and work income.

SPC Index results showed that coverage is the weakest part in the Index, also incentives to work remain the same during the year if we are comparing minimum SI benefits and SA benefits amounts to net MMS. To analyse work incentives further and investigate how different benefits create incentives to work for different households, poverty and unemployment traps are presented below. Table 6 presents poverty trap and Table 7 unemployment trap in Lithuania during 2018 to 2022. Poverty trap help to explore the SA system and whether it encourage people to participate in the labour market. The analysis of unemployment trap shows if SI (and SA, if person/household is eligible) system encourages return to labour market.

Table 6. Poverty trap in Lithuania if employment income would be MMS, AMS in 2018–2022.

	MMS					AMS				
	2018 (400 EUR)	2019 (555 EUR)	2020 (607 EUR)	2021 (642 EUR)	2022 (730 EUR)	2018 (808.7 EUR)	2019 (1136.4 EUR)	2020 (1241.4 EUR)	2021 (1352.7 EUR)	2022 (1504.1 EUR)
Single person	31%	27%	26%	28%	27%	19%	17%	16%	19%	19%
2 adults without children	52%	43%	42%	41%	38%	34%	30%	29%	31%	30%
Lone parent with 1 child	57%	52%	51%	49%	47%	39%	37%	39%	40%	40%
Lone parent with 2 children	63%	58%	61%	56%	55%	56%	54%	58%	58%	58%
2 adults with 1 child	64%	57%	58%	53%	52%	52%	48%	49%	51%	50%
2 adults with 2 children	68%	61%	63%	58%	57%	66%	61%	62%	63%	62%
2 adults with 3 children	69%	63%	65%	60%	59%	70%	69%	71%	70%	70%

Note: MMS and AMS are presented as gross income. Calculations are made in comparison to net income. In the case of single person, it is assumed that the person is a short-term recipient of cash SA (up to 12 months).
Source: own calculations

Results for single person household shows, that during 2018–2022 poverty traps are very low if a person starts working for the MMS and these traps are further decreasing and reaching 27% in 2022. If a single person starts working for AMS, poverty trap decreases further, not reaching 20%. Poverty trap also decreases for 2 adults without children, if one of the adults starts working for MMS or AMS. These households remain low in poverty trap because they are only eligible for cash SA and the benefit amount decreases as employment income increases. Further results show that higher poverty traps are among households with children because these households are eligible for categorical child benefit and means-tested cash SA and additional child benefit. Poverty trap for these households decline further as employment income rises. When one adult in the household starts working for MMS, the highest poverty trap is among the 2 adults with 3 children. It reaches 59% in 2022, which means that if families rely only on the SA system, they receive 59% of net MMS, it increases up to 70% if one adult gets net AMS.

Poverty trap and SPC Index results show that the adequacy of SA benefits should be improved, but incentives to work should also remain. Although, incentives to work should not be increased on account of benefit size.

Table 7. Unemployment trap in Lithuania if employment income would be MMS, AMS in 2018–2022.

	2018 (400 EUR)	2019 (555 EUR)	2020 (607 EUR)	2021 (642 EUR)	2022 (730 EUR)	2018 (808.7 EUR)	2019 (1136.4 EUR)	2020 (1241.4 EUR)	2021 (1352.7 EUR)	2022 (1504.1 EUR)
Single person	60%	76%	92%	74%	72%	55%	66%	83%	65%	66%
2 adults without children	66%	76%	92%	74%	72%	55%	66%	82%	65%	66%
Lone parent with 1 child	70%	83%	93%	79%	77%	59%	68%	84%	68%	68%
Lone parent with 2 children	79%	81%	85%	80%	79%	65%	75%	95%	78%	79%
2 adults with 1 child	82%	84%	88%	81%	80%	61%	70%	88%	72%	73%
2 adults with 2 children	86%	88%	90%	86%	85%	75%	72%	87%	72%	73%
2 adults with 3 children	87%	88%	91%	87%	87%	79%	80%	84%	79%	79%

Note: MMS and AMS are presented as gross income. Calculations are made in comparison to net income. Average of 9 months (while the person is eligible for unemployment benefit). If there is more than 1 adult in the household, it is stated that only one is eligible for unemployment benefit while another adult is not and stays unemployed. Source: own calculations

Unemployment trap is very high (reaches up to 87%) for all households with children if one adult previously worked for MMS and could get a similar job in 2022 in Lithuania. Unemployment trap reaches 72% for households without children if one person is employed for MMS. Even though salary increases, unemployment trap remains high for all households and varies from 66% to 87% if one adult receives from MMS to AMS. The dynamics of unemployment trap during 2018–2022 for some households increased.

High rate of unemployment trap is determined by the size of the unemployment benefit and other social benefits (means-tested) received in addition to unemployment benefit. The unemployment benefit design is made of 2 parts: the basic benefit part, which is a flat rate and the variable part, which depends on previous employment income, but with a cap of 58.18% of AMS. It is worth noting that unemployment benefit is limited to 9 months, and it decreases every 3 months, which leads to work incentives rising as the period of benefit payment ends.

5. Conclusions, recommendations, and further improvements

This paper analysed SP benefits compatibility and evaluation criteria in Lithuania for 2018–2022. The paper unites literature analysis on SP system evaluation and its main components. It contributes to the attempt to use the same evaluation criteria for SI, SA systems and the comprehensive assessment of SP compatibility through coverage, adequacy, and incentives to work.

Literature analysis showed that coverage, adequacy and incentives to work are the main elements to evaluate if a benefit is sufficient and if the overall SP system is compatible. A compatible SP system should ensure that if a person needs support, they should get it through SI or SA systems, e.g., all people from the targeted group should receive support. Compatible SP system benefits should be adequate, but there should be a difference between SI and SA benefits. Adequacy should ensure that benefits are sufficient to replace income due to social risks or are sufficient to maintain basic needs. Incentives to work criteria show that people in need should get adequate support, but at the same time, incentives to stay on or return to labour market should be kept.

The analysis of Lithuanian SP system compatibility showed that there is still a room for improvement: the adequacy of SI should be improved as some of the minimum benefits are lower than SA. Adequacy of SA benefits are also scarce since benefits amounts are lower than the MCNB. When improving benefit adequacy, work incentives should be kept in mind. Further, as calculations based on the EUROMOD model and HHT showed, poverty and unemployment traps are high in Lithuania during 2018–2022 for households with children if one adult in the household starts working for the MMS even though incentives to work should not be increased in the cost of benefit adequacy, which in Lithuania is relatively low.

SPC Index in SI and SA systems shows that SI system performs relatively better in Lithuania; however, SPC Index values are still low (coverage and adequacy criteria performs worse than in SI system). The weakest part of the Index is coverage reaching 5.3 points (while it reaches 6.7 in SI and 5.8 in SA). Incentives to work are improving in SI system during 2018–2022, but in SA and system coordination situation stagnates at 7 points out of 10. SPC Index for system coordination receives 6.5 points out of 10. Index can be improved by further analysis of benefit non-take-up in SI and especially in SA systems. This can be done by reviewing why targeted groups are not fully reached. Incentives to work should be revised, setting the goals up to what amount benefits could be adequate, but still encouraging to work.

Further improvements should be made when analysing SP system compatibility by incorporating additional benefit types, evaluating more criteria, adjusting the weighting of evaluation criteria within the methodology. Moreover, to expand the scope of the analysis and improve its accuracy, cross-country analysis would help identify where the Lithuanian SP system stands compared to other countries.

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Annex 1.

Table 1. SPC Index weight distribution.

Indicators		Indicator weight	Overall criteria weight
Social insurance			
Coverage in:	Old-age contributory pension	0.555	3.33
	Sickness benefit	0.555	
	Maternity benefit	0.555	
	Paternity benefit	0.555	
	Childcare benefit	0.555	
	Unemployment benefit	0.555	
Adequacy in:	Old-age contributory pension	0.555	3.33
	Sickness benefit	0.555	
	Maternity benefit	0.555	
	Paternity benefit	0.555	
	Childcare benefit	0.555	
	Unemployment benefit	0.555	
Incentives to work in:	Sickness benefit	0.666	3.33
	Maternity benefit	0.666	
	Paternity benefit	0.666	
	Childcare benefit	0.666	
	Unemployment benefit	0.666	
Social assistance			
Coverage in:	Cash social assistance	0.555	3.33
	Additional child benefit	0.555	
	Child benefit	0.555	
	Pregnancy grant	0.555	
	Student's childcare benefit	0.555	
	Old-age assistance pension	0.555	
Adequacy in:	Cash social assistance	0.555	3.33
	Additional child benefit	0.555	
	Child benefit	0.555	
	Pregnancy grant	0.555	
	Student's childcare benefit	0.555	
	Old-age assistance pension	0.555	
Incentives to work in:	Cash social assistance	1.665	3.33
	Additional child benefit	1.665	

Indicators		Indicator weight	Overall criteria weight
System coordination			
Coverage in:	Old-age (Old-age contributory pension, Old-age assistance pension)	1.11	3.33
	Childcare/ sickness (Sickness benefit, Maternity benefit, Paternity benefit, Childcare benefit, Additional child benefit, Child benefit, Pregnancy grant, Student's childcare benefit)	1.11	
	Unemployment/ poverty (Unemployment benefit, Cash social assistance)	1.11	
Adequacy in:	Old-age	1.11	3.33
	Childcare/ sickness	1.11	
	Unemployment/ poverty	1.11	
Incentives to work in:	Childcare/ sickness	1.665	3.33
	Unemployment/ poverty	1.665	

Table 2. Social assistance system evaluation criteria and benefits initial values for 2018–2022 for Lithuania.

Evaluation criteria/ benefit type	Coverage					Adequacy					Incentives to work				
	2018	2019	2020	2021	2022	2018	2019	2020	2021	2022	2018	2019	2020	2021	2022
Means-tested benefits															
Cash social assistance	11.1	11.2	9.6	11.9	11	49.8	48.6	68.1	68.9	77.1	33.8	30.8	39.1	38.3	37.4
Additional child benefit	80.6	84.1	105.5	114.4	119	11.6	8	15.6	15.8	17.7	7.9	5.1	9	8.8	8.6
Categorical															
Child benefit	78.3	83.3	84.4	85.4	82.1	12.3	20	23.4	26.9	30.1					
Pregnancy grant	101.2	57.9	84	146.8	107.2	31	30.3	97.6	98.9	110.8					
Student's childcare benefit	3.4	2.5	3.7	5.2	6	93.1	90.8	91.1	92.3	103.4					
Old-age social assistance pension	19.3	28.5	41	55	62.3	53.1	52.6	54.5	55	64.8					

Table 3. Social insurance system evaluation criteria and benefits initial values for 2018–2022 for Lithuania.

Evaluation criteria/ benefit type	Coverage					Adequacy					Incentives to work				
	2018	2019	2020	2021	2022	2018	2019	2020	2021	2022	2018	2019	2020	2021	2022
Old-age contributory pension	91.7	95.4	96.7	96.6	97.4	62.4	95	100	100	100					
Sickness benefit	49.6	47.6	54.7	52.4	64.9	52.1	43.4	59.7	65.1	69.7	30	23.4	29.1	30.7	28.8
Maternity benefit	85.3	76.7	76.7	90	86.1	73.5	71.8	71.9	72.9	81.7	49.9	45.5	41.3	40.5	39.7
Paternity benefit	54.7	54.8	55.3	63	66.6	73.5	71.8	71.9	72.9	81.7	49.9	45.5	41.3	40.5	39.7
Childcare benefit	75.3	69.1	71.1	73.9	76.6	73.5	71.8	71.9	72.9	81.7	49.9	45.5	41.3	40.5	39.7
Unemployment benefit	39	41.4	38	32.6	42.6	49	51.5	55	57.5	63.6	33.2	32.6	31.6	31.9	30.9

Table 4. Social protection system (system coordination) evaluation criteria and benefits initial values (%) for 2018–2022 for Lithuania.

Evaluation criteria/ benefit type	Coverage					Adequacy					Incentives to work				
	2018	2019	2020	2021	2022	2018	2019	2020	2021	2022	2018	2019	2020	2021	2022
Old-age	55.4	61.9	68.8	69.4	79.8	57.7	73.8	77.2	77.5	82.4					
Childcare/ sickness	66	59.5	66.9	78.9	76.1	52.6	51	62.9	64.7	72.1	37.5	33	32.4	32.2	31.3
Unemployment/poverty	25	26.3	23.8	22.2	26.8	49.4	50	61.5	63.2	70.4	33.5	31.7	35.4	35.1	34.2

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Ukraine's Green Economy Growth in the Context of Industry 4.0: Challenges and Solutions

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Abstract. The research highlights the importance of prioritizing new sources of economic growth for the world, with a specific focus on Ukraine. The information base of the study included data from the statistical and managerial reporting of enterprises, the State Statistics Service of Ukraine, and information-analytical materials from international organizations. The authors analyze scientific works associated with the European Green Deal (EGD) to identify historic periods of green economy growth and establish growth trends. The authors argue that favorable conditions are necessary to achieve sustainable green growth within the framework of the EGD. The study aims to introduce an improved economic definition, namely the efficiency of green (natural) capital, aligned with the provisions of the EGD in the context of Industry 4.0. The analysis demonstrated that the coefficient of green (natural) capital (GNC) efficiency is crucial in decision-making processes by enterprises, taking into account ecological and green (natural and resource) factors. The analysis also includes a flowchart of Ukraine's green economy growth in the environment of Industry 4.0 as of 2022. The research results have led to the improvement of scientific and methodological approaches to assessing the eco-economic efficiency of advanced green technologies. The introduced green (natural) capital indicator allowed to display of the theory of achieving more products and services with fewer resources, including natural and ecological ones.
Keywords: Green Growth Indicators, European Green Deal, efficiency of green (natural) capital, Industry 4.0.

Introduction

The world population became more concerned about the fact that the Western model of economic growth (Crafts, 1995; Friedland, R., & Sanders, J., 1985; Rodríguez-Pose, A., Tselios, V., 2010; Ekelund Jr, R.B. and Hébert, R.F., 2013) with its extreme anthropogenic

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burden on the environment, over-exploitation of natural resources, and dehumanization of society proved vulnerable to the global issues associated with the aggravation of raw material, ecological and demographic problems. In the view of intensification of technological globalization processes, Ukraine in its international scientific-technical cooperation should focus primarily on putting into practice the latest achievements of science and technology (Industry 4.0) to ensure the basis of the „green economy" (i.e., tackling challenges in the area of ecology, energy, transport of XXI century, information technology etc.). In the paper (Galushkina, T., 2011) considers trends and ways of creating «green» economy and Investigating stages of development of «green» economy and transformation processes taking place towards the reorientation of «brown» economy to «green». (Vargas-Hernandez, J., Rakowska,Jo. and Vargas-González Omar C., 2022) put attention that Green Economic Development could be the Framework for Green Finance and Green Investment.

Following the authors, building and introducing globally the model of a green economy sustainable growth should be regarded as the only option to overcome the above problem. Such a model entails maximum integration of achievements of science, technology and innovations (Chernenko, et al., 2020), which society enjoys under conditions of Industry 4.0, into the global production and social living environment of mankind. At the same time, the scientific literature is still not fully researched on the issues of determining the current state of the green economy of Ukraine, analyzing its growth potential in the context of the use of Industry 4.0 technologies. Recognizing the contribution of researchers, the scientific and methodological approach to assessing the development of the „green economy", namely, determining the interrelation of aspects of environmental and economic efficiency, requires further improvement.

Present-day experts of the Organization for Economic Co-operation and Development deem (OECD) that the great deal of the countries in the world and Ukraine among them should prefer new sources of economic growth. To pursue such a policy, one should have favourable conditions for getting on the path of harmonious sustainable development of a green economy compatible with the strategy of the EGD. In the environment of Industry 4.0 there exist 2 scenarios of such development of a green economy worth mentioning, i.e. innovations driven by human capital and an ecology-oriented economy. Put in other words, the global economy may grow towards Society 5.0 (Aquilani, et al., 2020) together with addressing ecological challenges. To attain the aforementioned, it is recommended to start with the implementation of the concept of sustainable (ecology-oriented, harmonious and financially solvent) growth which should be integrated into a comprehensive strategy covering demand and supply issues both on the level of the national economy as a whole and its individual sectors.

The primary objective of this article is to investigate how the green economy in Ukraine can expand by incorporating the provisions of Industry 4.0. This study seeks to provide a comprehensive understanding of the potential for growth in the country's green economy. The article will first provide an overview of the concept of Industry 4.0 and its potential impact on the economy. It will then examine the current state of Ukraine's

green economy. The article will also analyze the potential for growth in the green economy sector in Ukraine, including the role of Industry 4.0 technologies in facilitating this growth. Overall, this study aims to contribute to the development of a more sustainable and resilient economy in Ukraine by promoting the integration of green and Industry 4.0 technologies. By doing so, Ukraine can position itself as a leader in sustainable economic development and attract investment from international partners who prioritize environmental sustainability. The study also aspires to advance the scientific and methodological framework for assessing the progression of the „green economy" by introducing an enhanced indicator that considers environmental and economic efficacy. This novel indicator considers the green (natural) capital, the net income generated from investment in environmental protection measures, and Industry 4.0 conditions. It enables the tracking of the effectiveness of environmental protection measures relative to pollutant emissions. This approach deviates from conventional methods and strives to enhance the evaluation of the green economy's growth potential. Ultimately, the discussion will encompass the policy implications derived from the analysis. Key findings of this research can provide valuable insights for policymakers, businesses, and investors in Ukraine who are interested in promoting sustainable economic development. By incorporating Industry 4.0 provisions into the green economy, Ukraine can create new opportunities for innovation, job creation, and economic growth while reducing its environmental impact.

1. Review of the scientific literature

In was in 1989 when Professor Edward B. Barbier in cooperation with his colleagues, experts on economy and ecology first mentioned the definition of a green economy in a pioneering report for the UK Department of the Environment called *Blueprint for a green economy* (David, Anil, and Barbier, 1989). This research paper was developed for consultations of the UK Department on sustainable development issues. The theory of a green economy was further expounded in the works of the same authors (Barbier, Pearce, and Markandya, 1990) and Plan 3: Measuring Sustainable Development Efficiency (in 1990 and 1994). Later Professor Edward B. Barbier published another work titled *A Global Green New Deal* (February 2009) at the request of UNEP stating that within the next two years investments of 1% global GDP would lead to the creation of a critical mass of green infrastructure sufficient to lay solid groundworks for a green economy on a global scale (Barbier, 2009). It is also worth stating that early XXI century international organizations scrutinized important aspects of investing in sustainable development. Thus, based on the United Nations Environmental Programme Financial Initiative (UNEP FI), the United Nations Global Compact, and other such declarations, the United Nations' Principles for Responsible Investment (UN-PRI) were established in 2006 to encourage financial institutions to integrate ESG (environmental, social, and governance) factors into the decision-making process. In 2011 the European Commission published the Thematic Issues focused on the Global Green Economy (European Commission, 2011). In 2012 Hussein Abaza, a former Chief of the Economics and Trade Branch of the United Nations Environ-

ment Programme (UNEP), structured a number of papers devoted to green economy issues (UNEP, 2012). Thus, for example, Ulrich Brand in his paper *Green Economy – the Next Oxymoron?* focusing on sustainable development expresses the idea that "strategies of a green economy are going to be realized at the expense of other sectors and regions, e.g., the increase of renewable forms of energy at the cost of destructive palm oil production in Indonesia or biofuels in Brazil" (Ulrich, 2012). In their joint report *Moving towards a Common Approach on Green Growth Indicators (*Green growth knowledge platform, 2013) the authors propose a framework that provides a common basis for further developing GG/GE indicators, with a special emphasis on economic-environmental nexus.

Among the latest research of green economy issues, one should single out the work by Soderholm P. (2020) where the authors analyzed green capitalism and the uncertain business-as-usual scenario and the role of the state and designing appropriate policy mixes. Suggestions for public policies were brought forward by Lucreția Dogaru (2021). The aforementioned postulates were further supported by various researchers in their analyses of such issues. Thus, the work by Meghișan-Toma and others establishes the impact of green productivity on digitalization, green production and environment commitment (Meghișan-Toma, et al., 2022).

Ćetković et al. (2021) in their paper *Economic Analysis of Measures for GHG Emission Reduction* noted in respect to EGD measures as follows: "introducing taxes on carbon or trade systems restraint creates an environment for consumption choice, targeting low-carbon activities, increasing investment in more environment-friendly technologies". The work by Ionescu et al. (2022) establishes a new approach on the foundations of financial allocations for the sustainable growth of the digital economy needed in the current conditions of the global crisis and of the pandemic for the implementation of digital economy growth policies. Muhadinovic, Djurovic, and Bojaj in their paper (2021) investigate and forecast the linkage and causality between greenhouse gas emissions (GHG) and Gross Domestic Product (GDP).

Considering specific aspects of the current development of the world economy in the context of Industry 4.0 economic growth and overcoming of ecological problems should be brought into action by the transition to an ecology-oriented model of a green economy within the framework of the innovative development model of the EGD. The model generates new opportunities and challenges for all member-states of the European Union (EU).

Thus, Brătucu et al. (2022) propose to combine the model of the EGD – to which all 27 member-states have committed themselves by creating new opportunities for innovation, investment and jobs, with the aim of digitally transforming European society – with the problem of avoiding digital disruption in the EU. New opportunities for innovations should be definitely implemented using provisions of Industry 4.0. We believe that the primary tasks within the agenda of the EGD should be as follows: employment incentives in high-technology sectors of the economy; putting to minimum use of available natural resources (coal, oil and gas) and considerable increase of renewable energy sources in the system for energy supply, generation and introduction of energy-efficient, resource-saving technologies, development of hybrid vehicles. The above will strengthen the national economy, enhance its competitiveness due to cost-cutting of domestic products, keeping currency within the country's borders, ensuring partial employment, as well as its increased role in fighting

against the global challenges. This speaks for the country's intention to attain sustainable development of the national economy without disrupting ecological balance.

Industry 4.0, which represents the integration of advanced digital technologies in manufacturing and other industries, has the potential to support and promote the transition to a green economy in these concepts: circular economy and sustainable production (Bag, 2021; Ottonicar, 2022), green finance (Bhatnagar, 2021), green supply chain management (Umar, 2022), green jobs and green infrastructure (Rutkowska, 2020), green logistics (Seroka-Stolka, 2019), smart buildings, energy model of the building (Agouzoul, 2022), green finance, green climate funds and green bonds (Mohsin, 2023), and others.

In the realm of the European Green Deal, the paper by (Hasse, 2023) advocates for a critical reassessment of the pursuit of infinite economic growth within the constraints of planetary limitations. Emphasizing that the green transition goes beyond a mere quest for economic gains, this research underscores the importance of integrating a vision that prioritizes principles of social and environmental justice.

2. Description of research hypotheses

Robust definition of strategic objectives of the state policy takes the lead in restructuring the national green economy with a green growth. As evidenced by the experience of the countries with high performance in Green Growth Indicators, determination with due regard of outcomes and ecological-socio-economic impacts allows to revise and refuse low-efficient state policies (for example, subsidies given to fuel-production industries) and switch to such effective financial tools as fair pricing, promotion of investments into environment-friendly technologies and increase of responsible companies in society. It is essential that social responsibility should be supported by the state, international organizations and other key economic players. The framework of such support is displayed on Figure 1.

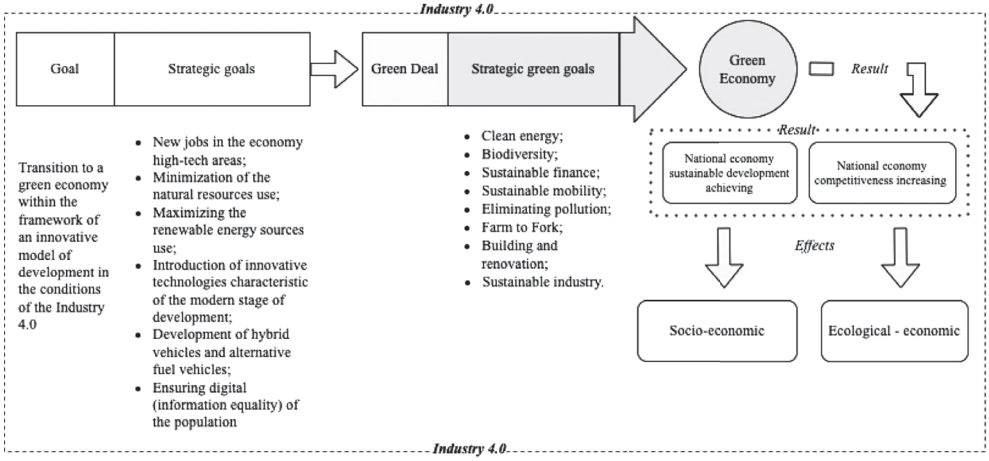

Figure 1. Green economy growth within the framework of innovative model adjusted for Industry 4.0 (as of 2022)

Following (Figure 1), a wide selection of initiatives associated with innovation promotion is also the major driver of creating new environment-friendly technologies, leaner production and expansion of employment by creating new jobs.

To have the possibility to create innovations, green latest technologies one should use various ways, methods and techniques covering not only pricing tools and incentives for companies' engagement in ecology-oriented activities, but also public procurements and financing of fundamental research (Chernenko et al., 2021). Against this background, the authors suggest a flow chart of green economy growth for Ukraine in settings of Industry 4.0 presented on (Figure 2).

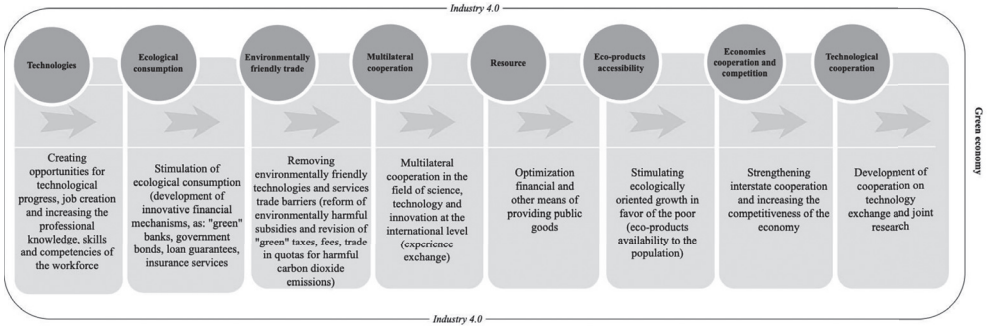

Figure 2. Flow chart of green economy growth for Ukraine in settings of Industry 4.0. (as of 2022)

Figure 2 shows visually the transition to green technologies, i.e. Ukrainian economy's pursuing to sustainable green development. It is influenced by certain circumstances such Industry 4.0. It is worth mentioning that the transfer and further sustainable development of Ukraine's green economy are aligned with UN recommendations on the implementation of green state policies and development of environment-friendly vehicles, usage of alternative energy sources, green building and industry. Implementation of the state green economy growth in Ukraine under conditions of Industry 4.0 is expected to give rise to the following:

- creation of new and renewable energy sources; innovative resource-saving technologies and refinement of electric power plants;
- machine building as the basis for high-technology renovation of all industry sectors resulting in the growth of high-quality metallurgy;
- nanotechnologies as one of prerequisites, specifically: microelectronics, information technologies and telecommunications;
- development of biotechnologies (becoming of prime importance in XXI-century global pandemic), improvement of chemical technologies, introduction of new materials, raw materials and byproducts;
- high-technology development of agriculture and processing industry;
- state-of-the-art transportation systems: building and reconstruction;

- environment protection and enhancement, recovering of people; development of the innovative public culture;
- production of vehicles, development and introduction of innovative technologies for their manufacturing.

For the Ukrainian economy to achieve high level of innovation and competitiveness the above directions of science and technology development should become top-priority and advanced from the perspective of their importance and efficiency while manufacturing.

3. Methods and methodology

To achieve the goal and address the main tasks of the article, the authors have applied various methods of scientific research, such as: dialectical, historical-logical, method of scientific abstraction. Methods of comparison, statistical grouping are used for the analysis of the number of air pollutant emissions and greenhouse gases, spending of business entities on nature-protection measures, economic-statistical methods are used to determine the dynamics coefficient of ecological spending efficiency and quantity of air emissions of enterprise. Tabular and graphical description methods are used to systematize the data and also, to visualize organized data related to a specific research question.

The primary purpose of this research is to suggest to the global community an improved methodology to assess ecological-economic efficiency of advanced green technologies (fostering such growth) in the context of increased interest of the global community to the notion of a green economy. Such methodology rests on the introduction of a new economic definition of efficiency of green (natural) capital in settings of Industry 4.0. It should be emphasized that a suggested improved methodology complies with basic postulates of the EU concept of the EGD.

Let us consider a standard production function with three factors (L,K,t) (Sharapov, Derbentsev and Semonov, 2004) and add an additional compulsory factor Z - efficiency of green (natural) capital:

$$Q = f(L, K, t, Z), \tag{1}$$

where as Q – potential production volume of advanced technologies at a certain period of time (from a macroeconomics perspective, this could be a Gross Domestic Product);

L – labour (human capital) engaged into production of advanced technologies;

K – capital (venture);

t – time during which advanced technologies are released with involvement of green component, innovative technologies;

Z – green (natural) capital to provide society with ecological sustainability, high level of innovation and competitiveness, i.e. enhance ability of the natural environment to supply the society with resources and ecological assets at a given time and in the future (over a period of time) for sustainable development of a green economy following the selected path.

With the help of a factor analysis it is possible to establish the impact of each factor on a function resulting indicator (1) describing sustainable development of the national green economy. After that such factors are considered while determining, as the authors suggest, an efficiency coefficient of green (natural) capital, advanced green technologies (labour, capital, natural resources, environment condition and quality). The authors believe that these factors move the green economy growth towards Industry 4.0 emphasizing high-priority trends of progress in science and technology.

An improved methodological approach to the assessment of ecological-economic efficiency of advanced green technologies is based on defining ecoefficiency, i.e. efficiency of green (natural) capital. To this end, new indicators should be introduced representing:

$\frac{Q}{Z} = GI$ – return of green (natural) resources over a period of time under conditions of Industry 4.0;

$\frac{Z}{Q} = GR$ – green capacity (natural resource intensity).

It is worth pointing out that the need to establish a coefficient of green (natural) capital efficiency (hereinafter referred to as "GNC") arose due to keeping the track of ecological and green (natural resource) factors in the decision-making process by enterprises being compatible with new rules of the EGD. A suggested indicator (GNC) reflects the theory of getting more products and services with less deployed resources including natural and ecological ones and should be determined as follows:

$$GNC = \frac{Green\ Result\ (GR)}{Green\ Impact\ on\ Environment\ (GI)}, \quad (2)$$

where as, GR – assessment of derived economic result or effect (added value of gross output, additional profit);

GI – environmental impact assessment (volume of consumed natural resources, economic losses from ecological destruction). For example, in 2018 V. Frechko, an inventor from Ukraine won the gold medal at Genius Olympiad in New York for his project Recycle of Fallen Leaves. An invention on manufacturing paper from recycled fallen leaves during a year allows to cut down deforestation by 18% in the world (processing just 600 kg leaves a day) (Frechka, 2018).

The given method proves useful when choosing among several alternative options for environmental impact decline or selecting the most appropriate and competitive advanced technologies. Such alternatives may be implemented subject to careful analysis of many details (design of product specifications, condition of financial and production capabilities of a company, repayment period of state-of-the-art advanced technologies, analysis of environmental impact types, environmental assessment of product life cycle, analysis of risk factors). Selectable indicators and parameters should comply with objectives and production environment of advanced technologies.

Schematically a formula numerator GNC (2) may be presented in the form of green results (GR):

$$GR = E - CS - AC - CC + OI - OE - CTax, \quad (3)$$

where as, E – earnings, money units;
CS – cost of sales, money units;
AC and CC – administrative and commercial costs, money units;
OI and OE – other income and expenses, money units;
CTax – corporate tax, money units.

Then formula (2) will look as follows:

$$GNC = \frac{GR}{GI} = \frac{E - CS - AC - CC + OI - OE - CTax}{GI} \quad (4)$$

(Formula 4) is an approach to assessing the growth of the „green economy", unlike existing ones, is based on the proposed indicator (coefficient) of environmental and economic efficiency, which takes into account the use of green (natural) capital, the level of net income received from each monetary unit invested in environmental protection measures, and the factors (features) of Industry 4.0. Formula (4) based on the research by (Galushkina, T., 2011) "Vector Of Green Economic Development Of Ukraine" which considering trends and ways of creating «green» economy. (Galushkina, T., 2011) identified that investigated stages of development of «green» economy and transformation processes taking place in Ukraine towards the reorientation of «brown» economy to «green».

It is noteworthy to acknowledge the manner in which this study advances upon prior research and the extanted literature. „Green Capital: A New Perspective on Growth" by

Christian de Perthuis and Pierre-André Jouvet (Perthuis, C. D., & Jouvet, P. A., 2015) – this book explores the concept of green capital and how it can be used to promote sustainable economic growth. „The Net Benefits of Pollution Prevention: A Case Study of the Paint Manufacturing Industry" by David Pennington and Charles H. Kriebel (Pennington, D., & Kriebel, C. H., 1992) - this article presents a case study on the net income generated from pollution prevention measures in the paint manufacturing industry. „Industry 4.0: The Future of Productivity and Growth in Manufacturing Industries" by Rüßmann, M., Lorenz, M., Gerbert, P., Waldner, M., Justus, J., Engel, P., & Harnisch, M. (2015) and „The Fourth Industrial Revolution" by Klaus Schwab (Schwab, K., 2016) – this book discusses the potential of Industry 4.0 technologies, such as automation and artificial intelligence, to transform manufacturing industries and promote economic growth. „Green Growth: Economic Theory and Political Discourse" by Richard Perkins and Eric Neumayer (Perkins, R., & Neumayer, E., 2012) - this article provides a critical analysis of the concept of green growth and its potential to promote sustainable development. „ Sustainability Assessment Tools" by Marco Taisch and others (Taisch, M., Sadr, V., May, G., Stahl, B.,

2013) – this article reviews existing information on the intersection of Industry 4.0 and sustainable production, highlighting the potential benefits and challenges of integrating these two concepts. However, based on the description provided, the approach mentioned (formula 4) seems to be a novel one that combines elements of green capital utilization, net income generated from environmental protection measures, and Industry 4.0 features to assess the growth potential of the green economy. This approach may differ from existing methods and could potentially provide more comprehensive insights into the economic benefits of sustainable development.

4. Data and analyses

The study is conducted to provide insights into how Industry 4.0 provisions can be incorporated into the green economy in Ukraine to promote sustainable economic development. The research will use a mixed-methods approach, including a literature review and case studies. The findings will be analyzed using statistical methods and presented as a comprehensive report with some recommendations for policymakers, businesses, and investors on promoting the growth of the green economy in Ukraine.

Before applying an improved methodological approach to calculations of certain enterprises it is recommended to assess the number of air pollutant emissions (Figure 3) and the general spending behavior of business entities on environmental protection (Figure 4).

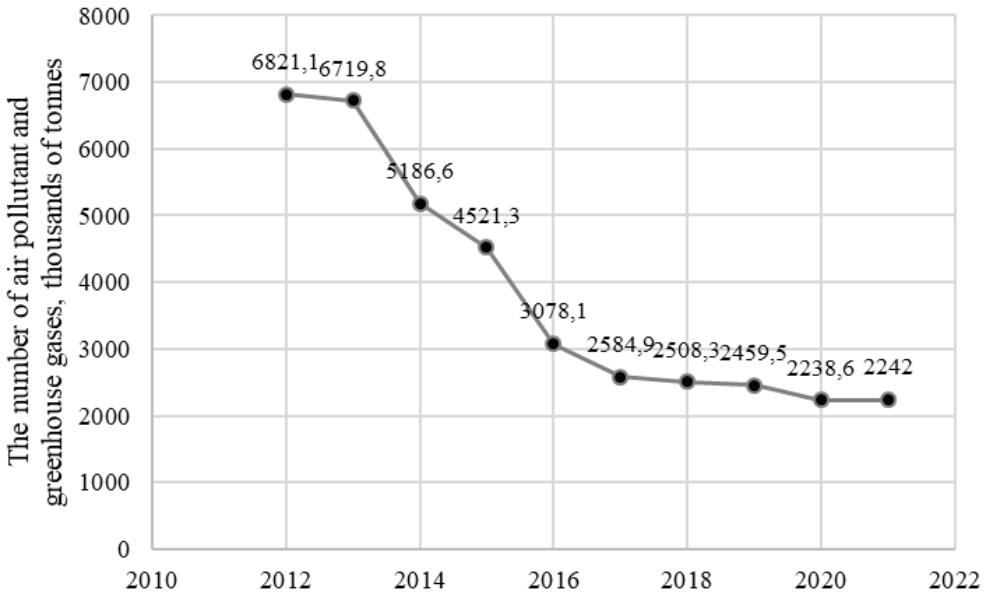

Figure 3. The number of air pollutant emissions and greenhouse gases in Ukraine (for the period 2010-2022)

Research findings (Figure 3) in Ukraine, the number of air pollutant emissions have been steadily declining since 2013, according to data analysis. The creation and implementation of environmental protection program by businesses is one of the major causes of this decline. Within the framework of its European integration, Ukraine should fulfill a number of commitments before EU on enhanced environmental protection and gradual reduction of polluting emissions (Figure 4).

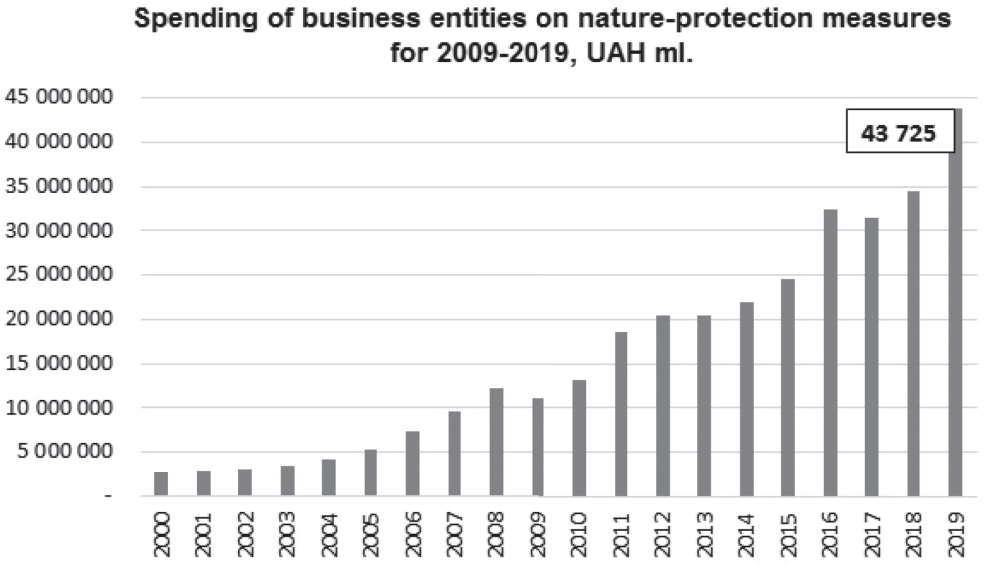

Figure 4. Spending of business entities on nature-protection measures for 2009-2019 in Ukraine

Research findings (Figure 4) presented at ECO BUSINESS Group demonstrate a steady trend of increased spending of Ukrainian business entities on nature-protection measures. Whereas in 2012 and 2013 such spending just crossed the limit of UAH 20 ml then in 2019 it increased almost twofold as compared to the aforementioned years and made UAH 43.7 ml. (Kuznetsova, M., 2020).

Let us consider the dynamic pattern and efficiency of spending on environmental activities by Ukrainian companies emitting the most pollutants and taking a proactive approach in introducing green technologies into manufacturing for a research period (Table 1).

Domestic enterprise environmental programs are typically designed for multi-year periods, making it difficult to evaluate their economic effects in relation to a specific year.

To address this issue, we propose an environmental and economic efficiency indicator that can be tracked over time to capture the cumulative effects of gradual financing in environmental protection measures.

Table 1. Comparative analysis of efficiency of green (natural) capital in 2018-2020 at enterprises of Ukraine

Enterprises	Year	Spending on nature protection measures, UAH ml.	Net profit, UAH ml.	Net operating income, UAH ml.	GNC (efficiency „Green (natural) capital")	Quantity of air emissions, thousand tons	Coefficient of ecological spending efficiency
PJSC "AZOVSTAL IRON & STEEL WORKS"	2018	331,2	3570,9	81960,9	10,8	88,8	247,5
	2019	834,8	-5670,9	57293,1	*-*	81,4	68,6
	2020	844,7	420,8	50563,3	0,5	84,3	59,9
PJSC "ILYICH IRON AND STEEL WORKS"	2018	1925,0	3372,3	79091,1	1,8	3743,9 (carbon dioxide)	41,1
	2019	2600,0	-5405,2	80921,2	*-*	3536,8 (carbon dioxide)	31,1
	2020	3046,0	186,5	77153,9	0,1	3921,6 (carbon dioxide)	25,3
National Nuclear Energy Generating Company «Energoatom»	2015	275,0	1115,4	32903,9	4,1	227,4	119,7
	2016	316,1	232,8	36067,9	0,7	234,1	114,1
	2017	489,9	3822,4	38487,7	7,8	230,0	78,6
	2018	763,7	4631,8	83402,4	6,1	236,4/4516,8 (carbon dioxide)	109,2
	2019	515,0	3773,6	90352,3	7,3	146,2/1386,8 (carbon dioxide)	175,4
	2020	3240 (3502)	-4845,2	75291,6	*-*	145,7/1555,8 (carbon dioxide)	23,2
DTEK	2007	91,4	1193	8969	13,1	391,9	98,1
	2008	211,6	119	12969	0,6	526,6	61,3
	2009	191,1	856	15009	4,5	464,5	78,5
	2010	194,7	2857	24294	14,7	493,2	124,8
	2011	320,3	3522	39594	11,0	588,9	123,6
	2012	916,4	5922	78340	6,5	1126,7	85,5
	2013	976,0	3332	92817	3,4	1090,9	95,1
	2014	777,2	-19660	93254	*-*	989,7	120,0
	2015	822,5	-41890	95375	*-*	771,7	115,9
	2016	858,3	-1215	131815	*-*	*-*	153,6
	2017	1116,5	4628	145070	4,1	863,8	129,9
	2018	1314,1	12373	157619	9,4	771,8	119,9
	2019	1350,1	12592	137742	9,3	723,1	102,0
	2020	728,1	-13895	116046	*-*	607,8	159,4
PJSC «Ukrhydro-energo»	2018	5,22	3668	7960	702,7	6,0	1524,9
	2019	59,35	3222	8262	54,3	4,5	139,2
	2020	44,36	4136	13153	93,2	4,0	296,5
JSP «Ukrzaliz-nytsia »	2018	522,7	203,9	83402,4	0,4	196,6	159,6
	2019	540,3	2988,2	90352,3	5,5	171,9	167,2
	2020	488,2	11899,7	75291,6	24,4	151,2	154,2

Source: compiled by the authors. (PJSC "Azovstal Iron & Steel Works" 2020 page 3; 2019 page 3; PJSC "Ilyich Iron and Steel Works" 2020 page 4; 2019 page 4).

- Due to the enterprise's apparent loss, it is not possible to calculate the coefficient.

We discovered that PJSC Ilyich Iron and Steel Works (PJSC IISW, 2019, 2020) and the National Nuclear Energy Generating Company Energoatom (SE „NNEGC „Energoatom“, 2019, 2020) had the highest pollutant emissions and the most extensive environmental programs by analyzing this indicator for a sample of enterprises (as shown in Table 1). In addition, the National Nuclear Energy Generating Company Energoatom demonstrated a significant reduction in pollutant emissions - by 69.3% - in the first year of the program‘s launch (2018-2019).

However, as these businesses implemented environmental protection measures, their Environmental Spending Efficiency Coefficient decreased. This pattern emphasizes the potential for these programs to provide both environmental benefits and cost savings over time.

The conducted calculations indicate that the proposed coefficient allows for a comprehensive assessment of the effectiveness of aligning financial goals with environmental responsibility for the enterprise. As evidenced by data on pollutant emissions, a portion of the surveyed enterprises successfully utilizes financial resources to protect the environment while simultaneously demonstrating profitable activities (JSP «Ukrzaliznytsia», PJSC «AZOVSTAL IRON & STEEL WORKS», PJSC «Ukrhydroenergo»). Simultaneously, at certain enterprises (DTEK), significant expenditures on green policy measures have resulted in a reduction of pollutant emissions into the air. The practical results obtained highlight the existence of certain challenges and affirm the relevance of applying the proposed model for assessing the effectiveness of implementing green economy measures in enterprises.

5. Results and discussion

The primary objective of comparing these research findings with the existing literature is to contextualize the results, validate the research, and make a meaningful contribution to the broader body of knowledge in the field of green economy. Through this comparative analysis, the authors aim to identify potential gaps in the current literature, which may open avenues for further exploration and research in the realm of transitioning towards a green economy in the context of Industry 4.0.

Industry 4.0 as well as the enhanced international division of labour in the area of science and commercial exploitation of scientific results, necessitate intensification of international scientific and technical cooperation of Ukraine and a review of its forms. Within the EGD, Ukraine recognizes the urgency to carry out technical and process modernization of all manufacturing up to the best global practices. To that end, one should take advantage of available innovative potential, broader international cooperation in the domain of science, education and production adjusted for their environmental impacts.

With due regard to Industry 4.0, as well as techno-globalism growth, Ukraine in pursuing its international scientific-technical cooperation should focus on the deployment of the latest achievements in science and technologies to attain sustainable development of its economy (i.e. settlement of differences in the field of ecology, energy, transportation,

IT), as well as address national security issues (socio-economic wellbeing, stability, counter-terrorism, cyberwars, pandemics with all clear threats to the society). It is worth mentioning that the legislation of Ukraine provides for the following priority areas of international cooperation embedded into national concepts of economy growth in various sectors, specifically scientific and innovative activities: resource-saving technologies, alternative energy sources, nano and biotechnologies; aerospace technologies; information technologies, creation of new competitive materials and products, computer and automated technology, robotic technology and other types of innovative products.

One of the top-priority areas of international cooperation should imply the development of up-to-date technologies in the context of national ecological security. This is exemplified remarkably by the consequences of the Chornobyl catastrophe (XX century) and the global pandemic (XXI century) suffered by the whole world.

Relevance of the given research involves drafting recommendations to the Government and country's leadership on cooperation with other countries to recover from global ecological crises and in the context of Industry 4.0 to promote Ukraine's transformation to an ecologically safe and responsible country of the world by means of the introduction of innovative ecotechnologies being the only a modern green existence (Figure 5).

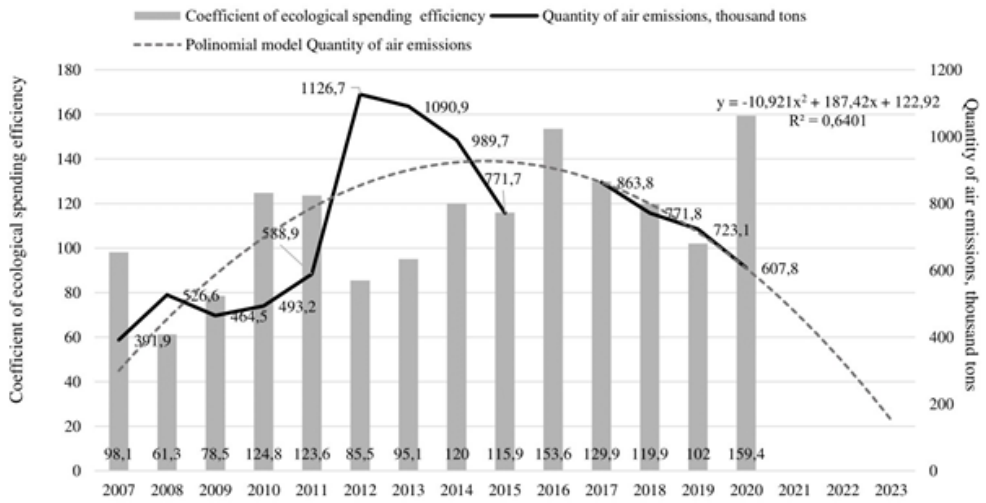

Figure 5. Dynamics coefficient of ecological spending efficiency and quantity of air emissions DTEK for 2007-2023

Source: compiled by the authors. (Activities in the sphere of sustainable development report for 2010-2011, (2012). *DTEK. PJSC "Azovstal Iron & Steel Works" 2020 page 3; 2019 page 3; PJSC "Ilyich Iron and Steel Works" 2020 page 4; 2019 page 4*).

The dependency presented (Figure 5) which was made on Annual reports in 2008-2011, Integrated reports in 2013-2020 by DTEK, shows that in years with the lowest efficiency coefficient values, DTEK enterprises had the highest volumes of pollutant emissions

(in 2008, the coefficient was 61.3, and emissions amounted to 526.6 thousand tons; in 2012 - 85.5 and 1126.7 thousand tons, respectively; in 2013 - 95.1 and 1090.9 thousand tons). With the increase in the effectiveness of environmental protection measures, DTEK demonstrated a decrease in emissions into the atmosphere. For example, in 2010, the coefficient was 124.8, and emissions were 493.2 thousand tons; in 2020 - 159.4 and 607.8 thousand tons, respectively. It is also worth noting that a relatively high level of efficiency coefficient, starting from 2014, leads to a sustainable reduction of pollutant emissions into the atmosphere over time (in 2017 - 863.8 thousand tons, in 2020 - 607.8 thousand tons).

The results of the analysis demonstrate that the proposed methodology is effective in evaluating the expansion of the green economy in Ukraine. The mentioned improved indicator of environmental and economic efficiency provides a comprehensive assessment of the impact of green investments on the economy, society and the environment. The findings indicate that the green economy has significant potential for growth in Ukraine and the green capital and Industry 4.0 technologies can enhance the efficiency and effectiveness of environmental protection measures. However, it is important to note that this study has limitations and further research is needed to fully understand the challenges and opportunities of transitioning to a green economy in Ukraine.

This research aimed to explore the peculiarities of green economy development in Ukraine amidst the fourth industrial revolution. The authors, by comparing the results of global studies, considered international advancements and identified how they differ from prior scientific works in the field of green economy. Current trends in green economy and Industry 4.0 initiatives have gained recognition globally, showcasing positive outcomes and innovative approaches. Consequently, Ukraine is recommended to consider global experience, particularly the European Green Deal (an initiative by the European Union with the goal of making Europe the first climate-neutral continent by 2050) and the Digital Strategy 2025 (aiming to integrate concepts of Industry 4.0 and environmental sustainability). This will enable the incorporation of digital technologies to optimize production and reduce environmental impact.

Conclusions

The results of the research performed are to improve the scientific and methodological approach to the assessment of ecological-economic efficiency of advanced green technologies which unlike existing methodology suggests a coefficient of efficiency of green (natural) capital (GNC). A suggested coefficient is driven by the need to keep the track of ecological and green (natural resources) factors which will enhance the integrity of management decisions taken by enterprises.

The concept of sustainable development gained further support and the authors regulated and structured the chronological order of the world green economy growth. Guided by methodological provisions of Green Growth Indicators the authors described Ukraine's green economy growth in the context of Industry 4.0. The research also presents a further categorial analysis of sustainable development theory, specifically a suggested definition

of efficiency of green (natural) capital aligned with basic provisions of the European Commission concept of the EGD.

Following the findings obtained, the authors consider that formulation and introduction worldwide of the model of green sustainable economic development should be further analyzed as the only option for overcoming global ecological-economic problems. Such a model should provide for maximum integration of scientific-technological and innovative achievements, the society would enjoy the world production and social living environment of mankind.

There are some limitations in this research work. The study is limited to the context of Ukraine and the findings may not be generalizable to other countries or regions. The study relies on secondary data sources, which may not always be accurate or up-to-date. The study does not provide a detailed analysis of the challenges that Ukraine may face in transitioning to a green economy. Also it is necessary to give some recommendations for farther future researches: a studies should consider the socio-economic and political factors that may impact the growth of green economy in Ukraine; it also should compare the experiences of Ukraine with other countries that have successfully transitioned to a green economy; the next future studies should explore the potential role of Industry 4.0 technologies in promoting the growth of green economy in Ukraine.

The findings align with certain aspects of the research conducted by other authors on the same topic. The study has identified several commonalities and differences between global trends and Ukraine's approach to integrating Industry 4.0 concepts into green economy growth. The alignment is evident in the recognition of global initiatives like the European Green Deal, Germany's Digital Strategy 2025. These initiatives share common goals of enhancing productivity, reducing environmental impact, and promoting innovation.

However, unlike existing approaches, the research combines a situational and comprehensive methodology, allowing for a synergistic effect by considering the unique challenges and opportunities of Ukraine (territorial pollution due to armed conflicts, destruction and damage to hydro, thermal, and nuclear power stations) alongside global trends in the application of the Industry 4.0 concept.

It would be beneficial to delve deeper into the specific mechanisms and policies that can enhance the integration of Industry 4.0 in Ukraine's green economy. Exploring case studies, success stories, and potential barriers in more detail could provide practical insights for policymakers and industry stakeholders. Additionally, examining the social and economic impacts of these initiatives on local communities and businesses would contribute to a comprehensive understanding.

Taking into account the current realities happening in Ukraine the destruction and damage to the infrastructure of hydro, thermal, and nuclear power stations, soil and water pollution, as well as air pollution resulting from armed conflicts on the country's territory, have necessitated the assessment of the effectiveness of the environmental component in the development and implementation of restoration projects in Ukraine. The acquired experience can be applied by other countries worldwide whose energy infrastructure has suffered from environmental and climatic catastrophes.

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A Study on the Effect of Imported Wheat Prices on Türkiye's Pasta Exports: ARDL Approach

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Abstract. Türkiye has possessed significant agricultural opportunities throughout its history. Although the effective utilization of these opportunities is a subject of debate today, the country still plays a significant role in the global trade of some agricultural products. When discussions about Türkiye's exports are examined, a common complaint is the external dependency of the export industry. However, there are also debates about the diminishing agricultural advantages that have been present since the past. When these discussions are brought together, the trade of certain processed agricultural products, whose raw materials are agricultural products, also becomes a noteworthy research topic due to a similar import dependency. In this study, an analysis was conducted using time series and the ARDL model to investigate whether there is a relationship between Türkiye's pasta export quantity, as one of the leading pasta exporter's globally, and the prices of wheat imports from Ukraine, Russia, and Bulgaria. Also robustness checks enhanced the analyzes by employing FMOLS and DOLS methods. The research findings indicate variations in the impact of wheat prices from country to country on the quantity of pasta exported by Türkiye. Recommendations regarding the importance of wheat production in Türkiye are also provided as a result of the research.
Keywords: Export-Import Analyzes, ARDL, FMOLS, DOLS

Introduction

The climate crisis and the sustainability agenda have led to increased discussions on agricultural production and consumption. While high-tech products dominate the lion's share of trade in the current global economic system, the inherent necessity of food in human life is making the importance of food more pronounced with each passing day during global crises. Events such as the COVID-19 pandemic (Hatipoğlu, 2021), the Russia-Ukraine war (Yenginar, 2022), and the ongoing Israel-Palestine conflict underscore the significance of food supply. Particularly in Türkiye, the sunflower oil crisis and food price inflation during the pandemic highlight some agricultural issues that the country needs to carefully address (Gündüz, 2021). From the past to the present, Türkiye has faced challenges in maintaining its title as an agricultural paradise (Aksoylu & Karaalp-Orhan, 2022). Factors such as

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rapidly increasing population, global migrations, inefficient use of agricultural land, and a decrease in irrigation areas for various reasons undermine Türkiye's claim of self-sufficiency in agriculture. In addition to these, more of the factors can be seen such as agricultural subsidies and rural-urban migration (Sugozu et al., 2017; Tasci et al., 2023). With these issues unfortunately claiming to be an agricultural heaven is losing its validity in today's context. The presence of products like chickpeas, beans, and lentils originating from the Americas, such as Mexico and Canada, on the shelves of markets indicates that Turkish cities, which were once associated with the production of these products, are now falling short in terms of production (TMO, 2021). Especially lentil import is kind of new for Türkiye (Gulumser, 2016). Apart from these examples, Türkiye occupies a distinctive position in terms of bread consumption compared to other countries around the world (Dolekoglu et. al., 2014). Bread and various dough products hold a significant place within the basic dietary habits of the Turkish population (Koca and Yazici, 2014). In fact, bread is considered a sacred blessing in Türkiye. Turkish women, even without the necessity of local bakeries or industrial bread production facilities, create different types of bread when they have access to flour. The majority of the Turkish population consumes bread or dough products in every meal of the day. This situation also highlights the demand for the fundamental raw material, wheat. The source of wheat is of great importance for Türkiye at this point. The table below shows the countries from which Türkiye imported the most wheat in 2022 (ITC, 2024a).

Table 1. Wheat Exporters for Türkiye (2022)

Exporter Country	Value Imported (USD Thousand)	Share of Türkiye's Imports %
Russia	2,395,449	71,4
Ukraine	719,333	21,4
Brazil	52,825	1,6
Mexico	34,957	1
Bulgaria	32,794	1
Kazakhstan	26,987	0,8
Moldova	23,780	0,7
Argentina	22,520	0,7
Syria	15,009	0,4
Latvia	14,982	0,4

These countries account for more than 99% of Türkiye's wheat imports. Additionally sectors in Türkiye that relies on wheat for sustenance is not limited to bread or pastry alone. Türkiye is one of the leading exporters of pasta worldwide. The ease with which pasta can be prepared for consumption has made it a universally beloved food, elevating it to the status of a significant product globally. It is worth emphasizing that, in terms of potential markets, this important product knows no bounds. The table below shows the countries that exported the most pasta in 2022 (ITC, 2024b).

Table 2. Leader Pasta Exporters of World (2022)

Exporter Country	Value Exported (USD Thousand)	Share of World's Imports %
Italy	4,169,527	28,7
China	1,195,235	8,2
South Korea	978,361	6,7
Türkiye	964,539	6,6
Thailand	663,258	4,6
Viet Nam	464,706	3,2
USA	438,995	3
Belgium	412,920	2,8
Germany	401,256	2,8
Netherlands	363,691	2,5

Table 2 shows that Türkiye ranks fourth among the world's top pasta exporting countries. However, viewing the pasta trade as a completely profitable and effortless venture would be an erroneous approach. This is because pasta, being a low-value-added product, can be produced and exported by many countries as can be seen from the Table 2 above. Though finding new export markets for many products may be challenging, products like pasta can easily enter any market based on customer preferences.

1. Theoretical Framework

The crucial issue here is whether one country possesses the factors to produce pasta efficiently. Heckscher (1919) and Ohlin's (1933) Factor Endowment Theory suggest that a country has a comparative advantage in exports based on its superiority in the production factors it possesses. When we look at the example of Türkiye, which has been considered throughout this study, it is expected that Türkiye indeed has a historical advantage in agricultural products. Türkiye, with its productive plains, is known as an important center for wheat. However, in contemporary times, Türkiye, despite its historical advantage in wheat production, is not self-sufficient and resorts to importing wheat from abroad. In other words, Türkiye purchases production factors, such as wheat, from other countries to use them in different stages of the production process. Examining Türkiye's imports, it can be observed that the majority of wheat is purchased from Ukraine, Russia, and Bulgaria (see Table 1). This deviation from self-sufficiency in wheat production aligns with the central premise of the Factor Endowment Theory, indicating that countries may engage in international trade to acquire the necessary production factors they lack domestically.

In this study, as the variables expected to influence Türkiye's pasta exports are not limited to imported raw material prices alone, there is a need for a theory to explain the relationship between exchange rates and exports. The Marshall-Lerner Condition, which suggests that increases in exchange rates will boost countries' exports (Bahmani et al., 2013), offers a second theoretical foundation for this study. In fact, the origin of this theory is based on Robinson's (1937) work, and it has been strengthened by criticism from Hirschman (1949),

drawing attention to issues such as price elasticity. However, fundamentally, as mentioned above, it is possible to conclude that increases in exchange rates will lead to higher exports. Additionally, according to the price effect approach, it can be argued that increases in exchange rates will encourage exporters to increase sales to earn more income, thus achieving an increase in the country's exports at the macro level (Zamani et al., 2013).

As seen in this study, the Factor Endowment Theory, an important international trade theory and Marshall-Lerner Condition will form the foundation of the research. Before delving into the methodology section, similar studies conducted globally will also be addressed.

2. Literature Review

Firstly, it is important to note that any product traded in the world is referred to as a commodity. In this context, studies related to factors influencing commodity exports will be examined. Through these studies, variables affecting the export quantity of a commodity will be revealed. Subsequently, research on pasta trade worldwide, especially in countries like Italy, and factors influencing pasta trade will be discussed. In the next stage, studies on the relationship between pasta and wheat in Türkiye will be examined. Last stage of literature review will host the studies about exchange rate and export relationship. This approach aims to provide a better understanding of why such a study is needed before moving on to the methodology section.

Nikonenko et al. (2020) state that the volatility in raw material prices affects the exports of commodity-exporting countries in world trade. Similarly, there are empirical studies that examine different countries for different commodities (McGregor, 2017; Jawaid and Waheed, 2011; Schmitt-Grohe and Uribe, 2018). In these studies, relationships between increases in commodity prices and the variability of global markets and economic growth are observed. In his research emphasizing the importance of commodity supply for different commodities, Tiess (2010) has stated that price increases can affect competition in various ways. In another study, Wlodarczyk (2018) has expressed that price volatility in commodity markets significantly affects the real economy. Niemi (2018) has stated that exports may vary depending on the price. Also, Khalifa (2016) has revealed that raw material prices are determinant for exports. The assumption that this highly probable change could be reflected in Türkiye's pasta exports through the change in raw material, namely wheat prices, is crucial for this study. Golikova et. al., (2020) have conducted research at a crucial point that will contribute significantly to this study. According to their study, price fluctuations in agricultural raw materials affect the planning of agricultural production. The existing research in the literature that examines the relationship between raw material prices and commodity exports strengthens the starting point and theoretical foundation of the study. Subsequent studies, however, focus specifically on pasta, which is the central focal point of this research.

Turning into international studies on the commercial structure of pasta, it is possible to encounter examinations from different perspectives. In their research highlighting modern pasta production in the context of sustainability, Recchia et al. (2019) emphasized

that companies engaged in global pasta exports using imported wheat are strong in this sector. It has been particularly noted that Mexico and Canada hold significant positions in wheat exports. In Italy, on the other hand, wheat is mainly supplied by local wheat suppliers, and wheat from France, the United States, and Australia are integrated into pasta production (Andrade-Sanchez, 2014; Samson et al., 2016). Mukhametzyanov et al. (2021), in their study on the production and export potential of grains and their subgroups, including wheat and other agricultural products that serve as raw materials for many products, including pasta, have indicated that these play a significant economic role. Therefore, the export of these products is also emphasized to have strategic importance. The strategic importance of the wheat used in pasta production aside, its quality is another noteworthy aspect. Bruneel et al. (2010) underscored the paramount importance of the quality of wheat utilized in pasta production, asserting that the nutritional characteristics of pasta vary depending on the type of wheat employed. Correspondingly, Hare (2017) emphasized the correlation between the quality of the wheat used and the resulting pasta quality. Menesatti and Bucarelli (2007), in their study, accentuated that achieving high quality in the pasta sector entails elevated costs. They elucidated that consumers with a strong inclination to pay value for pasta crafted through traditional production methods for its superior quality are willing to invest in such premium pasta without hesitation. In addition, Simeone et al. (2015) highlighted in their study on the Italian pasta sector that pasta prices play a crucial role in shaping competitive strategies. In a parallel vein, Cacchiarelli and Sorrentino (2018) identified the effectiveness of regulations imposed by market regulators in pasta markets. They specifically noted that regulations on wheat have a substantial impact on the pasta supply chain. Quality and market conditions also play a significant role in pasta trade and the supply chain. All these studies indicate that there are various areas providing research opportunities regarding the relationship between the wheat used and the produced pasta.

When it comes to research conducted in Türkiye, especially those related to the pasta trade, they have been included in this study. Keskin and Demirbaş (2011) emphasized the potential of the pasta sector in Türkiye during the relevant period in a study highlighting the potential of processed agricultural products in the country. In another study, Özaydın and Karakayacı (2023) examined the structure of the flour and bakery products industry in the food industry, underlining the necessity of imported wheat for pasta exports. Çetin (2020) emphasized the dependence on imports for exports in his study, which investigated agricultural production through foreign trade data. In a study examining the foreign trade structure of wheat and wheat products in Türkiye, Duru et al. (2019) identified that wheat was imported through the inward processing regime and exported as wheat-based products. Turhan (2018), in a study analyzing the competitiveness of the pasta sector, determined that Türkiye has developed competitive capabilities in the global pasta markets. In addition to these studies, some research highlights the presence of pasta production facilities in Türkiye equipped with leading technologies (Varlık, 2021). Furthermore, it is mentioned that certain cities in Türkiye could make significant contributions to wheat production, which is essential for pasta manufacturing (Acibuca, 2021).

As observed up to this point in the study, Türkiye stands out as a significant hub for pasta production. Moreover, it has the capability to produce the wheat necessary for pasta manufacturing; however, for various reasons, the wheat produced is not sufficient to meet the required quantity for export. Çığ et al. (2022) explained this situation by stating that Turkey produces enough wheat for its own consumption but imports wheat for pasta exports by taking advantage of the inward processing regime. Despite the inherent potential for Türkiye to be a pasta exporter based on the Factor Endowment Theory, scientific studies emphasizing the necessity of importing wheat have contributed to the formulation of hypotheses in this research. As indicated in the data and methods section of the study, there are ideas suggesting that the prices determined by the countries from which Türkiye imports the most wheat could be related to Türkiye's pasta export quantity.

Nevertheless, an entire model should not be built solely on the structure of imported raw materials. Therefore, it would be appropriate to include not only the purchase of imported raw materials but also the foreign currencies obtained in exchange for exports in the research. In other words, the exchange rate variable is also a crucial factor affecting exports, particularly for developing countries such as Türkiye. Various outcomes can be observed in studies investigating the influence of the exchange rate on trade. While some studies argue that exchange rate volatility reduces foreign trade (Baak et al., 2007; Cheung & Sengupta, 2013), other studies have found that exchange rate volatility does not affect exports (Lee & Masih, 2018). Of course, there are also studies observing that exchange rate volatility increases exports (Kasman & Kasman, 2005; Kılıç and Yıldırım, 2015). Similar studies exist regarding the impact of exchange rates on Türkiye's exports. Aktaş (2012) stated that the exchange rate does not affect exports, Nazlıoğlu (2013) found that changes in the exchange rate have different effects on sectors' exports, Uysal and Doğru (2013) indicated that exports decrease as the exchange rate increases, and Karakaş and Erdal (2017) mentioned that agricultural product exports increase as the exchange rate rises. Considering these studies, the model determined for the research in the next section is appropriate in terms of theory and literature.

3. Data and Methodology

3.1. Data

Econometric model of the study explains Türkiye's pasta exports using variables such as Russia's wheat export price, Ukraine's wheat export price, Bulgaria's wheat export price, and the exchange rate. Türkiye's pasta exports represent the quantity of pasta exported from the country. The prices of countries represent the average wheat selling prices in their exports to the world. The exchange rate shows the Central Bank of the Republic of Türkiye's USD/TRY rate. This exchange rate is included in the model due to the relationship between the exchange rate and exports as per classical economic thought. Graphs for these variables are presented in following figures. As the figures for the variables are at significantly different levels, the graphs are presented individually, as depicted in Figures below.

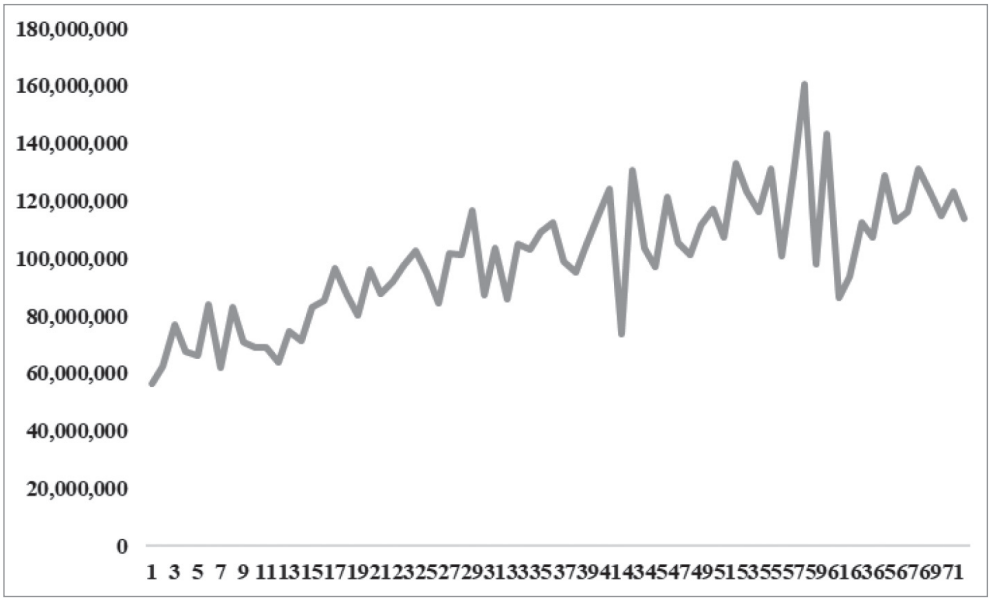

Figure 1. Trend of the Pasta Quantity (Kilograms) Exported from Türkiye

Turkey's pasta exports reached 114 million kilograms by the end of 2021, up from 60 million kilograms at the beginning of 2016. At one point, it was also observed that it reached levels of 160 million kilograms.

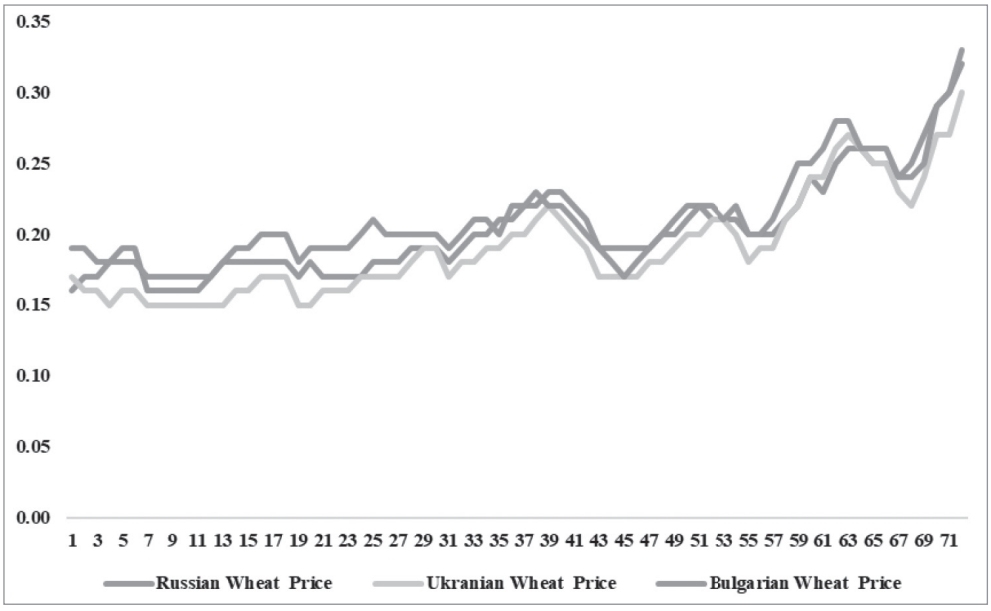

Figure 2. Trend of Russian, Ukrainian and Bulgarian Wheat Prices (USD)

The changes in the prices per kilogram of wheat, the primary raw material for pasta production, applied by Russia, Ukraine, and Bulgaria, which are among the countries Turkey imports the most from, can be seen in Figure 2. According to this, while Ukraine offers the lowest prices and Russia offers the highest, the three prices are quite close to each other. Nevertheless, it is understood that wheat prices have almost doubled over the years.

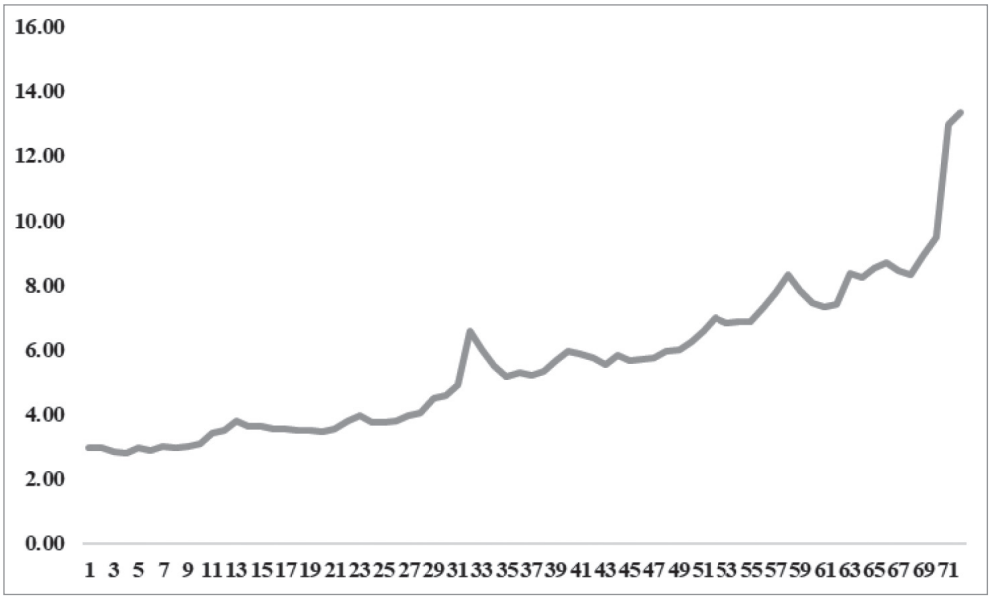

Figure 3. Trend of Exchange Rate in Türkiye (USD/TRY)

Finally, the changes in the exchange rate of the Turkish Lira against the US Dollar over the years are presented in Figure 3. Accordingly, the exchange rate has tripled from the beginning of 2016 to the end of 2021.

With these information, analyses were conducted using monthly data covering January 2016 to December 2021. The analysis period was determined based on the availability of data for all variables. Definitions of the variables and their sources are summarized in Table 3. All variables in the analysis were used in logarithmic form.

Table 3. Data and Sources Used in the Research

Variable	Description*	Period (Monthly)	Source
lnexp	Export quantity of Turkish pasta (ton)	2016(1) - 2021(12)	International Trade Center
lnuwp	Average price of Ukranian wheat (USD)	2016(1) - 2021(12)	International Trade Center
lnrwp	Average price of Russian wheat (USD)	2016(1) - 2021(12)	International Trade Center
lnbwp	Average price of Bulgarian wheat (USD)	2016(1) - 2021(12)	International Trade Center
lnexc	Exchange rate (USD/TL)	2016(1) - 2021(12)	Central Bank of Turkish Republic

* ln= Natural Logarithm of

In this study, conducted within the context of variables affecting the export of a specific sector, a model has been established. The model incorporates the above data and variables, taking into account the theoretical framework and support from the literature, as well as the consideration of raw material needs and costs. Constraints related to other variables that could not be included in the model are explained in the limitations section of the research.

3.2. Methodology

The empirical method chosen for this study is the ARDL boundary test approach proposed by Pesaran, Shin, and Smith (2001). This approach eliminates the necessity of having cointegration of the same order in standard cointegration tests and inefficiency in multivariate models (Pesaran, et. al., 2001). Furthermore, the boundary test approach ensures statistically efficient predictions, particularly in estimations conducted with small or limited samples (Altıntaş, 2013). In this study, the following model has been formulated to determine the potential impact of imported raw material prices on Türkiye's pasta export quantity.

$$lnexp = \alpha_0 + \alpha_1\, lnrwp_t + \alpha_2\, lnuwp_t + \alpha_3\, lnbwp_t + \alpha_4\, lnexc_t + \varepsilon_t \quad (1)$$

Here, α_0 represents the constant term, ε denotes the random error term, and t represents the time period ranging from t=1,2,...,72. The first step of the ARDL procedure involves applying a boundary test; upon favorable results from this test, the estimation of long- and short-term coefficients can be conducted. To implement the boundary test, an unrestricted error correction model (UECM) is initially estimated using the least squares technique. Accordingly, adapting Model (1) to the UECM is feasible as follows:

$$\begin{aligned}
&\Delta lnexp \\
&= \omega_0 + \omega_1\, lnexp_{t-1} + \omega_2\, lnrwp_{t-1} + \omega_3\, lnuwp_{t-1} + \omega_4\, lnbwp_{t-1} + \omega_5\, lnexc_{t-1} \\
&+ \sum_{i=1}^{p_1} \varphi_{1i}\, \Delta lnexp_{t-i} + \sum_{i=0}^{p_2} \varphi_{2i}\, \Delta lnrwp_{t-i} + \sum_{i=0}^{p_3} \varphi_{3i}\, \Delta lnuwp_{t-i} + \sum_{i=0}^{p_4} \varphi_{4i}\, \Delta lnbwp_{t-i} \\
&+ \sum_{i=0}^{p_5} \varphi_{5i}\, \Delta lnexc_{t-i} \\
&+ \varepsilon_t
\end{aligned} \quad (2)$$

Here, ω_0 represents the constant term, εt denotes the random error term, Δ signifies the first difference operator, and pi represents the lag length of the respective variable. At this stage, utilizing Model (2), a null hypothesis stating the absence of a long-term cointegration relationship among the variables, expressed as "H0: $\omega_1 = \omega_2 = ... = \omega_5 = 0$", is tested against an alternative hypothesis, articulated as "Ha: $\omega 1 \neq \omega 2 \neq ... \neq \omega 5 \neq 0$", using the Wald or F-statistic [FIII(lnexp/lnrwp,lnuwp,lnbwp,lnexc,)] (Pesaran et al., 2001). Accordingly, the test statistic value is compared with the table boundary values provided in Pesaran et al. (2001). When making this comparison, if the stationarity degrees of the variables are I(0)

or I(1), the table's lower or upper boundary value is used, respectively. If the t-statistic is smaller than the lower boundary value, it is concluded that there is no cointegration relationship. Conversely, if the calculated statistic exceeds the upper boundary value, it is determined that there is cointegration. If the computed statistic falls between the upper and lower boundaries, no inference can be drawn regarding cointegration. If all variables have a stationarity degree of I(0), the table's lower boundary value is used. If all variables have a stationarity degree of I(1), the table's upper boundary value is utilized. In both cases, if the calculated t-statistic exceeds the table value, it is concluded that there is a cointegration relationship (Bayir and Kutlu, 2019).

In determining the optimal lag length for each variable in the UECM, a total of (p + 1)k regression models are estimated using an information criterion such as Akaike or Schwarz, where p represents the chosen maximum lag length and k indicates the number of explanatory variables in the model (Ciftci and Yildiz, 2015). As emphasized by Pesaran et al. (2001), the presence of autocorrelation issues should be absent in the UECM for the validity of the boundary test. Additionally, for adequacy, the selected model is expected to pass diagnostic tests for changing variance, modeling error, and non-normal distribution aspects. If the boundary test confirms the presence of a long-term relationship between the variables, the analysis proceeds to the second stage. In this stage, using the Ordinary Least Squares OLS technique once again, a general ARDL model is estimated, where the dependent variable is regressed on its own lags and lags of explanatory variables (Pesaran and Shin, 1998). It is argued that combining the OLS technique in the ARDL method yields good results in calculating long- and short-term dynamics in models with 30-80 observations (Sulaiman & Abdul-Rahim, 2018); therefore, these methods have been employed. Within this scope, the general ARDL (q1, q2,q3,q4,q5) model, formulated based on Model (1), is presented below:

$$lnexp = \theta_0 + \sum_{i=1}^{q_1} \theta_{1i}\, lnexp_{t-i} + \sum_{i=0}^{q_2} \theta_{2i}\, lnrwp_{t-i} + \sum_{i=0}^{q_3} \theta_{3i}\, lnuwp_{t-i} + \sum_{i=0}^{q_4} \theta_{4i}\, lnbwp_{t-i} + \sum_{i=0}^{q_5} \theta_{5i}\, lnexc_{t-i} + v_t \quad (3)$$

In Equation (3), θ_0 represents the constant term, vt denotes the random error term, and qi signifies the lag length of the respective variable. According to the Granger Representation Theorem, when there is a cointegration relationship between two or more time series, there will also be a valid Error Correction Model (ECM) that reflects this relationship and the short-term dynamics (Engle and Granger, 1987). Therefore in the third and final stage of the ARDL procedure, leveraging the general ARDL model, an Error Correction Model (ECM) is constructed to link the long-term relationship with short-term dynamics, and this model is estimated using the OLS technique. Within this context, the ECM formulated based on Model (1) and consequently Model (3) can be formally expressed as follows:

$$\Delta lnexp = \lambda_0 + \sum_{i=1}^{r_1} \lambda_{1i}\, \Delta lnexp_{t-i} + \sum_{i=0}^{r_2} \lambda_{2i}\, \Delta lnrwp_{t-i} + \sum_{i=0}^{r_3} \lambda_{3i}\, \Delta lnuwp_{t-i} + \sum_{i=0}^{r_4} \lambda_{4i}\, \Delta lnbwp_{t-i} + \sum_{i=0}^{r_5} \lambda_{5i}\, \Delta lnexc_{t-i} + \sigma ECT_{t-1} + \mu_t \quad (4)$$

In Equation (4), λ_0 denotes the constant term, μt represents the random error term, Δ signifies the first difference operator, and ri represents the lag length of the respective variable (which, according to the lag lengths in Model (3), is qi - 1. Here, differenced lagged terms indicate short-term dynamics, while the term ECTt−1 represents the lagged error term derived from the long-term (cointegration) equation. The last term, referred to as the error correction term, reflects the rate at which variables converge to their equilibrium values after a shock occurs in the short term. For the correction of short-term imbalances and the system's ability to converge to a long-term equilibrium, the coefficient of the error correction term (σ) should be statistically significant and negative (Ciftci and Yildiz, 2015).

3.3. Findings

In this section, firstly Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests were conducted to determine the integration levels of the variables. The results of the ADF and PP unit root analyses in Table 4 indicate that the lnexp variable is stationary at the level, while the other variables are stationary at their first differences.

Table 4. Unit Root Test Results

Variables	ADF Test Statistics		PP Test Statistics		Result
	Level Values	1st Dif. Values	Level Values	1st Dif. Values	
lnexp	-1.907	-11.839	-4.448	-25.761	I(1)
lnrwp	0.252	-7.176	-0.082	-7.125	I(1)
lnuwp	0.123	-7.128	-0.025	-7.176	I(1)
lnbwp	1.194	-5.751	0.154	-6.833	I(1)
lnexc	0.753	-7.469	0.992	-7.427	I(1)

When evaluating the results in Table 4, it is observed that the conditions required for the use of the ARDL procedure are met. The results of the boundary test conducted as the first stage of the ARDL procedure are presented in Table 5. The calculated F-statistic for the joint significance of the one-period lagged level variables in the UECM exceeds the upper critical value at the 5% significance level. Consequently, the null hypothesis suggesting no cointegration among the variables can be rejected. This finding, indicating that the variables move together in the long run, is considered reliable in terms of diagnostic tests as well.

Table 5. ARDL Bound Test (Cointegration) Analysis

Estimated Model (T=64)	F-Statistics	Critical Values	Lower Limit	Upper Limit	Result
FIII(lnexp/lnuwp, lnrwp, lnbwp, lnexc)	3.85243*	1%	3.29	4.37	H0 rejected
		5%	2.56	3.49	
		10%	2.2	3.09	
Diagnostic Tests: $\chi^2(1)_{S.C.}$= 0.184 –(0.7563), χ^2 $(1)_{Het.}$= 0.683 (0.7487), F_{Res}= 0.159 (0.6912), J.-B.$_{Nor}$= 1.499 (0.4724)					

Note: * indicates significance at the 5% level. The UECM model was estimated with a maximum lag of „8“, and based on the Schwarz Information Criterion, a model with lag components (3,0,3,8,1) was selected. Critical values represent the critical values derived from Pesaran et al. (2001). Diagnostic tests display the diagnostic test statistics for the chosen UECM model, with the values in parentheses representing probability values. Here, S.C. denotes the Breusch–Godfrey autocorrelation LM test, Het. the ARCH changing variance LM test, Res. Ramsey's RESET test, Nor. the Jarque–Bera normality test. Also CUSUM test results are stabilized.

After confirming the presence of a long-term relationship among the variables following the boundary test, the second stage of the ARDL procedure can be initiated. In this phase, the general ARDL model is estimated using the OLS technique to compute the long-term coefficients [Model (1)]. Accordingly, the general ARDL model was estimated with a maximum lag length of 8 based on the Schwarz information criterion. The most suitable model, with lag lengths of ARDL(3,0,3,8,1), was identified, and Model (1) was computed using the coefficients from this equation. Subsequently, to obtain the short-term dynamics related to the long-term model, an error correction model was estimated. The estimates of the coefficients for both the long and short terms are presented in Table 6 and Table 7.

Table 6. ARDL (3,0,3,8,1) Estimation Results with Long Run Coefficients

Variable	Coeffecient	Std. Error	t-statistic	Probability
C	8.026.896	3.080.787	2.605.470	0.0125
lnexp(-1)*	-0.557846	0.175782	-3.173.516	0.0027
lnrwp**	0.696004	0.462927	1.503.486	0.1399
lnuwp(-1)	-1.941.850	0.763622	-2.542.948	0.0146
lnbwp(-1)	0.538170	0.640923	0.839680	0.4056
lnexc(-1)	0.577258	0.185079	3.118.978	0.0032
d(lnexp(-1))	-0.597062	0.157226	-3.797.484	0.0004
d(lnexp(-2))	-0.289753	0.119571	-2.423.264	0.0196
d(lnuwp)	0.285215	0.523147	0.545190	0.5884
d(lnuwp(-1))	1.880.433	0.661128	2.844.278	0.0067
d(lnuwp(-2))	1.982.191	0.555310	3.569.521	0.0009
d(lnbwp)	-1.106.616	0.526083	-2.103.501	0.0412
d(lnbwp(-1))	-1.028.258	0.776665	-1.323.941	0.1924
d(lnbwp(-2))	-1.678.892	0.591130	-2.840.141	0.0068
d(lnbwp(-3))	-0.417869	0.391608	-1.067.059	0.2918

Variable	Coeffecient	Std. Error	t-statistic	Probability
d(lnbwp(-4))	0.826844	0.382548	2.161.416	0.0361
d(lnbwp(-5))	0.177388	0.409107	0.433599	0.6667
d(lnbwp(-6))	0.358109	0.454355	0.788169	0.4348
d(lnbwp(-7))	1.299.144	0.463824	2.800.940	0.0075
d(lnexc)	0.000488	0.261315	0.001869	0.9985
Variable	**Long Term**			
	Coeffecient	**Std. Error**	**t-statistic**	**Probability**
lnrwp	1.247.663	1.025.459	1.216.687	0.2302
lnuwp	-3.480.980	1.759.751	-1.978.109	0.0542
lnbwp	0.964729	1.143.444	0.843705	0.4034
lnexc	1.034.799	0.308430	3.355.052	0.0016
c	1.438.910	1.569.258	9.169.362	0.0000

According to the calculated long-term coefficients in Table 4, it's found that the lnrwp, lnuwp, and lnbwp do not have a significant impact on lnexp. However, an increase in the lnexc positively and significantly affects lnexp. Therefore, as the exchange rate rises, pasta exports also increase. This result is in line with international economic theories. In the third stage of the ARDL approach, short-term relationships are being investigated. Within this context, the short-term model is estimated by including lagged values of the error terms of the model estimated as ARDL (3,0,3,8,1). The estimation results can be seen in Table 7.

Table 7. Error Correction Model Estimation Results for lnexp

Variable	Short Term			
	Coeffecient	**Std. Error**	**t-statistic**	**Prob.**
d(lnexp(-1))	-0.597062	0.122159	-4.887.576	0.0000
d(lnexp(-2))	-0.289753	0.104373	-2.776.133	0.0080
d(lnuwp)	0.285215	0.442762	0.644171	0.5228
d(lnuwp(-1))	1.880.433	0.514834	3.652.504	0.0007
d(lnuwp(-2))	1.982.191	0.487012	4.070.104	0.0002
d(lnbwp)	-1.106.616	0.474261	-2.333.349	0.0243
d(lnbwp(-1))	-1.028.258	0.526935	-1.951.392	0.0574
d(lnbwp(-2))	-1.678.892	0.469658	-3.574.715	0.0009
d(lnbwp(-3))	-0.417869	0.349538	-1.195.490	0.2383
d(lnbwp(-4))	0.826844	0.333052	2.482.628	0.0169
d(lnbwp(-5))	0.177388	0.357356	0.496391	0.6221
d(lnbwp(-6))	0.358109	0.372532	0.961283	0.3417
d(lnbwp(-7))	1.299.144	0.374517	3.468.849	0.0012
d(lnexc)	0.000488	0.220901	0.002210	0.9982
ECM (t-1)	-0.557846	0.109951	-5.073.582	0.0000

According to the results obtained, it is observed that lagged values related to lnexp have a significant negative impact at a 5% significance level in the short term. This effect continues for two months. While the changes in lnuwp do not have any significant effect on lnexp at a 5% significance level in the first month, it is observed that despite the increase in wheat prices in the following two months, Türkiye's pasta exports have increased. There is no apparent effect of lnrwp. Regarding lnbwp, there is no significant effect in the short term in the first two months; however, in subsequent months, it is observed that sometimes price increases negatively affect lnexp, and sometimes they have a positive impact. Exchange rate changes do not seem to have any short-term effects. To strengthen the validity of these findings, a robustness check was also conducted using the Fully Modified Ordinary Least Squares (FMOLS)and Dynamic Ordinary Least Squares (DOLS) method.

3.4. Robustness Check

In the initial model of the study, cointegration relationships among the series were identified using the ARDL method. In this section, to enhance the reliability and validity of the findings, the robustness of the results was tested using two separate models. The first of these methods is the FMOLS approach. This approach helps validate the results obtained from cointegration tests (Zimon et al., 2023). The formula for this approach, as utilized by Hansen and Phillips (1990) to amalgamate the most precise cointegration measures, is presented below:

$$\Delta lnexp_{2t} = \theta_0 + \sum_{i=1}^{t} \theta_1 \Delta lnexp_{2t-1} + \sum_{i=1}^{t} \theta_2 \Delta lnrwp_{t-i} + \sum_{i=1}^{t} \theta_3 \Delta lnuwp_{t-i} + \sum_{i=1}^{t} \theta_4 \Delta lnbwp_{t-i} + \sum_{i=1}^{t} \theta_5 \Delta lnexc_{t-i} + \lambda_1 lnexp_{2t-1} + \lambda_2 lnrwp_{t-1} + \lambda_3 lnuwp_{t-1} + \lambda_4 lnbwp_{t-1} + \lambda_5 lnexc_{t-1} + \varepsilon_t \quad (5)$$

As a second robustness test, the DOLS approach was utilized. The DOLS procedure involves incorporating exogenous variables along with their first-difference expressions to address endogeneity and calculate standard errors using a covariance matrix of errors that is robust to autocorrelation. DOLS estimators provide a reliable measure of statistical significance. Assessing the impact of the endogenous indicator on exogenous indicators in levels, leads, and lags is an effective method for dealing with various integration orders (Pattak et al., 2023). This approach enables the integration of different factors into the cointegrated framework (Dogan and Seker, 2016). The calculation for the DOLS method can also be considered based on Formula 5 above. The results for both approaches are presented in the table below.

When examining the results of the analysis conducted for robustness checking, it is observed that the long-term findings of the ARDL model align with the same conclusions. Accordingly, while no significant effects of imported wheat prices are observed, a 1% increase in the exchange rate is found to increase Türkiye's pasta exports by approximately 0.6454% according to the FMOLS model and by approximately 0.6658% according to the DOLS model.

Table 8. Robustness Check Results

Variable	FMOLS				DOLS			
	Coefficient	**Std. Error**	**t-Statistic**	**Prob.**	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
lnrwp	-0.3601	0.4306	-0.8363	0.4060	-0.7350	0.6287	-1.1690	0.2477
lnuwp	-0.2347	0.5294	-0.4434	0.6589	-0.0559	0.9649	-0.0579	0.9540
lnbwp	0.0803	0.4504	0.1783	0.8591	0.2929	0.7193	0.4072	0.6856
lnexc	0.6454	0.1120	5.7617	**0.0000**	0.6658	0.1642	4.0551	**0.0002**
C	16.5059	0.5855	28.1917	**0.0000**	16.5165	0.8194	20.1561	**0.0000**
R- Squared	0.571442				0.65487			

4. Discussions

In today's context, where food supply is of utmost importance, this research, recognizing the significance of wheat as a raw material in the production of some of the most fundamental food products, highlights the need for a multifaceted examination. The study aims to determine whether Türkiye's pasta exports, which are based on wheat, are related to the prices of imported wheat. According to the factor endowment theory, countries export based on the production factors they possess. This study reveals that in the long term, Türkiye's possession of wheat, whether domestic or imported, serves as a crucial factor in pasta production, contributing to averting crises in exports. It's evident that short-term crises based on occasional fluctuations in imported product prices do not have lasting effects, and Türkiye's pasta exports successfully navigate through these short-lived shocks. Even with an increase in the imported wheat price, Türkiye manages to increase its pasta exports by utilizing the purchased wheat. This study shows some similarities with the studies in literature review. Studies explaining the relationship between raw material prices and exports of commodity such as (Nikonenko et al., 2020; McGregor, 2017; Jawaid and Waheed, 2011) have similar results like this research.

As of 2022, Türkiye stands fourth in global pasta exports and similarly holds the fourth position in global wheat imports. Despite this balance between production capabilities and exports, Türkiye does engage in wheat exports, albeit in small quantities, as observed from statistical data. Some studies mentioned in the introduction section of this research suggest that raw material prices influence product exports across various industries (Schmitt-Grohe & Uribe, 2018). However, this study focused on Türkiye indicates that imported wheat prices don't significantly affect pasta exports in the long term. Still, it aligns with similar short-term shock scenarios documented in literature. When considering the wheat supply for pasta exports highlighted in past studies, the occurrence of short-term shocks becomes an explanatory aspect. Evidently, Türkiye's pasta exports exhibit a dependence on imported wheat. Hence, despite price fluctuations, wheat procurement continues to support pasta exports. In this context, one of the most critical aspects for Türkiye is the necessity to increase wheat production and, when insufficient, supplement it with imported wheat to sustain exports. Because as Tiess (2010) mentioned price of raw material does not always fit to competition.

Another finding of this study is the effect of exchange rates on pasta exports. The studies that found that the exchange rate increases exports (Kasman & Kasman, 2005; Kılıç and Yıldırım, 2015; Nazlıoğlu, 2013; Karakaş & Erdal, 2017) have reached a similar conclusion to this research. On the other hand, studies that have observed the negative impact of the exchange rate on exports (Baak et al., 2007; Cheung & Sengupta, 2023; Uysal & Doğru, 2013) have yielded contradictory results thus far. The comparison with the results obtained from this study and the past studies in literature are briefly summarized in the table below.

Table 9. Brief Summary of Comparison Between Past Studies in Literature

Research	Findings	Similarity Assestment with this Study	
		Short Run	Long Run
Kasman & Kasman, 2005	Exchange rate increase -> exports (+)	Contradictory	Similar
Baak et al., 2007	Exchange rate volatility -> foreign trade (-)	Contradictory	Contradictory
Tiess, 2010	Price increases -> international competition (-)	Similar	Contradictory
Cheung & Sengupta, 2013	Exchange rate volatility -> foreign trade (-)	Contradictory	Contradictory
Uysal & Doğru, 2013	Exchange rate increase -> exports (-)	Contradictory	Contradictory
Kılıç & Yıldırım, 2015	Exchange rate increase -> exports (+)	Contradictory	Similar
Khalifa, 2016	Raw material prices -> commodity exports (-)	Similar	Contradictory
Karakaş & Erdal, 2017	Exchange rate increase -> exports (+)	Contradictory	Similar
Niemi, 2018	price increases -> commodity export (-)	Similar	Contradictory
Golikova et al., 2020	Raw material prices -> commodity exports (-)	Similar	Contradictory
Nikonenko et al., 2020	Raw material prices -> commodity exports (-)	Similar	Contradictory

In addition to the results of these studies, it is also possible to discuss the findings in terms of the factor endowment theory and the Marshall-Lerner condition. Accordingly, based on theories from previous years, it is possible to say that Türkiye's pasta exports are not affected by imported input prices in the long run, due to the strength derived from the current factor conditions. On the other hand, it is observed that an increase in the exchange rate also boosts pasta exports, almost as if fulfilling a classic economic prophecy.

5. Limitations

In the literature review section of the study, it is observed that the quality of wheat concerning pasta exports is a topic of interest. The research can be considered limited due to the absence of a variable indicating quality among the variables used in this study. Additionally, since the study is conducted specifically for Türkiye, the three neighboring countries with the highest exports have been selected. For studies involving different countries, wheat prices from additional importing countries could also be considered. From a theoretical perspective, the inability to measure the effect of price elasticity on the

relationship between exchange rates and exports within the context of the Marshall-Lerner condition can also be considered as another limitation of the study.

The data set used in the study was selected based on common and up-to-date time intervals. Access to longer-term and broader data sets could be achieved if all countries had complete data entries in the ITC Trademap database. The dataset for the 72-month time series used in the research can also be considered a constraint in this context. The exclusion of data, such as monthly wheat and pasta consumption, among the study variables has hindered the establishment of a more comprehensive model. However, it is worth noting that such data could not be included in the model due to their unavailability on a monthly basis.

6. Conclusion

Findings of this study suggest that Türkiye's pasta export is not significantly influenced by the price of the imported wheat in the long term. In the short term, while there seems to be no effect observed from Russia's wheat export prices, the occasional increase in Ukraine's wheat price appears to increase pasta exports, potentially due to Türkiye being both a producer and importer of wheat from various countries. Similarly, examining the effects of Bulgaria's wheat prices on Turkish pasta exports reveals that price increases sometimes reduce pasta exports and sometimes increase them. However, research findings indicate that all these effects are short-lived. In the long term, it has been observed that Türkiye's pasta exports are positively affected only by increases in the exchange rate. The fact that Türkiye's pasta exports are not significantly affected in the long term by the wheat prices from the countries it primarily sources wheat from can be considered a significant opportunity.

It has been determined that increases in the exchange rate lead to an increase in Türkiye's pasta exports in the long run. Considering Türkiye's status as a developing country, it is natural for businesses to focus on exports to take advantage of the rising exchange rate. Indeed, as can be seen in the relevant figure, the exchange rate has been consistently increasing in Türkiye in recent years. Additionally, given that Türkiye's trade deficit is a chronic issue, it can be argued that generating foreign currency income is a valid motive for all businesses capable of exporting. In other words, in a developing country where exports cannot meet imports, businesses also seek to position themselves advantageously under the assumption that the exchange rate increase will be persistent. Furthermore, another aspect of the increase in the exchange rate is that businesses exporting from Türkiye may have a price advantage in global competition compared to their international competitors.

7. Theoretical Implications

The findings obtained with the model established in this study are significant for international trade, economics, agricultural economics, and macroeconomics research. Particularly noteworthy is the scarcity of studies that examine international trade at the product and

product group levels, as well as the limited research that presents the impact of supply and raw material variables at the macro level on exported products. In this context, the research findings suggest that delayed effects may be present, especially in the short term. Therefore, it is recommended to conduct similar studies in various countries and with different product groups. Especially within the framework of factor endowment theory, it is observed that traditional international trade theories still hold explanatory power for today's trade. Additionally price elasticity variables could be used in future studies if available. Therefore, researchers are encouraged to focus on studies that integrate historical theories (such as Factor Endowment Theory and Marshall-Lerner Condition) with contemporary approaches. Particularly, it is believed that research on the export products of developing countries to various countries, goods, and time periods, tested with diverse methods, should be encouraged to enhance the understanding of international trade. In addition to all this, it is recommended not to overlook the exchange rate variable in export studies, considering that the classic economic view, which suggests that exports also increase with an increase in the exchange rate is once again proven correct.

8. Practical Implications

The research results suggest that there is not only a responsibility for pasta producers but also for policymakers. Although not included in the model of this study, it can be said that considering the emphasized quality of raw materials in the literature, imported wheat should also be carefully selected for the country in this regard. It is accurate to say that the price of wheat to be imported into the country need to be inspected, and tariff measures should be taken to ensure that local wheat producers can compete without being harmed. Furthermore, considering Türkiye's consumption of wheat-based products from a health perspective, wheat imports should be shaped according to the health certificate requirements of leading countries in the world.

In addition, considering the long-term impact of the exchange rate on pasta exports, Türkiye's monetary and fiscal policies regarding the exchange rate are noteworthy. Indeed, although the sudden increases seen in recent years may present a positive picture in terms of foreign currency earnings for exporters, it can be said that proper decisions need to be made considering the possibility of increased costs being covered with foreign currency. Since the competitive performance of exporters in the international market will also depend on the balance of income and expenses, effective management of the exchange rate is crucial for both governments and companies to minimize risks.

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The Asymmetric Effects of Global Energy and Food Prices, Exchange Rate Dynamics, and Monetary Policy Conduct on Inflation in Indonesia

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Abstract. This research analyzes the asymmetric effects of global energy and food prices and monetary variables, including the exchange rate and money supply, on the consumer price index (CPI). The model is intended to differentiate the influence of increases and decreases in global energy and food prices, exchange rates, and money supply which cause inflation/deflation from changes in the CPI. The analysis uses the Nonlinear Autoregressive Distributed Lag (NARDL) and Quantile Regression models on data from January 2001 to February 2023. The study results show that the decline in global energy prices significantly reduces the CPI in the long run. Energy subsidies allow increases in international energy prices not to increase the CPI significantly. Meanwhile, the increase in global food prices causes inflation in the short run. The exchange rate has the most significant effect on the CPI. Depreciation of the rupiah significantly increases the CPI, which means it causes inflation, while appreciation of the rupiah does not have a significant effect. Finally, increases and decreases in the money supply have a considerable positive effect on the CPI, which confirms the logic of the monetarist view that inflation is a monetary phenomenon. Efforts to reduce dependence on imports of food and energy commodities are the key to reducing risks when importing energy and food due to rupiah depreciation. Efforts to consistently stabilize the exchange rate can support controlling and stabilizing import prices. Energy and food subsidy policies are vital in controlling inflation due to increased world energy and food prices.
Keywords: asymmetric effects; global energy and food prices; Consumer Price Index; Nonlinear Autoregressive Distributed Lag model; Quantile Regression model

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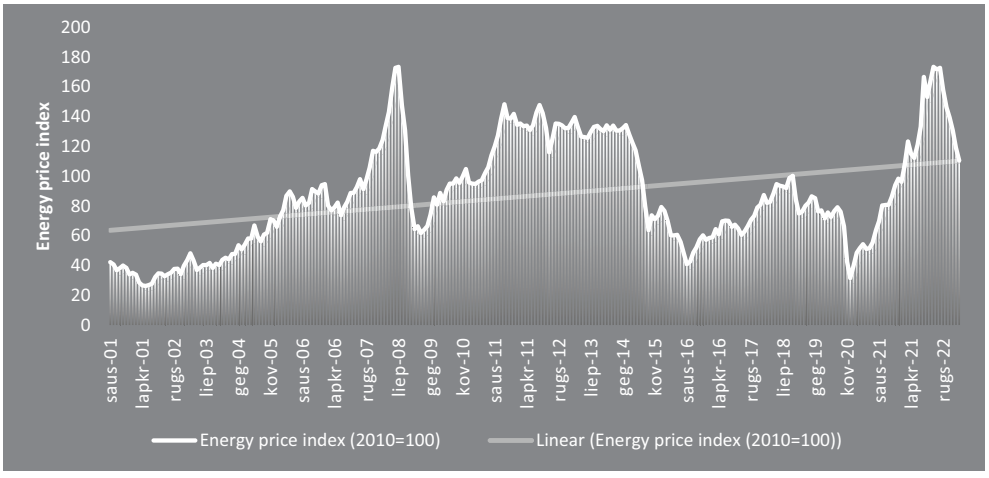
1. Introduction

The dynamics of the global economy are increasingly inseparable from the global economic crisis in the last decade. These global economic dynamics are increasingly impacting a country's economy. A country's openness to facing an increasingly dynamic global environment will make it vulnerable to changes in external factors. Changes that make an economy vulnerable increasingly receive attention from researchers and policymakers.

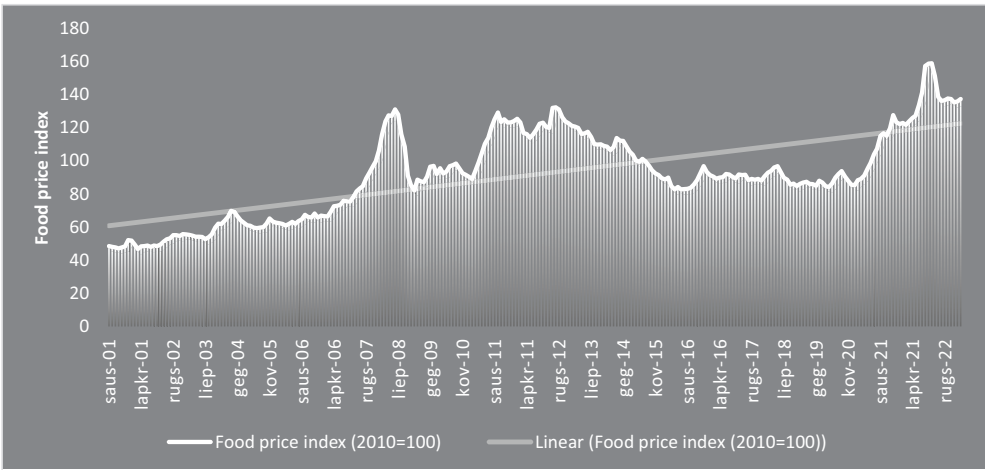
One of the critical problems that has received world attention is the issue of inflation and rising energy and food prices, which have a greater impact, especially on developing countries. One of the global issues related to soaring global energy and food prices is inflation. World price fluctuations can spill over into a country's domestic inflation (Bäurle et al., 2021). Recently, inflation has become a primary global concern. The IMF, World Bank, and economists believe that rising inflation due to rising energy and food prices will encourage an increase in interest rates to control high inflation, which can hamper aggregate demand. Crises that may arise due to soaring world energy and food prices are more likely to occur in countries that depend on energy and food imports, especially developing countries.

The dynamics of world energy prices in more than two decades are characterized by the frequency of energy price spikes being more frequent than declines, as shown in Figure 1. As a representation of global energy prices, the price index shown is a composite of crude oil, natural gas, and coal prices, with the largest weighting being crude oil. Meanwhile, the dynamics of global food prices are characterized by fluctuations in food prices with an increasing trend in the long term, as shown in Figure 2. Global food prices are a composite price index consisting of oils and meals, cereals, and other foods. More frequent increases in energy prices and fluctuations in food prices, which tend to rise in the long term, are severe challenges for countries that depend on energy and food imports in general, which can then threaten domestic food security.



Source: World Bank Commodity Price Data (updated on April 2023)

Figure 1. Dynamics of World Energy Prices January 2001 - February 2023 (in Price Index, 2010=100)



Source: World Bank Commodity Price Data (updated on April 2023)

Figure 2. Dynamics of World Food Prices January 2001 - February 2023 (in Price Index, 2010=100)

The energy and food crises are characterized by soaring world energy and food prices due to limited supply, which can then increase the burden on household income (Guan et al., 2023). In countries focusing on inflation, monetary policymakers are always alert to external factors that can impact domestic inflation (Rachman, 2015). Even though countries are increasingly integrated with the global economy, the influence of monetary policymakers still plays an essential role in domestic inflation dynamics (Bems et al., 2022). In countries that implement inflation targeting in their monetary policy, inflation stabilization becomes the main focus of their targets.

Indonesia, a nation that implements inflation targeting, is a case in point. With its high openness, characterized by extensive export and import activities, Indonesia is inextricably linked to the issue of domestic inflation due to the surge in global energy and food prices. Particularly for energy and food imports, which remain substantial, Indonesia is at risk when there is a hike in energy and food prices and a depreciation of the rupiah, highlighting the complex challenges it faces.

Main external factors, such as global energy and food prices, which could cause inflation in Indonesia, need to be researched as potential sources of domestic supply shocks. The increase in global energy and food prices, which triggers global inflation, can also cause domestic inflation through changes in import prices, which are passed on to changes in consumer prices. Literature documentation from previous empirical studies states that global commodity prices and changes in domestic currency exchange rates are proven to be factors that have a significant contribution to inflation in a country among existing external factors (including Naghdi & Kaghazian, 2015; Rizvi & Sahminan, 2020; Kayamo, 2021; Yan & Bian, 2022). Changes in energy and food prices impact changes in import prices of final products and inputs, which in turn affect the CPI. Meanwhile, changes in exchange rates based on the exchange rate pass-through model affect import prices. The

degree of ERPT will impact the level of inflation transmission to domestic inflation through international trade. Therefore, in this relationship, the exchange rate influences inflation.

Apart from being related to global commodity prices, preliminary studies on the influence of exchange rates on various aspects of the economy have been carried out in various countries. Among the main macroeconomic variables, the exchange rate has a significant contribution to influencing the domestic economy. In the literature, the exchange rate influences economic growth (including Morina et al., 2020; Karahan, 2020; and Utomo and Saadah, 2022) and also influences inflation (including Fetai et al., 2016; Monfared & Akin, 2017; Sharma & Dahiya, 2023) and is a significant issue especially in countries that focus on inflation (López-Villavicencio & Pourroy, 2019; Valogo et al., 2023).

From various previous studies and research on the influence of global commodity prices and exchange rates by joint modeling of monetary variables, most of the analysis assumes that the effects are symmetrical and apply equally to increases and decreases. However, changes between increases and decreases in the independent variable are not always responded to by changes in the dependent variable symmetrically or equally. It may be asymmetric, which means that the effect of an increase differs from that of a decrease, which is related to the nature of price rigidity. Price rigidity can prevent price fluctuations. Price rigidity can occur because firms can maintain fixed prices due to market power (Anders et al., 2023). However, price rigidity can partly occur, called asymmetric price rigidity, where prices are more rigid upward than downward (Levy et al., 2020), and price declines were common occurrence outside the services sector (Visockytė, 2018). Asymmetric price rigidity can support asymmetric price behavior, which encourages asymmetric effects from price changes in price pass-through from world commodity prices to import prices and CPI. Even though there has been research with asymmetric influence analysis, the analysis is carried out partially and only analyzes certain variables, which are the model's primary focus. Likewise, the effects of asymmetry or differences in estimated parameters are only analyzed between increases and decreases. Meanwhile, the CPI is not affected in the same magnitude or constant at various CPI levels based on changes in energy and food prices, exchange rates, and money supply, where monetary policy will generally boil down to adjusting the money supply to stabilize inflation and output.

This research develops a model to analyze changes in global energy and food prices, exchange rates, and money supply on CPI. This research proposes a dynamic model that aims to develop the Autoregressive Distributed Lag (ARDL) model into a Nonlinear Autoregressive Distributed Lag model to differentiate the effect of increasing and decreasing independent variables on the response variable. The NARDL model analyzes the asymmetric influence between global energy and food prices by involving exchange rates and money supply as monetary variables. Meanwhile, quantile regression models were estimated to analyze the differences in influence between various CPI levels, i.e., low, moderate, and high CPIs.

Furthermore, after Section 1, which provides an introduction, this paper is structured according to its objectives: Section 2 outlines a brief of theoretical basis and literature review relating global energy and food prices to inflation and the relationship between the exchange rate and money supply to CPI. Section 3 explains the data and methodolo-

gy. Section 4 presents the empirical findings and discussion. Finally, section 5 provides conclusions and policy implications.

2. Theoretical basis and literature review

2.1. Theoretical basis

This study analyzes the effect of world energy and food prices and exchange rates based on the microeconomic theory foundation for producer behavior with flexible prices. As in Adolfson (2001, 2007), the open economy's aggregate supply and demand model adjusted for incomplete exchange rate pass-through is based on the optimization behavior of domestic producers in the open economy. The prices of imported goods charged to the domestic market are flexible with no nominal rigidities.

In this model, domestic producers in the production of goods (Y) are assumed to use composite inputs consisting of domestic intermediate goods (Z^d) and imported goods (Z^m). The production function following the Cobb-Douglas production function is as follows.

$$Y_t = (Z_t)^{1-\delta} = \left[\left(Z_t^d\right)^{1-\varphi}(Z_t^m)^{\varphi}\right]^{1-\delta}, \qquad 0 \le \delta < 1 \tag{1}$$

The price of composite intermediate input in domestic currency is expressed as follows.

$$P_t^Z = \frac{\left(p_t^d\right)^{1-\varphi}(p_t^m)^{\varphi}}{(1-\varphi)^{1-\varphi}(\varphi)^{\varphi}} \tag{2}$$

where p_t^d denotes price of domestic intermediate goods, p_t^m denotes price of imported goods, φ denotes imported inputs share in the domestic production. The firm maximizes profits assuming an imperfectly competitive market with flexible prices, which is expressed by

$$\max_{\hat{p}_t^d \hat{p}_t^{d*} Z_t} \hat{p}_t^d C_t^d + \hat{p}_t^{d*} e_t C_t^{d*} - P_t^Z Z_t \tag{3}$$

$$s.t \quad Y_t = (Z_t)^{1-\delta} \ge C_t^d + C_t^{d*} = (1-\varphi)\left(\frac{\hat{p}_t^d}{\hat{p}_t}\right)^{-\sigma} C_t + \left(\frac{\hat{p}_t^{d*}}{\hat{p}_t^*}\right)^{-\sigma} C_t^* \tag{4}$$

Aggregate domestic and foreign consumption is assumed to follow the constant elasticity of substitution (CES) function. Producers meet demand for domestic products equivalent to $Y = C^d + C^{d*}$, which means domestic demand plus foreign demand. Meanwhile, e_t represents the exchange rate, expressed as the domestic currency per unit of foreign currency. C_t is the domestic aggregate consumption index, a combination of the consumption bundle of domestic and foreign goods, and $\hat{p}t$ is the corresponding price index. The asterisk represents the foreign counterpart. This model also assumes that there is no strategic interaction because the goods are well differentiated allowing producers to ignore their influence on aggregate prices and take competitors' prices, in this case the prices of imported goods ($\hat{p}_t^m$), as fixed.

Based on the first-order conditions, flexible prices are imposed on the domestic and foreign markets, so each price can be stated as follows.

$$\hat{p}_t^d = \left(\frac{\sigma}{1-\sigma}\right) mc(Z_t, P_t^Z) \tag{5}$$

$$\hat{p}_t^{d*} = \left(\frac{\sigma}{1-\sigma}\right) mc(Z_t, P_t^Z) \frac{1}{e_t} \tag{6}$$

σ is a constant price elasticity which is positive. Marginal cost (*mc*) is as follows

$$mc = \frac{P_t^Z}{(1-\delta)Z_t^{-\delta}} = \frac{P_t^Z}{(1-\delta)Y_t^{\frac{-\delta}{1-\delta}}} \tag{7}$$

Therefore, the price charged on the domestic market as in equation (5) can be expressed as

$$\hat{p}_t^d = \left(\frac{\sigma}{1-\sigma}\right) mc(Y_t, P_t^Z) \tag{8}$$

Thus, the domestic equilibrium price of a good with flexible prices consists of a constant and identical markup over marginal cost. With a constant markup as implied in the CES function, as stated by Adolfson (2001), the influence of the exchange rate on prices charged on the domestic market is only through its influence on the marginal costs of domestic producers, which is through its influence on imported intermediate inputs used in the production of domestic goods.

For imported goods, the behavior of foreign producers in the optimization problem is equivalent to domestic producers in producing domestic goods using imported intermediate goods. Foreign producers face the following optimization problem.

$$\max_{\hat{p}_t^m, \hat{p}_t^{m*}} \hat{p}_t^m C_t^m + \hat{p}_t^{m*} e_t C_t^{m*} - A_m(C_t^m + C_t^{m*}, P_t^{Z*}) e_t \tag{9}$$

$$s.t \quad C_t^m + C_t^{m*} = \omega \left(\frac{\hat{p}_t^m}{\hat{p}_t}\right)^{-\sigma} C_t + \left(\frac{\hat{p}_t^{m*}}{\hat{p}_t^*}\right)^{-\sigma} C_t^* \tag{10}$$

Where $\hat{p}_t^m$ is the price of foreign goods charged in the domestic market and denoted in domestic currency, $\hat{p}_t^{m*}$ is the price of foreign goods charged in the foreign market and denoted in foreign currency, A_m denotes total cost function of foreign producer, P_t^{Z*} is the input prices for foreign producers denoted in foreign currency, ω denotes the share of imported foreign goods of domestic consumption, and σ denotes the constant price elasticity of demand. The first order condition of profit maximization of foreign producers results in the prices charged on the domestic market.

$$\hat{p}_t^m = \left(\frac{\sigma}{1-\sigma}\right) mc^*(C_t^m + C_t^{m*}, P_t^{Z*}) e_t \tag{11}$$

and since total demand for foreign goods, $Y_t^* = C_t^m + C_t^{m*}$, then equation (11) can be expressed as

$$\hat{p}_t^m = \left(\frac{\sigma}{1-\sigma}\right) mc^*(Y_t^*, P_t^{Z*}) e_t \quad (12)$$

This means that the world market price for domestic imported goods is equal to the aggregate foreign price level, $\hat{p}_t^{m*} = \hat{p}_t^*$.

Based on equations (8) and (12), the domestic aggregate price level is a composite of the price of domestic goods using imported intermediate inputs and the price of final imported goods charged in the domestic market. From the composite between $\hat{p}_t^d$ and $\hat{p}_t^m$, with the incomplete exchange rate pass-through model, the aggregate price level ($\hat{p}_t$) can be determined by the price of domestic goods using imported inputs (P_t^Z) and the exchange rate (e_t), which influences the prices of imported input and final goods ($\hat{p}_t^m$). World commodity prices such as oil and food, as modeled in a study by Carri'ere-Swallow et al. (2021), are the commodity prices determined on the world market and expressed in US dollar denominations. In this study, aggregate price modeling involves world energy prices as an extension of oil commodities, and world food prices and exchange rates. Therefore, with the incomplete exchange rate pass-through model, domestic aggregate price is a function of world energy prices, world food prices, and the exchange rate.

$$p = f(p^{en}, p^f, e) \quad (13)$$

The increase in energy prices through world oil, gas, and coal prices will increase domestic fuel, gas, and coal prices and production costs for industries that generally require energy as a supporting material. The increase in energy prices for households will directly impact the rise in CPI, which is contributed by household fuel expenditure and indirectly transportation expenditure and expenditure on commodities whose production processes use energy. Meanwhile, the increase in world food prices will have a direct impact on the rise in the price of directly imported food and the increase in the price of domestic food made from imported food raw materials, and this will contribute to the rise in the CPI through household spending on food and beverage. The effect of a decrease in global energy and food prices can have the opposite impact, with the magnitude of the effect not being similar.

Domestic currency depreciation will increase import prices, which in turn will increase the CPI from rising prices of imported goods in domestic currency. The effect of domestic currency appreciation can reduce import prices and CPI, but with a non-identical effect size, allowing asymmetric exchange rate pass-through.

In a monetary policy environment that focuses on stabilizing inflation, domestic aggregate price modeling is completed by involving the monetary aggregate, i.e., the money supply, as a monetary variable that also influences inflation. Inflation, as a monetary phenomenon in Friedman's view, is caused by the money supply, which drives aggregate demand. The encouragement of aggregate demand that continues in the long run will only cause inflation.

As Nguyen et al. (2022) point out, an excess of aggregate demand compared to aggregate supply due to excess money in circulation will cause inflation. There is a one-way relationship between money supply and inflation, not vice versa. Ryczkowski (2021) states

that empirically there is a causality between money growth and inflation, and supports a return to a monetary framework that controls the money supply to control inflation. An increase in money supply will cause an imbalance between money supply and money demand, a situation that can have significant economic implications. To return to balance, some of the excess money will be used to purchase goods and services. An increase in demand for goods that cannot be met by the supply side will cause excess demand which then drives inflation.

Irving Fisher's exchange equation, MV = PY where M is the volume of currency traded, V is currency velocity, P is the price of goods, and Y is the level of real income (output), meaning that there is a direct link between money and inflation (Sultana et al., 2018). Because V is relatively stable over time, as the monetarist view, money growth that is faster than output will only result in inflation. The monetarist view implies that tightening monetary policy to control inflation is the key to monetary action through controlling the money supply. As a further development of equation (13), the following function expresses domestic aggregate price modeling as an empirical strategy with incomplete exchange rate pass-through in a monetary policy environment that focuses on inflation stabilization.

$$p = f(p^{en}, p^{f}, e, m) \tag{14}$$

where p^{en} denotes world energy price which is a composite of oil, natural gas and coal, P^{f} denotes world food price which is a composite of oils and meals, cereals and other foods, e denotes the domestic exchange rate against the US dollar. The monetary aggregate variable (m) chosen in this model is M1 which represents more transactional money. Assuming asymmetric effects, the influence of global energy and food prices, exchange rates and money supply on domestic prices is differentiated between increases and decreases. To represent inflation, prices are expressed in natural logarithms, the change in which means inflation/deflation.

2.2. Global energy and food prices on inflation

Implementation of monetary policy in countries that focus on inflation will always be oriented towards stabilizing inflation. Stabilization of domestic inflation is often faced with the challenges of a dynamic global economy. Rapid changes in global commodity prices increasingly characterize the dynamism of the global economy. The increase in inflation today is increasingly evident due to the rise in global commodity prices, especially global energy prices. Several studies have documented the positive impact of rising global energy prices on domestic inflation in advanced developing countries (emerging markets), including a study by Rizvi and Sahminan (2020). The increase in oil and energy prices increases inflation significantly; this can be caused by inflation originating from sectors that utilize energy, especially oil, gas, and coal., which can be caused by inflation originating from sectors that utilize energy, mainly oil, gas, and coal. Oil prices have an asymmetric influence, as Sek (2022) and Arintoko et al. (2023) provide their empirical findings. Oil prices have an asymmetric impact on domestic inflation, which occurs

through increases in consumer prices, producer prices, and industrial prices. The rise in oil prices significantly impacts inflation by increasing the transportation consumer price index (CPI). Ayisi (2019) and Bawa et al. (2020) also provide evidence of the asymmetric effect of changes in oil prices on inflation.

Sek (2019) discusses the concept of price rigidities, which can occur due to effective monetary policy. This policy can lead to asymmetric effects from changes in oil prices. Energy prices, represented by crude oil, natural gas, and coal, can influence inflation. Binder (2018) and Zhang et al. (2017) provide empirical evidence that an increase in natural gas prices leads to inflation. Guo et al. (2016) empirically demonstrate that coal prices have a positive and asymmetric impact on inflation, as measured by the CPI.

Besides energy prices, global commodity prices and food prices can also impact domestic inflation, especially in countries that import food commodities. Furceri et al. (2016) prove that the increase in global food inflation impacts domestic inflation from cross-country studies in developed and developing countries. The increase in global food inflation has a more significant impact on developing countries than developed ones. Rising inflation has significantly impacted global food prices in developing countries such as Indonesia and India (Rizvi & Shaminan, 2020). Specifically, changes in international food prices have driven considerably domestic food inflation, as a study by Samal et al. (2022) provides empirical evidence.

2.3. Exchange rates, money supply and inflation

Apart from global commodity prices, exchange rates can influence inflation. Sek (2022) proves that the exchange rate predominantly influences domestic inflation, so the exchange rate is the main factor that significantly influences domestic inflation. The exchange rate influences inflation through changes in import prices in sectors that use imported inputs. Inflation and exchange rates have also been proven to have a relationship in the short run, as proven by Sharma and Dahiya (2023). Monfarid and Akin (2017), Omolade et al. (2019), and Ugwu et al. (2021) also prove that empirical changes in exchange rates encourage inflation.

Kassi et al. (2019) and Fandamu et al. (2023) provide empirical evidence that the influence of the exchange rate on consumer prices occurs through incomplete and asymmetric exchange rate pass-through. Depreciation of the domestic currency has a more significant impact on changes in consumer prices than appreciation. The study by Hong et al. (2022) shows that the existence of asymmetry in exchange rate pass-through implies that local currency depreciation is a challenge in price stabilization.

Regarding monetary variables, inflation modeling by Chen et al. (2020) involves the money supply as a monetary variable, which is hypothesized to affect inflation positively. Empirical results show that the money supply positively affects CPI inflation apart from oil prices. The same results were stated by Samal et al. (2022), who noted that the money supply as a monetary policy variable influences inflation positively. Roshan (2014), Kugler and Reynard (2022), and Madurapperuma (2023) also provide evidence that an increase

in the money supply causes inflation. According to the Monetarist view, an increase in the money supply encourages household aggregate demand to increase, which causes prices to rise.

With a focus on inflation, monetary policy generally aims to stabilize inflation. In implementing monetary tightening to control inflation, monetary policy is not recommended to be aimed solely at controlling the influence of rising energy prices, which impact inflation, because it can cause monetary policy to become counterproductive (Atiq-ur-Rehman, 2013).

3. Data and methodology

3.1. Variable and data

According to the developed model, consumer price index in the natural logarithm is involved as the dependent variable in this research. Meanwhile, the independent variables include energy prices, food prices, exchange rates, and money supply as monetary policy variables. Prices are expressed in terms of the natural logarithm of the CPI, whose changes express inflation. CPI is based on the base year 2012 (2012=100). Energy prices are expressed in a monthly index, a combination of the prices of crude oil, natural gas, and coal with a weight of 84.6, 10.8, and 4.6 percent each, based on 2010 US dollar nominal = 100. The energy price index is analyzed using the natural logarithm (ln) which is abbreviated to PEN. Food prices are expressed in a monthly index, a combination of oils and meals, cereals, and other foods weighing 40.75 each, 28.25, and 31 percent, based on 2010 US dollar nominal = 100. The food price index is analyzed using natural logarithm (ln) which is abbreviated to PF. The exchange rate is measured in IDR/USD. The analyzed data is expressed in natural logarithms (ln) and shortened to ER. Finally, the money supply is calculated by M1 (narrow money), which is more liquid and transactional. M1 is measured in billions of rupiah, expressed in natural logarithms (ln), and abbreviated to MS depicted in the model.

The period analyzed in this research is January 2001 to February 2023. Analysis of changes in global energy and food prices in influencing CPI is modeled with monetary variables, including exchange rates and money supply. Data was accessed from online sources, such as Bank Indonesia for CPI, exchange rate, and money supply, and the World Bank for data on energy and food prices.

3.2. Model

This research estimates the CPI equation, a Nonlinear Autoregressive Distributed Lag (NARDL), and a Quantile Regression (QR) model. Explanatory variables include global energy and food prices, exchange rates, and money supply, which are differentiated between increases (x^+) and decreases (x^-) through positive and negative partial decomposition. This model is the application of the NARDL model developed by Shin et al. (2014), and several variations of the model have been applied in several previous studies, including

Arintoko (2021a) and Arintoko (2021b). Equation (15) is a developed model to analyze the influence of increases and decreases in global energy and food prices, exchange rates, and money supply on CPI. CPI changes in the natural logarithm reflect inflation.

$$\Delta LCPI_t = \alpha_0 + \alpha_1 LCPI_{t-1} + \alpha_2^+ LPEN_{t-1}^+ + \alpha_2^- LPEN_{t-1}^- + \alpha_3^+ LPF_{t-1}^+ + \alpha_3^- LPF_{t-1}^- + \alpha_4^+ LER_{t-1}^+ + \alpha_4^- LER_{t-1}^- + \alpha_5^+ LMS_{t-1}^+ + \alpha_5^- LMS_{t-1}^- + \sum_{i=1}^{k-1} \beta_{1i} \Delta LCPI_{t-i} + \sum_{i=0}^{l-1} \left(\beta_{2i}^+ \Delta LPEN_{t-i}^+ + \beta_{2i}^- \Delta LPEN_{t-i}^-\right) + \sum_{i=0}^{m-1} \left(\beta_{3i}^+ \Delta LPF_{t-i}^+ + \beta_{3i}^- \Delta LPF_{t-i}^-\right) + \sum_{i=0}^{n-1} \left(\beta_{4i}^+ \Delta LER_{t-i}^+ + \beta_{4i}^- LER_{t-i}^-\right) + \sum_{i=0}^{p-1} \left(\beta_{5i}^+ \Delta LMS_{t-i}^+ + \beta_{5i}^- \Delta LMS_{t-i}^-\right) + \varepsilon_{1t} \quad (15)$$

Note:

$$LPEN_t^+ = \sum_{j=1}^{t} \Delta \mathrm{LPEN}_j^+ = \sum_{j=1}^{t} max\left(\Delta \mathrm{LPEN_j}, 0\right) \quad (16a)$$

$$LPEN_t^- = \sum_{j=1}^{t} \Delta \mathrm{LPEN}_j^- = \sum_{j=1}^{t} min\left(\Delta \mathrm{LPEN_j}, 0\right) \quad (16b)$$

The decomposition of positive and negative partial sum decompositions for other variables, namely LPF, LER, and LMS, is calculated similarly to equations (16a) and (16b).

The expected long-run parameters and asymmetric effects of equation (15) are as follows:

$$-\frac{\alpha_2^+}{\alpha_1} > 0, -\frac{\alpha_2^-}{\alpha_1} > 0, -\frac{\alpha_2^+}{\alpha_1} \neq -\frac{\alpha_2^-}{\alpha_1} \quad (17a)$$

$$-\frac{\alpha_3^+}{\alpha_1} > 0, -\frac{\alpha_3^-}{\alpha_1} > 0, -\frac{\alpha_3^+}{\alpha_1} \neq -\frac{\alpha_3^-}{\alpha_1} \quad (17b)$$

$$-\frac{\alpha_4^+}{\alpha_1} > 0, -\frac{\alpha_4^-}{\alpha_1} > 0, -\frac{\alpha_4^+}{\alpha_1} \neq -\frac{\alpha_4^-}{\alpha_1} \quad (17c)$$

$$-\frac{\alpha_5^+}{\alpha_1} > 0, -\frac{\alpha_5^-}{\alpha_1} > 0, -\frac{\alpha_5^+}{\alpha_1} \neq -\frac{\alpha_5^-}{\alpha_1} \quad (17d)$$

For short-run parameter estimation of the NARDL model and the accompanying error correction term (ECT), the NARDL model is also expressed in equations (18) and (19) for the following.

$$\Delta LCPI_t = \alpha_0 + \sum_{i=1}^{k-1} \beta_{1i} \Delta LCPI_{t-i} + \sum_{i=0}^{l-1} \left(\beta_{2i}^+ \Delta LPEN_{t-i}^+ + \beta_{2i}^- \Delta LPEN_{t-i}^-\right) + \sum_{i=0}^{m-1} \left(\beta_{3i}^+ \Delta LPF_{t-i}^+ + \beta_{3i}^- \Delta LPF_{t-i}^-\right) + \sum_{i=0}^{n-1} \left(\beta_{4i}^+ \Delta LER_{t-i}^+ + \beta_{4i}^- LER_{t-i}^-\right) + \sum_{i=0}^{p-1} \left(\beta_{5i}^+ \Delta LMS_{t-i}^+ + \beta_{5i}^- \Delta LMS_{t-i}^-\right) + ECT_{t-1} + \mathrm{w}_{1t} \quad (18)$$

with:

$$ECT_{t-1} = LCPI_{t-1} - (\lambda_1^+ LPEN_{t-1}^+ + \lambda_1^- LPEN_{t-1}^- + \lambda_2^+ LPF_{t-1}^+ + \lambda_2^- LPF_{t-1}^- + \lambda_3^+ LER_{t-1}^+ + \lambda_3^- LER_{t-1}^- + \lambda_4^+ LMS_{t-1}^+ + \lambda_4^- LMS_{t-1}^-) \quad (19)$$

The expected value for ECT is between -1 and 0.

The relationship between the ARDL model and quantile regression estimation has also been developed by Cho et al. (2023). The purpose of applying quantile regression is to analyze differences in the influence of independent variables on response variables between quantiles with a model that can overcome the problems of heteroscedasticity and non-normality because it is not sensitive to outliers (Huang et al., 2017). The application of quantile regression is suitable because there are possible differences in the influence of changes in energy prices, food prices, exchange rates, and money supply on CPI at different CPI levels between low CPI (low quantiles), moderate CPI (middle quantiles) and high CPI (upper quantiles). The quantile regression model is generally stated as follows.

$$Q(y|X = x_i; q) = f(\widehat{\beta}; x_i) \quad (20)$$

With probability $\left(y \leq f(\widehat{\beta}; x_i)\right) = q$ and

$$x_i = \sum_{i=1}^{n} x_i^+ + \sum_{i=1}^{n} x_i^- \quad (21)$$

x's are independent variables and y is a response variable.

4. Results and discussion

4.1. Results

A statistical description of the variables analyzed in this study is presented briefly in Table 1. The CPI has a similar statistical figure with a higher mean than the median with global energy and food prices. However, the CPI has the smallest range during the study period. This characteristic indicates a tendency for higher prices to increase in the second half of the study period for CPI, global energy, and food prices.

Table 1. Summary of statistics

Variable	Minimum	Maximum	Mean	Median	Std. Dev.
CPI	41.6400	152.8200	98.4459	97.9150	33.3655
PEN	26.2500	173.4800	86.963	81.4500	36.2373
PF	46.7900	159.0400	91.748	90.5250	26.0480
ER	8,279.00	16,367.00	11,276.37	10,259.00	2,329.571
MS	145,345.0	2,608,797	855,993.6	705,248.0	624,908.0

As a trigger for CPI increases, global energy prices have a relatively high standard deviation, which indicates high price variations or fluctuations. However, energy prices appear more variable than global food prices, with a higher standard deviation. The range of minimum and maximum energy prices is higher than that of food prices. This condition indicates that energy price movements are more volatile than food prices. However, with the same base year, 2010=100, the mean of global food prices is higher than energy prices, so the impact on domestic food prices is also significant. The increase in food prices was contributed mainly by oils and meals, and cereals, while energy prices were mostly contributed by crude oil.

Based on summary statistics, the exchange rate measured in rupiah per US dollar shows high variations with a range of lowest and highest values, where the highest value is almost twice the lowest value. An increase in the exchange rate means a depreciation of the rupiah, and vice versa. During the research period, the exchange rate tended to increase, meaning the rupiah tended to depreciate against the US dollar.

The money supply, measured in billions of rupiah of M1, shows higher variations in the exchange rate with a range of minimum and maximum values, where the maximum value is 17.95 times the minimum value. The median value is far from the average value, so the standard deviation is also very high, close to the median value. This statistical picture indicates that the variation in the money supply is very high. During the research period, there was a tendency to increase the money supply by M1.

Furthermore, in applying the NARDL model, such as in the ARDL model, the characteristics of data stationarity of the variables analyzed in the model need to be tested through the unit root test. Unit root tests apply the Augmented Dickey-Fuller (ADF) test, and DF GLS, which is a modification of the ADF test. The application of the ARDL model can be justified if all variables are stationary at the first level or difference or a combination thereof without any variables being stationary at the second difference. The results of the unit root test on the variables in this research model are presented in Table 2.

The unit root test results test via the ADF and DF GLS tests for all variables are stationary at the first difference or can be expressed as I(1). All variables in the model are I(1) without I(2) so that the NARDL model application can be carried out.

The NARDL model specification in this study positions CPI as an endogenous variable or response variable based on theoretical grounds and empirical studies; meanwhile global energy and food prices, exchange rates and money supply as exogenous variables. By separating the increase and decrease in global energy and food prices, exchange rates and money supply, a model is formulated to capture asymmetry effects into the NARDL model. With a model specification where CPI is the endogenous variable, the selection of the optimum lag is based on the minimum AIC value. The model with the optimum lag which has the minimum AIC value is the selected econometric model because it has the minimum error with the model specifications by theory. The selected model is ARDL(3, 0, 1, 1, 0, 2, 2, 1, 1).

Table 2. Unit root test results

Variable		ADF Test	DF GLS test
In level	LCPI	-1.3896	0.0566
	$LPEN^{+}$	-1.3611	-1.2782
	$LPEN^{-}$	-2.9518	-2.9111*
	LPF^{+}	-1.4201	-1.2661
	LPF^{-}	-2.6218	-2.2636
	LER^{+}	-3.5338**	-2.0086
	LER^{-}	-3.6743**	-0.5116
	LMS^{+}	-1.9799	-1.9818
	LMS^{-}	-3.0726	-1.9393
In first difference	ΔLCPI	-13.0540***	-13.0965***
	$\Delta LPEN^{+}$	-13.2000***	-12.1875***
	$\Delta LPEN^{-}$	-10.0332***	-8.4359***
	ΔLPF^{+}	-10.9556***	-10.2144***
	ΔLPF^{-}	-10.2303***	-10.2189***
	ΔLER^{+}	-12.5601***	-4.38651***
	ΔLER^{-}	-14.2403***	-13.0727***
	ΔLMS^{+}	-4.0294***	-6.4099***
	ΔLMS^{-}	-6.7164***	-9.3188***

*** significant at α = 1 percent; ** significant at α = 5 percent

An essential element in the ARDL and NARDL models is a long-run relationship between the response variable and the independent variables, reflecting the theoretical or expected relationship between variables. A bound test is applied to test whether there is a long-run relationship. The test result via bound tests for the model is presented in Table 3.

Table 3. Bounds test results

F-statistic	Sig.	Lower Bound	Upper Bound	Conclusion
6.3865	10%	1.85	2.85	There is a long-run relationship
	5%	2.11	3.15	
	1%	2.62	3.77	

H_0: No long-run relationships

From the tests carried out through the bounds test, as summarized in Table 3, the F-statistic is significant at = 1 percent to reject the null hypothesis. It can be concluded that the model has a long-run relationship. A long-run relationship exists in the model between CPI and the independent variables, including energy prices, food prices, exchange rates, and the money supply, each increasing and decreasing. The model has a significant long-run relationship at = 1 percent. This conclusion is based on the F-statistic value

exceeding the upper bound, which means bound test results reject the null hypothesis, which states no long-run relationship.

The expected model stability of the selected model based on the CUSUM test is fulfilled. The CUSUM test results depicted graphically do not exceed the significance limit of 5 percent (see Figure 3). This result means that the model chosen as the best model was tested for stability for the specified research period. A model analysis using a quantile regression model approach will complement the discussion of the ARDL model estimation results regarding stability and non-normality issues.

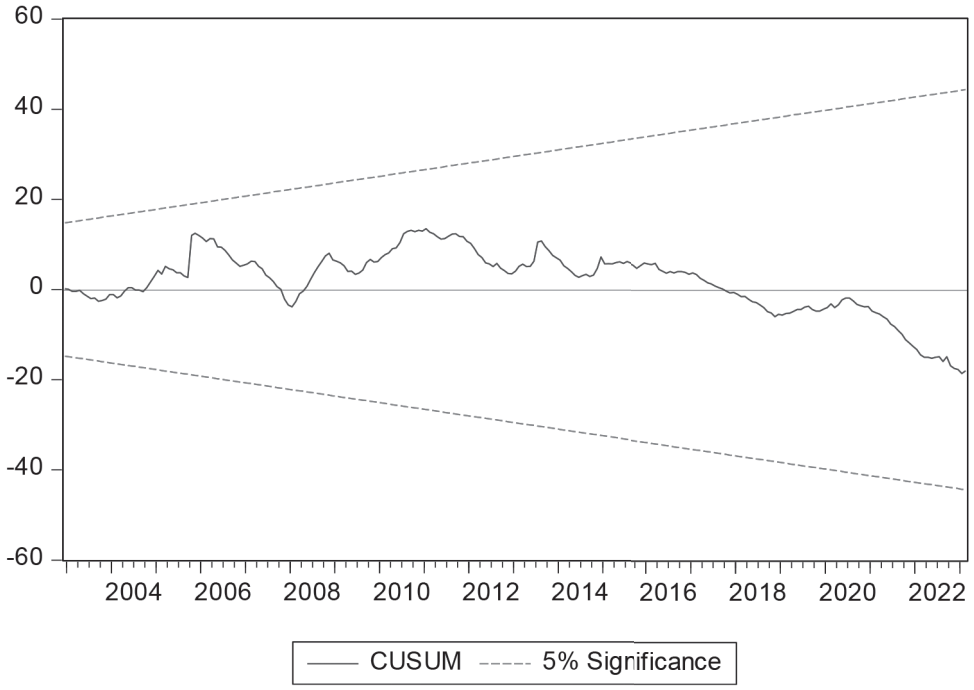


Figure 3. Result of Model Stability Test

Based on the estimates of the best NARDL models, the results of estimating the long-run effects of the model are presented in Table 4. Energy prices affect the CPI positively, but only when energy prices fall significantly reduce prices in the long run. A decrease in energy prices ($LPEN^{-}$) reduces CPI significantly with a larger coefficient than an increase in energy prices ($LPEN^{+}$) at $\alpha = 1$ percent. A decrease in energy prices reduces the CPI, which has a relatively large and significant impact compared to an increase in energy prices which increases the CPI. This result means that a decrease in energy prices impacts deflation, while an increase in energy prices does not significantly cause inflation. Therefore, energy prices have an asymmetric effect on inflation. Meanwhile, global food prices do not significantly influence CPI in the long run, for increases (LPF^{+}) and decreases (LPF^{-}).

Exchange rate has a positive effect on CPI. An asymmetric effect is found in this model where a reduction in the exchange rate (LER^{-}) or appreciation does not significantly reduce

CPI. On the contrary, an increase in the exchange rate (LER^+) or depreciation of the rupiah significantly increases CPI, which means it causes inflation. With α = 1 percent, an increase in the exchange rate or depreciation of the rupiah significantly causes inflation with a more significant coefficient. This result means that rupiah depreciation significantly affects rising CPI more than rupiah appreciation in decreasing CPI. In other words, the depreciation of the rupiah is more significant in causing inflation than the appreciation of the rupiah in causing deflation.

The money supply, as measured by M1, which shows the level of economic liquidity, has a significant impact on increasing the CPI. Monetary expansion, characterized by an increase in the money supply (LMS^+), increases the CPI significantly, which means it causes inflation. Likewise, a monetary contraction indicated by a decrease in the money supply (LMS^-) also significantly reduces the CPI, which means it causes deflation. The difference in coefficients for increases and decreases in money supply indicates a positive asymmetric effect on increases and decreases in CPI.

Table 4. Long-run coefficients

Variable	Coefficient	Conclusion
$LPEN^+$	0.0641	Not significant
$LPEN^-$	0.1775***	Significant at α = 1 percent and in line with expected positive value
LPF^+	0.0647	Not significant
LPF^-	0.0007	Not significant
LER^+	0.8252***	Significant at α = 1 percent and in line with expected positive value
LER^-	0.4690	Not significant
LMS^+	0.5402***	Significant at α = 1 percent and in line with expected positive value
LMS^-	1.0948***	Significant at α = 1 percent and in line with expected positive value

The regression results with the quantile regression model are added to complete the discussion of the long-run NARDL model regression results. The aim is to enrich the discussion by demonstrating that asymmetric effects are possible not only between the effects of increases and decreases in global energy and food prices, exchange rates, and money supply but also differences in effects between CPI levels, which are differentiated between quantiles. Applying quantile regression can also overcome heteroscedasticity and non-normality problems in the model. The regression results with the quantile regression model are presented in Table 5.

The quantile regression with the middle quantile (median) shows that only a decrease in global energy prices significantly affects decreasing CPI and not an increase in energy prices, which increases CPI. These results confirm the estimation results of the NARDL model and show the existence of an asymmetric effect of changes in global energy prices on changes in CPI. Figure 4 shows that in almost all quantiles, increases in energy prices ($LPEN^+$) do not significantly influence the increase in CPI and have low coefficients that are close to zero. Meanwhile, decreases in energy prices (PEN^-) significantly reduce CPI

and have a relatively high coefficient compared to the coefficient for increases in global energy prices. These results confirm the results of the NARDL model that changes in international energy prices have an asymmetric positive influence on CPI in the long run.

Table 5. Regression results of the quantile regression model (Median)

Variable	Coefficient	Conclusion
C	3.6460	
$LPEN^+$	0.0044	Not significant
$LPEN^-$	0.1314***	Significant at α = 1 percent and in line with expected positive value
LPF^+	-0.0362	Not significant
LPF^-	-0.0117	Not significant
LER^+	0.4378***	Significant at α = 1 percent and in line with expected positive value
LER^-	-0.2910***	Significant at α = 1 percent but not in line with expected positive value
LMS^+	0.3011***	Significant at α = 1 percent and in line with expected positive value
LMS^-	0.4845***	Significant at α = 1 percent and in line with expected positive value

The increase in global food prices (LPF^+) did not significantly affect the rise in CPI in all quantiles, with most coefficients below zero. Meanwhile, the decline in global food prices (LPF^-) significantly impacted the decline in CPI only in the upper quantiles, especially the 7th and 8th quantiles. In general, these results also confirm the results of the NARDL model estimation for the insignificant effect of global food prices on CPI for both increases and decreases in the long run.

An increasing exchange rate (LER^+) or depreciation of the rupiah in almost all quantiles, except the first quantile, significantly increases the CPI, which means it causes inflation. The positive coefficients confirm the impact of rupiah depreciation, which can cause inflation as estimated by NARDL, and provide additional information that significant rupiah depreciation causes inflation to occur at almost all CPI levels. Meanwhile, due to the negative coefficients, the appreciation of the rupiah exchange rate (LER^-) did not reduce the CPI significantly as expected. In conclusion, the rupiah exchange rate has an asymmetric effect on the CPI, and an asymmetric exchange rate pass-through occurs. Exchange rate pass-through is only significant when the rupiah depreciates against an increase in CPI.

From the monetary side, a significant increase in money supply (LMS^+) increases the CPI, which means it causes inflation. Likewise, a substantial decrease in money supply (LMS^-) reduces the CPI, which means it causes deflation. With positive coefficients but with a different size, the money supply has an asymmetric effect on CPI, confirming the NARDL model's estimation results. Reducing monetary aggregates through M1 significantly reduces CPI in the long run with a more significant impact than increasing monetary aggregates, which increases CPI.

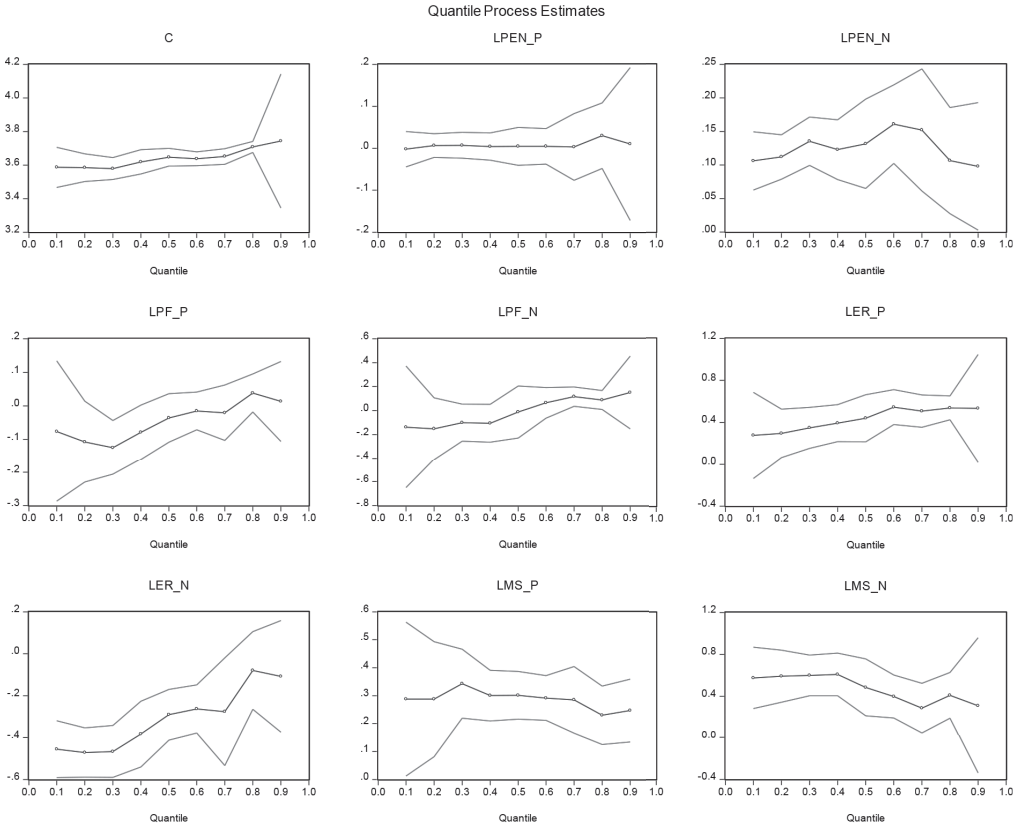


Figure 4. Quantile regression estimation

The short-run effects captured by the NARDL model estimates are presented in Table 6. As expected, the decline in global energy prices ($LPEN^-$) did not significantly reduce the CPI in the short run. Meanwhile, the increase in world food prices (LPF^+) significantly caused inflation in the short run. In the short run, the effect of rupiah depreciation (LER^+) was distributed for two months with a total negative effect on CPI changes and not meeting expectations. On the other hand, the appreciation of the rupiah (LER^-) had effects distributed over two months, but the total effect was positive on changes in CPI. So, the rupiah appreciation significantly reduces CPI or can cause deflation. From the monetary side, only an increase in money supply (LMS^+) significantly influences changes in CPI, while a decrease in money supply (LMS^-) has no significant effect. There is a symmetric effect in the short run where an increase in money supply (M1) significantly increases CPI or causes inflation, while a decrease in M1 does not significantly reduce CPI.

The ECT coefficient in the model is significant, with negative values less than zero and higher than -1. This result means that CPI level will move towards long-run equilibrium when CPI deviations in the short run are corrected.

Table 6. Short-run coefficients

Variable	Coefficient	Conclusion
$\Delta DLCPI_{t-1}$	0.1517**	Significant at α = 5 percent and in line with expected positive value
$\Delta DLCPI_{t-2}$	-0.1138**	Significant at α = 5 percent but not in line with expected positive value
$\Delta LPEN^{-}_{t}$	-0.0138*	Significant at α = 10 percent but not in line with expected positive value
ΔLPF^{+}_{t}	0.0422**	Significant at α = 5 percent and in line with expected positive value
ΔLER^{+}_{t}	-0.0177	Not significant
ΔLER^{+}_{t-1}	-0.0582***	Significant at α = 1 percent but not in line with expected positive value
ΔLER^{-}_{t}	0.0038	Not significant
ΔLER^{-}_{t-1}	0.0656***	Significant at α = 1 percent and in line with expected positive value
ΔLMS^{+}_{t}	0.0547***	Significant at α = 1 percent and in line with expected positive value
ΔLMS^{-}_{t}	-0.0181	Not significant
ECT_{t-1}	-0.0398***	Significant at α = 1 percent and in line with expected value

4.2. Discussion

Global energy prices have asymmetric effects on CPI. The increase in global energy prices, mainly caused by rising oil prices, does not significantly increase the CPI in the long run. The role of energy subsidies, especially fuel and gas subsidies for households, makes it possible to inhibit the significant increase in CPI due to rising global energy prices. The policy simulation in the study conducted by Akhmad et al. (2023) shows that an increase in fuel prices without being supported by an increase in subsidies will impact increasing inflation in Indonesia. Results of the study conducted by Murjani (2022) confirm that energy subsidies significantly reduce CPI in Indonesia in the short and long run. The increase in world oil prices is the most critical contributor to the increase in domestic fuel prices.

On the other hand, a significant decrease in energy prices reduces the CPI in the long run with a coefficient greater than the coefficient for an increase in energy prices. The decline in world energy prices creates favorable conditions for controlling domestic inflation. The empirical finding that a significant effect is only proven for a decrease in global energy prices on a decrease in CPI rather than an increase in energy prices on an increase in CPI, in the long run, is possible because of the nature of asymmetric price rigidity as stated by Levy et al. (2020). The impact of energy subsidies allows prices to be more rigid upward rather than downward. The findings of the asymmetric effect complement the results of research conducted by Bala and Chin (2018), which shows that in the short and long run, the asymmetric effect of changes in energy prices influences domestic inflation.

The estimation results of the ARDL and Quantile Regression models show that overall increases and decreases in world food prices do not significantly increase or decrease CPI in the long run. The role of food subsidies, such as rice subsidies and market operations by BULOG, a state-owned public company engaged in food logistics, helps stabilize food prices so that stable prices can be maintained from increases and decreases in global food prices in the long run. Food subsidies effectively control consumer prices, as supported by a study

by Ginn and Pourroy (2022), which found that food subsidies can reduce inflation volatility. Food subsidies can also create food price rigidity. Meanwhile, food price fluctuations that affect the CPI are also largely caused by domestic factors related to food production and availability disruptions. Therefore, increases and decreases in global food prices do not significantly increase and decrease CPI in Indonesia in the long run. The increase in global food prices significantly increases the CPI in the short run. The primary commodities that Indonesia still imports include wheat, rice, sugar, soybeans, milk, beef, and garlic. Domestic consumption needs cannot be immediately met by production but by imports, allowing the effects of rising global food prices to be passed through to consumer prices in the short run. The finding of this asymmetric effect complements the results of research conducted by Furceri et al. (2016), Samal et al. (2022), and Arintoko et al. (2023) that in addition to the long run, global food prices have a positive impact on domestic inflation in the short run.

Apart from rising global energy and food prices, exchange rate depreciation can also cause import prices to increase, which can further increase the CPI, which means inflation. Oil and food import activities when the rupiah depreciates will significantly impact the increase in domestic food prices contributing the increase in CPI. The exchange rate is the most dominant and considerable factor causing inflation in this research and confirms previous studies, including those by Fetai et al. (2016) and Sek (2022). In the long run, rupiah appreciation does not significantly reduce CPI, while depreciation significantly increases CPI. Therefore, there is an asymmetric exchange rate pass-through in the long run. Depreciation of the rupiah rather than appreciation, which is passed on to the CPI through import prices, which is usually called asymmetric exchange rate pass-through, has been widely proven in several previous studies, including research by Kassi et al. (2019), Musti (2020), and Fandamu et al. (2023).

Our study uncovers asymmetric exchange rate effects in the short run. Unlike the long run, a significant appreciation of the rupiah leads to a reduction in CPI, while depreciation does not show a substantial increase in CPI. Rupiah appreciation has a more pronounced impact on decreasing CPI than depreciation's impact on increasing CPI. Therefore, we can empirically demonstrate the asymmetric effect of exchange rates on CPI in both the short and long run, albeit under different circumstances.

Money supply by M1 has a significant effect on CPI both when M1 increases and decreases. A significantly growing M1 increases the CPI in the long run, while a diminishing M1 decreases the CPI. This indication shows that inflation as a monetary phenomenon is supported in this study. In the long run, an increase in the money supply increases the CPI, which means it causes inflation. Conversely, a decrease in the money supply reduces the CPI. Increases and decreases in money supply due to adjustments through monetary policy significantly affect CPI. Therefore, inflation is directly related to monetary aggregates, which increase in the long run. These results confirm previous empirical findings, including studies conducted by Roshan (2014), Kugler and Reynard (2022), and Madurapperuma (2023). Meanwhile, in the short run, only an increase in M1 causes a significant rise in CPI, while a decrease in M1 does not. The implication is that when the money supply increases, the monetary authority will focus on monetary control to stabilize prices in the short run.

5. Conclusions

This research aims to analyze the asymmetric influence of changes in global energy and food prices and monetary variables, including the exchange rate and money supply, on the CPI. Overall, the research results summarize that global energy prices have an asymmetric positive impact on CPI in the long run. The increase in energy prices does not have a significant effect on increasing the CPI. On the other hand, the decline in global energy prices significantly reduces the CPI. Energy subsidies to households have a direct impact by inhibiting increases in consumer prices amidst rising global energy prices, which have the potential to be passed through to consumer prices.

The asymmetric influence of food prices on CPI only occurs in the short run. Food subsidies allow domestic consumer prices to experience rigidity so that they have no significant impact on CPI, either increasing or decreasing in the long run. In the short run, global food prices significantly increase the CPI.

The exchange rate has a positive influence on CPI. The asymmetric effect of the exchange rate is characterized by a more significant impact of rupiah depreciation on changes in CPI in the long run. Depreciation of the rupiah increases import prices, which is then transmitted to an increase in the CPI, which causes inflation. Meanwhile, in the short run, the appreciation of the rupiah significantly impacted the decline in CPI. The impact of the exchange rate on CPI has a significant positive effect. The effect of the exchange rate also has a significant influence with differences in coefficients between various CPI levels identified through quantile regression.

Money supply as a monetary aggregate through M1 is proven to have a significant positive influence on CPI in the short and long run, according to theoretical expectations. The increase in CPI means that inflation is still a monetary phenomenon, despite other causal factors.

The monetary authority is the monetary policy maker that implements its policies to control inflation and does not only focus on the targeted monetary aggregate. However, in implementing monetary policy, the central bank must also pay attention to the causes of inflation from the supply side. Inflation originating from the supply side is strongly influenced by changes in global energy, food prices, and exchange rates. The synergy of policies and inflation control efforts carried out by the central bank is essential. This plays a vital role by increasingly coordinating and communicating with the central and regional governments to stabilize inflation. Efforts that can be increased could be more focused on the availability and adequacy of energy and food supplies. Apart from that, efforts are also needed to reduce dependence on food and energy imports to minimize risks when there is an increase in global energy and food prices. Subsidies are essential to prevent rising inflation, but they must also be accompanied by efforts to provide renewable energy as an alternative for future energy consumption. Finally, it is essential for exchange rate stabilization efforts to remain focused on controlling and stabilizing import prices.

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Modelling the Relationship Between Public Expenditure, Tax Revenue and Economic Growth in Türkiye Using the AARDL Approach

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Abstract. This study aims to investigate the macroeconomic impact of fiscal policy in Türkiye, where fiscal policy faces several challenges. Using annual time series data from 1980 to 2021, we examine the impact of tax and public expenditure subcomponents on GDP using the augmented autoregressive distributed lag (A-ARDL) bound test approach proposed by Sam et al. (2019). The A-ARDL test results indicate that tax revenue has a positive impact on economic growth in the short run, while tax revenue has a negative impact on economic growth in the long run. Furthermore, we conclude that increases in current and investment expenditures have a positive impact on economic growth in the short and long run, while increases in transfer expenditures have a negative impact on economic growth in the short run.
Keywords: Fiscal policy, Tax revenue, Public expenditure, Economic growth, Türkiye

1. Introduction

Historically, there have been periods when the importance of fiscal policy as a policy instrument has increased or decreased. For example, with the stock market crash and the Great Depression, policymakers pushed for a more active role of the state in the economy (Horton & El-Ganainy, 2019). As a result, market failures allowed for the implementation of fiscal policy, which was Keynes's primary tool for the interventionist economic approach. However, after the 1970 oil crisis, both advanced and emerging economies faced the problem of fiscal

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imbalances and the debt-to-GDP ratio rose above 100 percent in some countries that financed their budget deficits by borrowing (Karagöz & Keskin, 2016, p. 409). This large fiscal shock forced policymakers to answer various questions about how to solve the problems. During this period, when the concept of government failure began to be scrutinized in academic circles (Buchanan, 1983; Krueger, 1990), a negative perspective on the implementation of fiscal policy emerged. The negative view of fiscal policy was not limited to the 1970s, but continued until the early 2000s (Dullien, 2012, p. 7).

Despite these changes, which reduced the role and influence of government in the economy, many countries resumed more active fiscal policies when the global financial crisis threatened a global recession (Horton & El-Ganainy, 2019). For instance, during the economic crisis of 2008, governments intervened to support financial systems, stimulate economic growth, and mitigate the impact of the crisis on vulnerable populations. This made the role and objectives of fiscal policy particularly important. Indeed, in the statement following their April 2009 summit in London, G20 leaders declared that they had embarked on an unprecedented and coordinated fiscal expansion (Horton & El-Ganainy, 2019). As fiscal stimulus expanded and was on the agenda of all countries, it was debated whether tax cuts or spending increases would be a better solution for these countries (Alesina & Ardagna, 2009).

After the 2008 crisis, the expansion of fiscal stimulus was supported not only by national and international monetary and fiscal authorities but also by economists. Indeed, the results of the policies implemented confirmed the effectiveness of fiscal policy in stabilizing aggregate demand, especially during periods of extraordinary economic weakness (Dullien, 2012). Similarly, the changes in fiscal policy due to the coronavirus pandemic (COVID-19), which started in 2019, were notable (Weinstock, 2021). In response to pandemics that have historically caused severe recessions, many countries and policymakers have resorted to active fiscal policies or offered various fiscal policy packages (Afonso & Coelho, 2023; Boug et al., 2023; Chudik et al., 2021). As a result, even if the fiscal consolidation approach is insufficient, fiscal policy has been reinvigorated in the global discourse over the last quarter century (Woldu & Kano, 2023) and finding an effective fiscal policy mix is more important today than ever (Donadelli & Grüning, 2021). In this subject, information on the economic effects of fiscal policy is an important element to guide the achievement of fiscal sustainability and should be taken into account in the design and recommendation of public policies (Sosvilla-Rivero & Rubio-Guerrero, 2022). Therefore, in this study, which aims to examine the effects of tax and expenditure policies, we consider Türkiye as an interesting and important example. This is because Türkiye, which struggled with high budget deficits in the 1990s, managed to create a strong fiscal structure by ensuring fiscal discipline in the early 2000s. However, due to the policies implemented in recent years, fiscal policy in Türkiye has faced various challenges and the macroeconomic effects of fiscal policy have become an important topic of debate.

Our main hypothesis is that fiscal policy has a significant effect on GDP growth in Türkiye, but this effect differs significantly across the subcomponents of fiscal policy instruments. Within the scope of this hypothesis, the main motivation and objective of

this study is to empirically determine whether fiscal policy is effective in stimulating economic activity in Türkiye and, if so, the strength and duration of these effects. In this sense, specific questions such as whether the subcomponents of fiscal policy instruments have different effects in promoting economic growth and which of the subcomponents of fiscal policy instruments have stronger effects on economic growth constitute the research questions of our study. The answers to these questions will contribute to the ongoing debate on the role of fiscal policy. Based on the basic information provided, the sections of the study after the introduction are organized as follows. The empirical literature related to previous studies is presented in Section 2. The data set, model and methodology are indicated in Section 3. Section 4 presents the empirical results. The paper ends with conclusions and policy recommendations.

2. Literature Review

Fiscal policy, in which governments can influence economic activity by using public expenditures, tax revenues or both (Alves & Palma, 2023; Karaş & Karaş, 2023; Weinstock, 2021), has recently attracted attention. This is particularly evident during economic cycles (Caldara & Kamps, 2017; Ramey & Zubairi, 2018; Terra et al., 2021). On the other hand, regardless of business cycles, many countries resort to contractionary fiscal policy measures to reduce public debt levels that increase as a result of fiscal expansion (Alesina & Ardagna, 2009; Alesina et al., 2015; Arizala et al., 2021; Christelis et al., 2019; Rompuy, 2021; Woldu & Kano, 2023). Despite the role of fiscal policy, there is no consensus on the size and effectiveness of the subcomponents of fiscal instruments and there is still debate on the implementation of fiscal policy from a macroeconomic perspective (Fukuda, 2023; Gootjes & Haan, 2022; Heimberger, 2023; Mawejjeve & Odhiambo, 2022).

The impact of fiscal policy is assessed by Blanchard and Perotti (2002) using data on the elasticity of fiscal variables. They conclude that expansionary fiscal shocks boost output, have positive effects on private consumption, and negatively affect private investment. Castro (2006), who analyzed the macroeconomic effects of fiscal policy in Spain with data for the period 1980–2001, concluded that increases in public expenditures have a positive effect on GDP in the short run. However, this effect was found to be negative in the medium and long run. Pointing to the non-Keynesian effects of fiscal policy, the article showed that a fiscal consolidation based on expenditure cuts can have an expansionary effect on economic activity. Giordano et al. (2007) found in a related study that public spending has a positive and long-term impact on output in Italy. The SVAR method is used by Mountford and Uhlig (2009) to analyze the effects of fiscal policy in the United States using quarterly data covering the years 1955–2000. According to the study's primary findings, tax cuts financed by deficits are the best fiscal policy for improving GDP and stimulating the economy. However, this research illustrates the neoclassical view of government intervention in the economy because of the long-term costs of fiscal expansion with public expenditures. Conversely, Jawaid et al. (2010) find that the Keynesian

perspective is reflected in these effects and that fiscal policy is a crucial macroeconomic policy tool for supporting output growth in Pakistan.

Parkyn and Vehbi (2014) examine the impact of public expenditure and revenue on output in New Zealand. They find that public expenditure shocks have a small positive effect on output in the short run but lead to lower output in the medium and long run. Although the effect of changes in tax revenue on GDP is less pronounced, it is found to be moderate. Therefore, the researchers found that the impact of discretionary fiscal policy on GDP is pro-cyclical. Using data from 1970 to 2009 for 20 OECD countries, Yang et al. (2015) conclude that short-term fiscal adjustments always have a contractionary effect on economic activity. Regarding the function of the composition of the fiscal adjustment, they find that output reductions from expenditure-based fiscal adjustments are smaller than those from tax-based fiscal adjustments. However, theoretical models suggest that households' marginal propensity to consume may sometimes have binding borrowing constraints and may be asymmetric in the face of temporary changes in income or expenditure (Sosvilla-Rivero & Rubio-Guerrero, 2022). In this context, Bunn et al. (2018) find that households' marginal propensity to consume is higher under negative income shocks than under positive shocks. This implies that a large part of the expenditure asymmetry can be explained by households' balance sheet characteristics such as high debt levels, small liquidity buffers, concerns about the credit, and the possibility of low future income.

Pula and Elshani (2018) for Kosovo economy and Arin et al. (2019) for OECD countries conducted similar studies and found results supporting the Keynesian view. In another study, Afonso and Aubyn (2019) examined the macroeconomic impact of public and private investment spending based on data from 17 OECD countries in 1960–2014, using VAR analysis. Using impulse response functions, the researchers found that public investment spending has a contractionary effect in Finland, the UK, Sweden, Japan, and Canada, and a positive effect in most other countries. The study also found empirical evidence that public investment spending crowds out private investment spending. In terms of expenditures, current spending boosts economic growth, according to the findings of the Selvanathan et al. (2021) study. In contrast to this study, Onifade et al. (2020) find that current expenditures have strong and opposite effects on economic growth.

Sosvilla-Rivero and Rubio-Guerrero (2022) examined the short- and long-term symmetric and asymmetric effects of fiscal policy on output. Using quarterly data from 1980 to 2020, they find that while reductions in public spending or increases in net incomes reduce the short- and long-term effects on growth, increases in public spending and decreases in net incomes contribute to Spain's economic growth in the short and long run. Golpe et al. (2023), in their study with quarterly data for the period 1990–2019 for 12 EU countries, found that monetary policy plays a leading role in economic growth in the complex economic system, while aggregate public expenditures are an important instrument supporting the driving force of fiscal policy. Amri et al. (2023) used a panel data set of 24 Indonesian provinces from 2006 to 2015 to apply a dynamic GMM model to estimate the effect of public expenditure on growth. The researchers found evidence that public spending significantly boosts economic growth. However, it turned out that

local tax efforts had a negative impact on growth in the economy. However, the results of the study conducted by Alves and Palma (2023) with the Mixed Frequency Vector Autoregressive (MIDAS-VAR) model for Brazil showed that public expenditures have no significant effect on real GDP growth.

Turning to the case of Türkiye, there have been many studies on the relationship between fiscal policy and GDP growth. However, the limited number of studies with subindicators of fiscal policy instruments suggests that more studies are needed for more specific results. Using data for Türkiye from 1998 to 2016, Karahan and Çolak (2019) show that public spending has a positive impact on economic growth in the short run and a negative impact in the long run. From an economic policy perspective, there is significant evidence that expansionary fiscal policy can support economic growth in the short run. Arteris et al. (2021) conducted a different study and analyzed the comparative effectiveness of monetary and fiscal policy for Türkiye. Although both fiscal and monetary policies can affect output growth to different degrees, empirical evidence suggests that monetary policy has a greater impact on output growth. The results on fiscal policy show that direct and indirect taxes negatively effect output growth in the short and long term, while public consumption and investment expenditures have a positive effect on output. Özer and Karagöl (2018) analyzed the effect of monetary and fiscal policies on growth in the Turkish economy for the period 1998–2016 and found that monetary policy has only a short-term effect on growth, while fiscal policy affects growth in the long run and causes growth. Duran (2022), using the ARDL bounds test for the period 1975–2020, finds that the effect of subcomponents of public expenditure on economic growth in Türkiye is positive. In summary, it is noted that there is disagreement in Türkiye's empirical literature on the topic.

3. Data set, model and methodology

3.1. Data and model

The study examines the effects of fiscal policy in Türkiye over the period 1980–2021. Accordingly, Table 1 shows the variables used in the study and the sources from which the data were compiled. The econometric model used in the study is based on the Keynesian expenditure model. John Maynard Keynes created a simplified version of the economy known as the Keynesian Expenditure Model or Aggregate Expenditure Model. The main focus of this model is the relationship between the level of aggregate expenditure and the level of real GDP. In an open economy, *consumption (C), investment (I), government spending (G), and net exports (NX)* are the basic expenditure components in the model (Keynes, 1936). The sum of government spending, net exports, investment, and consumption is the final planned total expenditure in the economy. When planned total expenditures *(AE)* and total income *(Y)* are equal, macroeconomic equilibrium is reached. In this case, for the equilibrium condition:

$$AE = Y = (C_0 + c(Y - T)) + I_0 + G_0 + (X - M) \quad (1)$$

In summary, the equilibrium level of real GDP in the Keynesian Expenditure Model is represented by this equation. It indicates that the equilibrium GDP is determined by *autonomous consumption (C_0), marginal consumption propensity (C), autonomous investment (I_0), autonomous government spending (G_0), taxes (T),* and *net exports (NX)*. This means that a change in taxes or autonomous expenditures (like government spending, investment, etc.) will result in a change in national income. In this theoretical framework, we generate our econometric model in which the net export variable is not utilized as follows:

$$GDP_t = \alpha_0 + \alpha_1 TR_t + \alpha_2 CE_t + \alpha_3 IE_t + \alpha_4 TE_t + u_t \quad (2)$$

In Eq. (2), the subscript states the time period. In addition, α_0 shows a constant term, while u_t refers to the error term. In addition, we employed *Gross Domestic Product (GDP)* as the dependent variable, while using *Tax Revenues (TR), Current Expenditure (CE), Investment Expenditure (IE),* and *Transfer Expenditure (TE)* as independent variables.

Table 1. The description of variables

Variables	Unit	Source
Gross Domestic Product (GDP)	Annual Growth Rate (%)	The World Bank
Tax Revenues (TR)	Share of in GDP (%)	Directorate for Strategy and Budget
Current Expenditure (CE)	Share of in GDP (%)	
Investment Expenditure (IE)	Share of in GDP (%)	
Transfer Expenditure (TE)	Share of in GDP (%)	

3.2. Methodology

3.2.1. Unit root test

As is known, traditional unit root tests such as Augmented Dickey–Fuller (ADF) (1979) and Phillips–Perron (PP) (1989) are linear traditional unit root tests that do not take into account structural breaks. The Fourier ADF test developed by Christopoulos and Leon Ledesman (2010), which can be considered one of the current unit root tests modelling structural breaks in series with trigonometric terms, was used. The main advantage of this test is that it allows for smooth transitions as well as structural changes. Fourier ADF test statistics are calculated as follows (Christopoulos & Leon-Ledesman, 2010):

$$y_t = \delta_0 + \delta_1 \sin\left(\frac{2\pi kt}{T}\right) + \delta_2 \sin\left(\frac{2\pi kt}{T}\right) + v_t \quad (3)$$

Here, k denotes the frequency number of the Fourier function, t denotes the trend, and T states the number of observations. The test statistic is calculated in three steps.

In the first stage, the appropriate frequency k* is determined. Thus, the nonlinear deterministic component in the above model will be determined by choosing the optimal k among k values between 1 and 5, which will be the value that minimizes the residual sum of squares through the least squares estimator.

$$\hat{v}_t = y_t - \left[\hat{\delta}_0 + \hat{\delta}_1 sin\left(\frac{2\pi k^* t}{T}\right) + \hat{\delta}_2 sin\left(\frac{2\pi k^* t}{T}\right)\right] \quad (4)$$

In the second stage, the least squares residuals in the first stage are tested for unit root. Three separate models with the following linear and nonlinear structure are proposed:

$$\Delta v_t = \alpha_1 v_{t-1} + \sum_{j=1}^{p} \beta_j \Delta v_{t-j} + u_t \quad (5)$$

$$\Delta v_t = \rho v_{t-1}(1 - \exp(-\theta \Delta v_{t-i}^2)) + \sum_{j=1}^{p} \alpha_j \Delta v_{t-j} + u_t \quad (6)$$

$$\Delta v_t = \lambda {v^3}_{t-1} + \sum_{j=1}^{p} \beta_j \Delta v_{t-j} + u_t \quad (7)$$

Here θ>0 and u_t represents the error term. If the null hypothesis stating the existence of a unit root is rejected in the second stage, that is, if the series is stationary, the third stage is started. If the null hypothesis is rejected, it is concluded that the series is stationary around the structural deterministic function (Christopoulos & Leon-Ledesman, 2010).

3.2.2. Augmented ARDL method

ARDL cointegration test, unlike traditional cointegration tests, provides analysis for variables with different degrees of stationarity (Pesaran & Shin, 1995; Pesaran et al., 2001). The ARDL test requires that the dependent variable I(1) and the independent variables I(0) or I(1) be stationary (Pesaran et al., 2001). However, the augmented ARDL (A-ARDL) method introduced by Sam et al. (2019) does not require the dependent variable to be stationary at I(1). To implement the ARDL model in cases where the dependent variable is stationary, McNown et al. (2018) and Sam et al. (2019) introduced a new F-test for lagged independent variables. Therefore, it can be utilized especially when the dependent variable is stationary at I(0) (Sam et al., 2019). Three tests (F bounds test statistics, t bounds test statistics, the Exogenous F-Bound) are employed for A-ARDL method. When these three tests are statistically significant together, there is a cointegration relationship between the variables. We established the ARDL model as follows.

$$\begin{aligned} \Delta GDP_t = \beta_0 + \sum_{i=1}^{k} \beta_1 \Delta TR_{t-1} + \sum_{i=0}^{l} \beta_1 \Delta CE_{t-1} + \sum_{i=0}^{m} \beta_2 \Delta TE_{t-1} + \sum_{i=0}^{n} \beta_3 \Delta IE_{t-1} \\ + £_1 TR_{t-1} + £_2 CE_{t-1} + £_3 TE_{t-1} + £_4 IE_{t-1} + u_t \end{aligned} \quad (8)$$

In Eq. (8), a_0 denotes the constant term, while Δ denotes the difference operator, and u_t indicates the error term, respectively. k, l, m, and n terms denote optimal lag length. The null and alternative hypotheses regarding the ARDL bounds test are presented below.

H_0: £$_1$ = £$_2$ = £$_3$ = £$_4$ = 0 *(No cointegration relationships existed between variables)*
H_1: £$_1$ = £$_2$ = £$_3$ = £$_4$ ≠ 0 *(Cointegration relationships existed between variables)*

In Eq. (8), £$_1$, £$_2$, £$_3$, £$_4$ denote the long-run paramaters. However, in Eq. (9), the short-run and error correction model (ECM) is given below:

$$\Delta GDP_t = \beta_0 + \sum_{i=1}^{k} \beta_1 \Delta TR_{t-1} + \sum_{i=0}^{l} \beta_2 \Delta CE_{t-1} + \sum_{i=0}^{m} \beta_3 \Delta TE_{t-1} + \sum_{i=0}^{n} \beta_4 \Delta IE_{t-1} + \varrho_1 ECM_{t-1} + u_t \quad (9)$$

In Eq. (9), β_1, β_2, β_3, and β_4 state the short-run parameters, while ECM_{t-1} denotes the error correction term with a lagged, and ϱ_1 denotes the error correction paramater. The fact that the coefficient of ECM_{t-1} is statistically significant and has a negative sign means that any long-run disequilibrium between the dependent variable and a set of independent variables will converge back to the long-run equilibrium association.

4. Empirical results

Table 2 provides the statistical values of the variables used in the study. It appears that the mean of GDP is 4.59%, the mean of TR is 13.43%, the mean of CE is 7.23%, the mean of TE is 10.99% and the mean of IE is 1.78%. On the other hand, the median of GDP is 5.03%, the median of TR is 14.93%, the median of CE is 7.72%, the median of TE is 11.50%, and the median of IE is 1.67%. In addition, the maximum value of GDP is 11.35%, while the minimum value of GDP is -5.75%. The maximum value for TR is 18.01%, while the minimum value for TR is 7.85%. The maximum value of CE is 8.83%, while the minimum value of CE is 4.33%. The maximum value of TE is 22.80%, while the minimum value of TE is 3.79%. The maximum value of IE is 2.81%, while the minimum value of TR is 0.85%. The JB normality distribution results of the variables reveal that the variables have a normal distribution except for the TR and CE variables.

Table 2. Descriptive Statistics of tha data

	GDP	TR	CE	TE	IE
Mean	4.59	13.43	7.23	10.99	1.78
Median	5.03	14.93	7.72	11.50	1.67
Maximum	11.35	18.01	8.83	22.80	2.81
Minimum	-5.75	7.83	4.33	3.79	0.85
Std. Dev.	4.31	3.69	1.37	4.93	0.47
Skewness	-0.77	-0.25	-0.87	0.42	0.10
Kurtosis	2.96	1.37	2.47	2.58	1.99
Jarque-Bera	4.17	5.05	5.90	1.54	1.83
Probability	0.12	0.07	0.05	0.46	0.39

The quantile distributions of the variables in Figure 1 also indicate that there is no difference in the geometric scale of the variable distributions. Therefore, the series are used in their raw form and a linear model is fitted. Figure 2 also presents a graphical view of the variables.

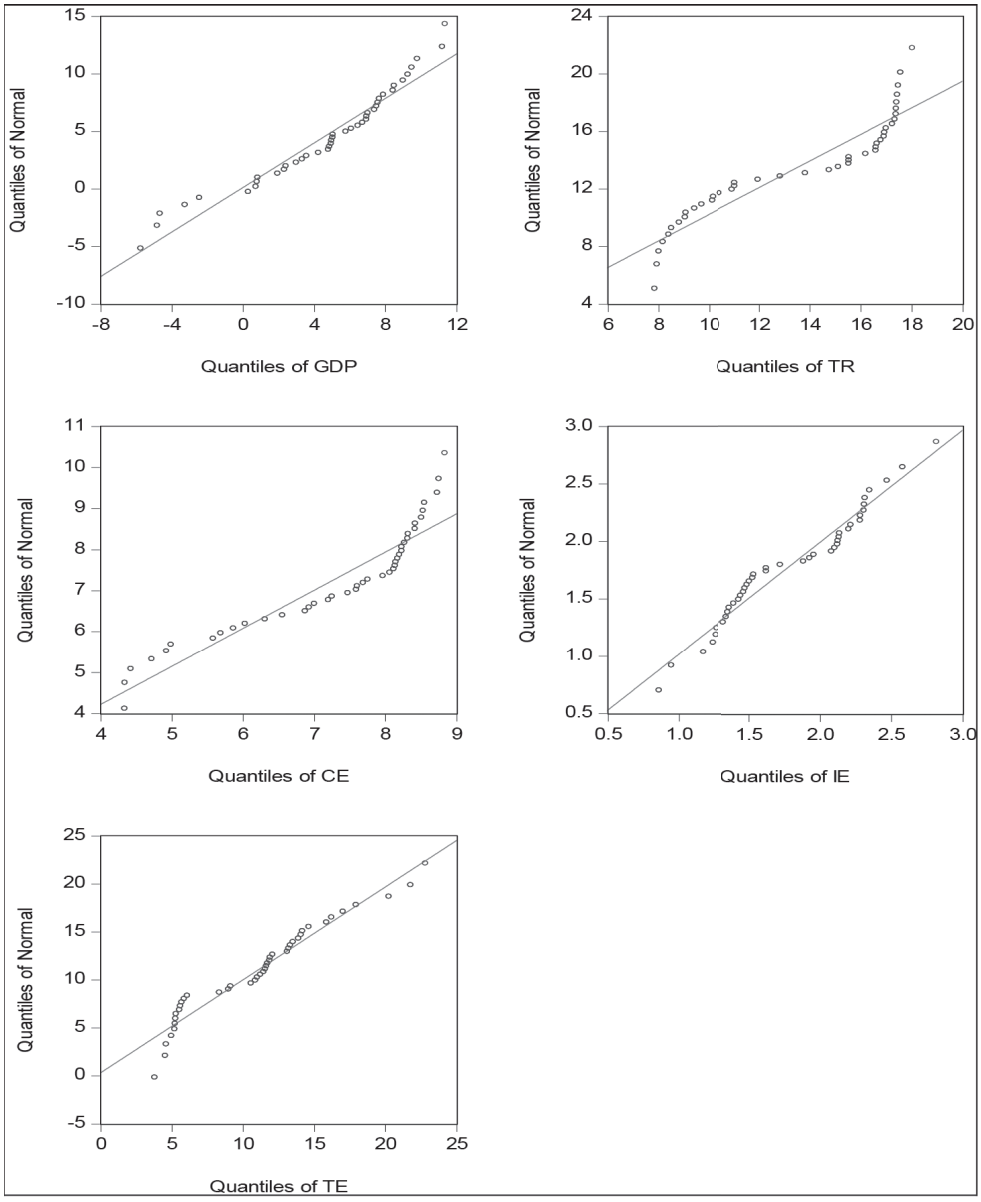

Figure 1.

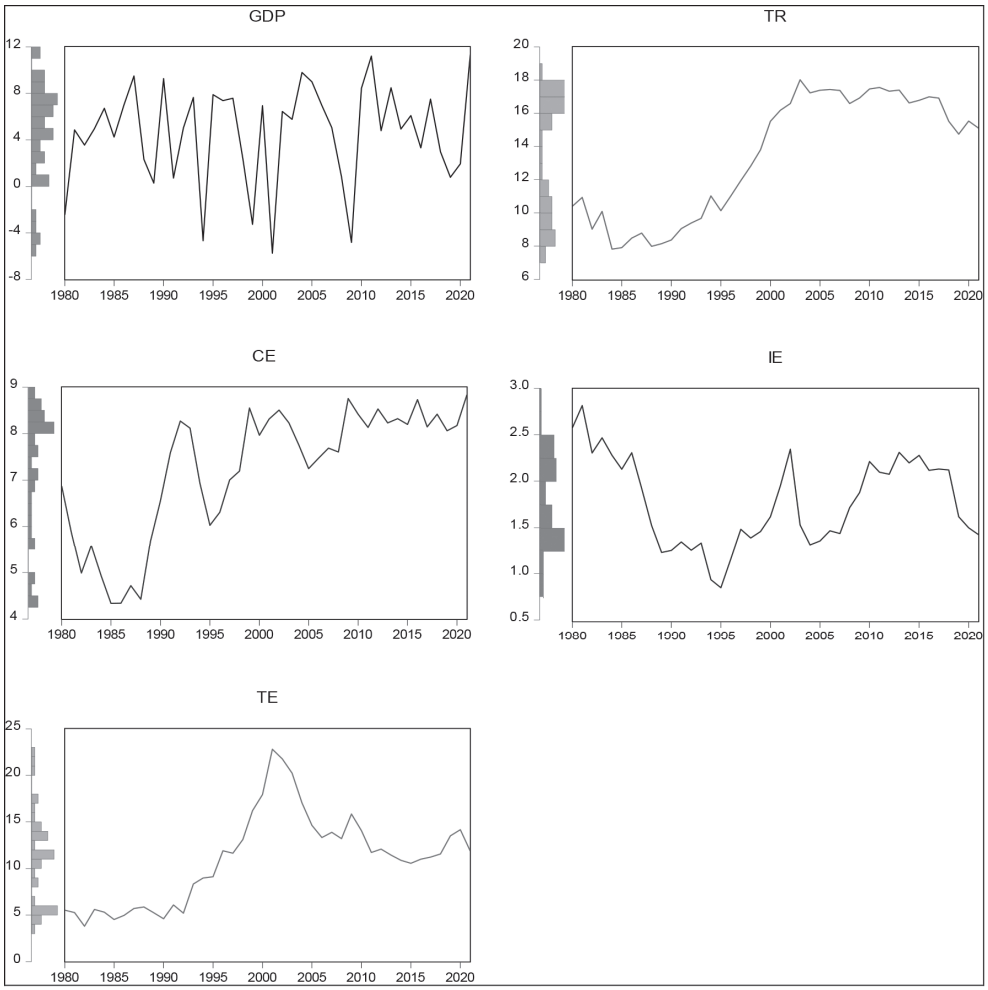

Figure 2. Graphical view of variables

4.1. Unit root test findings

In this study, traditional unit root tests (ADF and PP) were first used to measure the level of stationarity of the series. According to this, as seen in Table 3, the null hypothesis is rejected for both the constant model and the constant and trend model for the dependent variable used. In other words, GDP is stationary at the level values of the variable. Table 3 indicates that the independent variable CE is stationary at level values for the model with trend and constant. Apart from this, the other independent variables became stationary after taking the first difference for both the model with constant and the model with constant and trend. In summary, our dependent variable is stationary at I(0) and our independent variables are stationary at I(0) and I(I). Moreover, ADF and PP unit root test results are consistent with our Fourier ADF unit root test results indicated in Table 4. In line with

these test results, it is appropriate to apply the A-ARDL test method proposed by Sam et al. (2019) in the advanced stages of our study.

Table 3. ADF and PP unit root test results

Level			**The first differences**		
Panel A. ADF Unit Root tests	***C***	***C+T***		***C***	***C+T***
Variables	**t-Statistic**	**t-Statistic**	**Variables**	**t-Statistic**	**t-Statistic**
GDP	-6.85***	-6.78***	***ΔGDP***	-	-
TR	-0.87	-0.9563	***ΔTI***	-6.71***	-6.64***
CE	-1.22	-3.20*	***ΔCE***	-5.54***	-
IE	-2.15	-2.11	***ΔIE***	-6.09***	-6.09***
TE	-1.36	-1.12	***ΔTE***	-4.97***	-4.98***
Panel B. PP unit root tests	***C***	***C+T***		***C***	***C+T***
Variables	**t-Statistic**	**t-Statistic**	**Variables**	**t-Statistic**	**t-Statistic**
GDP	-7.39***	-7.30***	***ΔGDP***	-	-
TR	-0.97	-1.31	***ΔTI***	-6.82***	-6.75***
CE	-1.43	-3.10	***ΔCE***	-5.52***	-5.45***
IE	-2.18	-2.14	***ΔIE***	-6.09***	-6.09***
TE	-1.54	-1.46	***ΔTE***	-5.01***	-5.01***

Note. *, **, and *** denote the significance level at the 10%, 5%, and 1%, respectively.

Table 4. Fourier ADF unit root test results

	Constant				**Constant and trend**			
	FADF	**F(k)**	**k**	**optimallag**	**FADF**	**F(k)**	**k**	**optimallag**
GDP	-5.806***	2.44	5	1	-5.71***	2.31	5	1
TR	-0.971	253.07	1	1	-2.80	125.67	1	1
CE	-2.087	20.30	1	1	-2.78	11.62	4	1
IE	-2.658	15.40	1	1	-3.49	44.42	1	1
TE	-2.217	44.51	1	1	-2.61	29.45	1	1

Note. *** denotes the significance level at the 10%. For critical values, we referred to the work of Christopoulos and Leon-Ledesma (2010).

4.2. Augmented ARDL test findings

In particular, the A-ARDL procedure is applied when the dependent variable is I(0). In classical ARDL cointegration tests, ‘‘F’’ and ‘‘t’’ bound tests are employed. However, the Exogenous F-Bounds test used in the AARDL method only considers the lagged value of the independent variable(s). In this context, Table 5 indicates the F bounds test

statistics ($F^{III}_{overall}$), the t bounds test statistics (t^{III}_{DV}), and the Exogenous F-Bound test (F^{III}_{IDV}). Accordingly, we reach $F^{III}_{overall}$=14.83, and t^{III}_{DV}= -7.77. These values are greater than the critical values proposed by Narayan (2005) and Pesaran et al. (2001) at the 1% significance level. Therefore, according to the F-Bounds and t-Bounds test results, the variables are cointegrated at the 1% significance level. Additionally, in Table 5, it is indicated that the Exogenous F-Bound test statistic is 7.58. It is shown that this test statistic is larger than the critical values proposed by Sam et al. (2019). Therefore, the null hypothesis, stating that there is no cointegration, is rejected. That is, we determine that there is cointegration relationships between variables. Table 5 also shows the results of the diagnostic tests. Accordingly, the autocorrelation problem, which refers to the existence of a relationship between the error terms, is examined first. For this purpose, the Breusch–Godfrey serial correlation test was used. The null hypothesis of this test is

Table 5. F-Bounds, t-Bounds, Exogenous F-Bounds, and Diognastic test results

Model	**The Estimated Model**	**Tests**	**Critical Values**	
GR= f(TR, CE, IE, TE)	(2, 3, 4, 3, 4)		Narayan (2005) (k=1, N=40)	
		$F^{III}_{overall}$ = 14.83***	10%	5.00
			5%	6.16
			1%	8.82
		t^{III}_{DV} = -7.77***	Pesaran et al. (2001) (k=1, N=40)	
			10%	-2.91
			5%	-3.22
			1%	-3.82
		F^{III}_{IDV} = 7.58**	Sam et al. (2019) (k=1, N=40)	
			10%	5.37
			5%	7.41
			1%	12.40
Diognastic tests	Test Statistics	Critical Values		
χ^2_{Auto}:	2.70	0.25		
χ^2_{Hetero}:	0.82	0.66		
$\chi^2_{JB\ Norm}$:	2.01	0.36		
χ^2_{Ramsey}:	0.90	0.38		
Cusum	Stability			
CusumSQ	Unstability			

Note. $F^{III}_{overall}$ states overall F statistics for unrestricted intercepts, no trends. Additionally, t^{III}_{DV} indicates t-statistics for the dependent variable for unrestricted intercepts, no trends; while F^{III}_{IDV} means F statistics for the independent variable for for unrestricted intercepts, no trends. *, **, and *** denote the significance level at the 10%, 5%, and 1%, respectively.

that there is no relationship between the error terms, and the alternative hypothesis is that there is a relationship between the intertemporal error terms. The null hypothesis is not rejected according to the test statistics (2.70) and critical values (0.25) of the relevant test. Therefore, it is concluded that there is no autocorrelation problem in the estimated model. The Breusch–Pagan–Godfrey test was used to test whether the variance of the error term was affected by changes across observations. While the null hypothesis of this test states the existence of homoskedasticity, the alternative hypothesis states the existence of heteroskedasticity. According to the test statistics and critical value results of the relevant test, the null hypothesis is not rejected. In other words, the error term of the established model has homoskedasticity. We used the Jarque–Bera test for normality assumption. This test tests whether the error terms are normally distributed. The null hypothesis of the test is that the error term is normally distributed and the alternative hypothesis is that the error term is not normally distributed. Accordingly, the Jarque–Bera test value is 2.01 and the probability value is 0.36. This result indicates that the null hypothesis is not rejected, i.e. the error term is normally distributed. Finally, the Ramsey Regression Equation Specification Error Test (RESET) test determines whether there is a model specification error. Ramsey Reset test results proved that the null hypothesis stating that there is no model specification error was not rejected. The Cusum and Cusum SQ tests provide information on the stability of the established model. Figure 3 illustrates that the Cusum test revealed that the model was stable, while the Cusum SQ test revealed that there was a structural change in 2016. However, when the date of the structural change in 2016 was modelled as a dummy variable, it was concluded that it was not statistically significant.

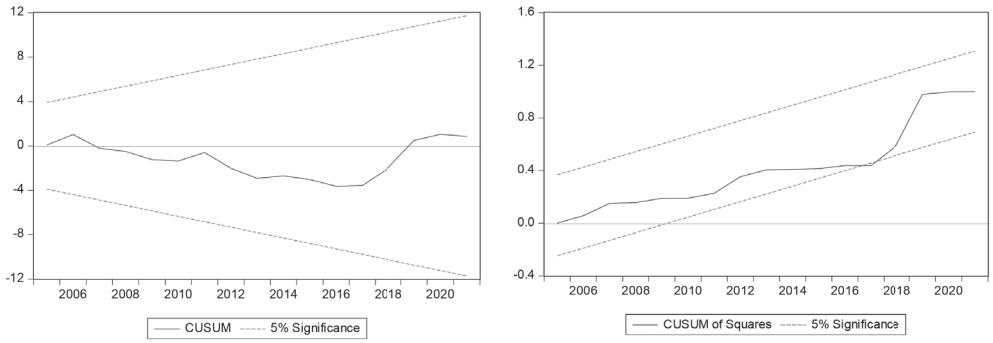

Figure 3. Cusum, and Cusum of Squares

Table 6 indicates the long-run and short-run coefficients of the A-ARDL. First, we interpret the long-run coefficients. According to this, a 1 unit increase in TR reduces GDP by 1.15 units, assuming that other factors remain constant. This result is evidence that the increase in tax revenue and the high tax burden reduce economic growth in the long run. Another result is that, assuming that other factors remain constant, a 1 unit increase in CE raises GDP by 2.47 units in the long run. Thus, the increase in current expenditure on the public finance side has an important function in ensuring economic growth. A

similar result holds for investment expenditure. Therefore, assuming that other factors remain constant, an increase in IE by 1 unit is associated with an increment in GDP of 3.87 units in the long run.

Following the results of the analysis, there are short-term test results. According to these, assuming that other factors are constant, a 1 unit increase in the lagged value of GDP rises GDP by 0.43 units in the short run. In other words, GDP is positively affected by its lagged values. On the other hand, assuming that other factors are constant, a 1 unit increase in the 1 lagged value of TR rises GDP in the short run. It was noted above that the lagged increase in tax revenue has a positive effect on GDP in the short run, but a negative effect in the long run. Furthermore, assuming that other factors are constant, it was found that in the short run, a 1 unit increase in CE rises GDP by 1.71, while a 1 unit increase in IE rises GDP by 6.86. Finally, assuming that other factors are constant, it was found that in the short run, a 1 unit increase in TE reduces GDP by 1.68 units. The error correction term in the short-term model was determined as -1.56. This value is statistically significant. However, the coefficient value is outside the values 0 and -1. This value indicates that the equilibrium will be approached in a wave manner rather than monotonically. However, once this process is completed, convergence to the equilibrium path accelerates (Narayan & Smyth, 2006).

Table 6. The results of the A-ARDL long-run and short-run estimates

Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
Long-run estimates:				
TR	-1.15**	0.39	-2.89	0.01
CE	2.47***	0.67	3.64	0.00
IE	3.87***	1.08	3.57	0.00
TE	0.08	0.18	0.47	0.64
C	-4.83	3.04	-1.58	0.13
Short-run estimates:				
D(GDP(-1))	0.43***	0.10	4.07	0.00
D(TR)	0.66	0.42	1.57	0.13
D(TR(-1))	2.81***	0.44	6.32	0.00
D(CE)	1.71**	0.66	2.60	0.01
D(IE)	6.86***	1.22	5.59	0.00
D(TE)	-1.68***	0.19	-8.83	0.00
ECM(-1)*	-1.56***	0.16	-9.79	0.00
No. of Obs.	38			
R-squared	0.95			
Adjusted R-squared	0.93			

Note. *, **, and *** denote the significance level at the 10%, 5%, and 1%, respectively. ECM denotes the error correction term.

According to the results of the analyses, the positive sensitivity of economic growth in Türkiye to public expenditures in the short and long run supports the Keynesian fiscal policy implementation. Among the subcomponents of public expenditures, investment expenditures are the factor that affects economic growth the most. This result is consistent with a priori expectations and previous studies showing that public investment expenditures lead to an increase in productive capacity (Arteris et al., 2021; Afonso & Aubyn, 2019; Sosvilla-Rivero & Rubio-Guerrero, 2022). In the long run, the effect of tax increases on economic growth is negative in line with the theoretical expectation. This result provides important information that taxes should not have a deterrent effect on economic, commercial, investment, and production activities. In this sense, our general results are in line with the results of Giordano et al. (2007), Jawaid (2010), and Selvanethan et al. (2021) in the literature. These findings, which are consistent with our research, indicate that fiscal policy can be an effective macroeconomic policy tool and that expenditure-based fiscal adjustments have a greater policy impact than tax-based fiscal adjustments. Moreover, our results show that the increase in transfer expenditures hinders economic growth. The negative effect of transfer expenditures on economic growth can be taken as important information that transfer expenditures in Türkiye are not economic and a significant portion of transfer expenditures consists of duty losses and debt interest payments. However, the findings of Duran (2022) on transfer expenditures do not confirm this conclusion.

5. Conclusion and policy recommendation

In this study, we empirically investigate whether fiscal policy is effective in stimulating economic growth in Türkiye and, if so, what is the size and duration of these effects. In doing so, we use the tax variable and in particular the subcomponents of public expenditure to analyse the macroeconomic effects of fiscal policy from 1980 to 2021. The test results reveal that while tax increases have a positive impact on economic growth in the short run and a negative impact in the long run, public expenditure increases economic growth in both the short run and the long run. In this way, the study supports the implementation of Keynesian fiscal policy while providing significant evidence of the effectiveness of expenditure-based fiscal policy. Moreover, the study shows that for the Turkish economy, public investment expenditures have a significant and strong effect on economic growth, while transfer expenditures reduce economic growth. The results of this study will be particularly useful for prioritizing investment spending and redesigning transfer spending.

5.1. Policy recommendation

Our research findings provide various policy recommendations regarding the implementation of fiscal policy as a strong macroeconomic policy tool for economic growth in the Turkish economy. In order to achieve sustainable and high economic growth in Türkiye, it is necessary to increase investment expenditures from the public budget as a matter of priority. In addition, emphasis should be placed on economically qualified transfer ex-

penditures to prevent the decrease in GDP due to transfer expenditures and to promote the increase in the share of transfer expenditures in GDP. In this regard, to increase economic and social transfer expenditures in Türkiye, unproductive transfer expenditures that do not lead to an increase in the productive capacity of the economy, such as duty losses and debt interest payments, should be reduced first. For this purpose, primary surplus and sound debt management strategies should be pursued to channel borrowed resources to more productive areas and reduce the cost of borrowing. Given the long-term negative impact of taxes on economic growth, it is important to establish a sound tax structure that doesn't discourage investment and production. In addition, since external shocks significantly affect the effectiveness of fiscal policy in Türkiye, it is suggested that variables representing external shocks should also be used in future studies.

5.2. Limitation and future implementation

Given the limitations of the study, we recommend that the scope of our current research on the macroeconomic impact of fiscal policy be expanded to include additional variables such as income distribution, inflation, and unemployment. Studies in this direction will also be useful in determining whether economically growing countries produce development-oriented policies. Again using the case of Türkiye, the scope of work can be extended to include broader categories of public expenditure, taxes, and nontax revenues, taking into account general government revenues and expenditures instead of central government revenues and expenditures. Future studies could also include a large sample of countries to assess the effectiveness of the large fiscal stimulus provided during COVID-19 and the situation in other countries where fiscal policy faces different challenges. It is expected that further studies on this aspect will provide a clearer picture of the macroeconomic effects of fiscal policy.

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Role of Innovation on Green Economic Growth: Empirical Analysis from the Countries of the Western Balkans

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Abstract. The impact of innovations on the growth of the green economy is a crucial aspect for a country's economy. The promotion of these innovations and investments is also vital for sustainable and long-term development. This paper aims to present the role of innovation on green economic growth in the countries of the Western Balkans (Kosovo, Albania, North Macedonia, Montenegro, Bosnia and Herzegovina and Serbia) over a 13-year period, from 2010 to 2022.Data for the research were obtained from the World Bank and the Global Economy Database, where the study data type is Panel. The econometric models used are: the ordinary least squares (OLS) model, the Fixed Effect (FE) model, the Random Effect (RE) model and the Hausman Taylor (HTH) model. The dependent variable is green economic growth, while the independent variables include the innovation index (INV), research and development expenditures (R&D), information technology exports (ITE), patent applications from residents (PA), manufacturing output (MAN), business freedom index (BFI), investment freedom index (IFI), and economic freedom index (EFI). The findings of this paper show that the countries of the Western Balkans should promote key factors such as: innovation as an important driver, with a positive impact on green economic growth; research and development expenses; patent applications, and favorable business and economic environments to facilitate long-term green economic growth and promote environmental sustainability. The results indicate that the coefficient for innovation is positive (B=0.41) and statistically significant at the 1% level, supporting the hypothesis that the increase in innovation has a positive impact on green economic growth in the countries of the Western Balkans.
Keywords*:* Green economic growth, Innovation, Research and Development, Western Balkans.

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1. Introduction

Global climate change and environmental pollution are the challenges presented at the global level and the demand for their management encourages more and more countries to use the growth of the green economy. Considering the importance of environmental health, it is necessary to know the impact of innovation, policy reforms and institutional quality on green economic growth. The more the countries of the Western Balkans take steps to stimulate and expand innovations in green economic growth, the healthier their environments will be, reducing exposure to the effects of global climate change. Economists have addressed a wide variety of topics related to the green economy and have made important analyzes of how innovations and changes in global environmental management policies can reduce the negative impact of humans on the environment and thus, in the first place, improve healthy lives and promote well-being in general. A clean environment means a better life on our planet and sustainable green development. Another study recently conducted by Ge et al. (2023) also pays attention to the fair distribution of resources, because the objectives of economic growth on the one hand promote the ways of green development, but on the other hand they can inhibit the effects of green development. Therefore they point out that the productivity of the total green factor can be improved, but the intensity of pollution emissions can be increased. They reveal that outcomes can be affected by green innovation and resource misallocation, as well as strategic interaction.

The main objective of this paper is to present the impact of innovation on green economic growth in the countries of the Western Balkans, where the research provides an empirical statistical analysis through secondary data.

The research question of this paper is: What is the impact of innovation on green economic growth in the countries of the Western Balkans? While the hypothesis of the research is: The increase in innovation has a positive impact on green economic growth in the countries of the Western Balkans.

This paper investigates the impact of innovation on green economic growth in the Western Balkans. These countries possess significant untapped green potential, but face challenges such as institutional limitations, inconsistent government support, mismanagement, brain drain, and limited existing innovation.Our aim is to shed light on the crucial role of innovation in driving a green economic transition in the region. We believe this research will raise awareness among policymakers and stakeholders of the positive impact that increased green innovation can have. Ultimately, focusing on green innovation can contribute to mitigating climate change and fostering a healthier planet.

This study fills a critical gap in the existing literature by providing an empirical analysis of the impact of innovation on green economic growth specifically within the Western Balkans region. These findings will be of significant interest to policymakers, industry professionals, and other stakeholders seeking to promote sustainable development in the region.

In order to investigate the impact or effect of innovation on green economic growth, quantitative methodology was used, which is based on secondary data. The econometric

models that were executed are; first the ordinary least squares (OLS) model, then the Fixed Effect (FE) model, the Ranom Effect (RE) model and the Hausman Taylor (HTH) model. The reason for using the Hausman-Taylor model, unlike most of the conducted research, also solves the problem of endogeneity.

This paper is divided into a total of six chapters, the following chapter presents the literature review, the third chapter explains the methodology and data collection procedure, the fourth chapter of the paper presents the empirical results, the fifth chapter presents the discussion of results and the last chapter presents the conclusion and recommendations.

2. Literature review

In this part of the paper, the empirical evidence of the impact of innovation on green economic growth is presented, and the paper is linked with the opinions of other authors. A significant number of authors researching the green economy suggest that any innovation in growing the green economy will create a better environment by reducing the negative effects of environmental pollution and slowing global climate change, which are the biggest challenges of our time. In addition to technological innovation, there is also a special emphasis on the institutional quality in the management of these policies, as well as carbon reduction, as a promoter for sustainable development (Obobisa et al., 2022).

Ahmed et al. (2022) during the study on the role of green innovation in the economy of South Asia, emphasize that energy production, innovation and green trade are factors that contribute to the growth of the green economy of these countries. Undoubtedly, one of the main requirements that the authors highlight that contribute to high-quality economic development is green innovation and institutional constraints that should advance the market system and increase support from governments (Li et al., 2021).

Anwar et al. (2024) emphasize the importance of comprehensive policy frameworks for fostering green economic growth and sustainable development. Their research identifies economic policy uncertainty, green innovation, and financial development as key drivers of a green economy. Building on this, Degbedji et al. (2024) find that institutional quality varies across countries, and strong institutions are crucial for achieving green economic growth.

The countries of the Western Balkans, like many others, face challenges in managing the risks posed by natural disasters, which are exacerbated by climate change. Their green economy is also less developed compared to EU countries. Therefore, our focus in this paper is to make the findings of how many authors use research on how innovations affect the growth of the green economy that these countries undertake, with a relatively low rate of utilization of green resources compared to European countries. Licastro and Sergi (2021) assert, that the countries of the Western Balkans deserve more attention in the reviews of academic literature, because their untapped green potential can be an indicator for policy makers to policies for their countries to progress as greener countries. Merko et al. (2019) emphasize that the construction of green GDP indicators is of particular importance, which shows how much it is to face the cost of ecological and environmental

degradation, taking Albania as an example. So, any innovation or push towards a green economy has the cost consequences of releasing pollutants into the environment such as CO2 and depleting natural resources. Another paper is analyzed by Kaldellis et al. (2018) where the relationship is revealed as to how the speed of the green transition is affected by migrations and especially the possible brain drain, which would greatly contribute to the acceleration of the green transition. But the authors, based on European integrative perspectives, give a promising signal that the involvement of young scientists in green research may be a solution.

Like many other countries in the Western Balkans, Kosovo, a relatively new nation, struggles to create robust job sectors. This lack of strong job markets, coupled with high levels of mismanagement and governance issues, hinders the development of a green economy and fosters brain drain, a major obstacle to progress. Brain drain, the emigration of highly skilled individuals, weakens a country's innovation potential, which is crucial for a successful green transition.

Using panel data techniques, Zhang et al. (2021) examined that promoting a sustainable green economy is done through public spending on human resources and green technology development. Similarly, some researchers have found that the favorable strategies for developing countries are increased investment in human resources and technological development as well as green industries (Wang et al., 2022).

Fang et al. (2022) analyze how technology can help minimize CO2 emission levels and improve industrial practices. Their research suggests that developing countries might benefit more from these advancements compared to developed countries. Furthermore, Soundarrajan and Vivek (2016) have found that it is important to green growth while keeping carbon low, through green finance as an investment or lending program. Kwilinski et al. (2023) strongly emphasize the importance of available resources, desired outcomes, and undesired outcomes during study. The paper shows that compared to green investments, economic openness and governance efficiency as a factor with a positive impact on green economic growth, green innovations are limited by asymmetry in technological progress. Zeraibi et al. (2023) emphasize the importance of the industrial sector actively investing in renewable energy and environmental quality to reduce environmental degradation. Maradana et al. (2017) find a complex relationship between innovation and economic growth per capita. The causality can be unidirectional (driven by supply or demand) or bidirectional. The type of innovation indicator also affects the observed causality. Jacobs (2012) analyzes green growth by describing the term green economy as a sister concept to sustainable development. Jacobs analyzes three forms of claims of environmental policy as a driver of growth: the Keynesian argument in recession for what he calls "green incentives", growth from natural capital and correcting the failures of market and theories of comparative advantage and long waves of capitalism. Author Barbier (2011) carries out the research that sustainable development will not occur through green growth as long as we face ecosystem loss. And this is accomplished by overcoming financing challenges through international payments. While Popok et al. (2020) emphasize that the modern approach to the green economy must take into account all sectors of the economy.

Gurtowski (2011) potentially the reference between the challenges of innovation and traditional polluting industry is inevitable. In general, the authors refer to the challenges of improving green economic efficiency. Also Chen et al. (2024) notes that green economic efficiency is enhanced by technological, structural and energy effects.

It is more than clear that countries to achieve green development rates and reduce long-term pollution, must manage energy reduction and strengthen technology investments, through which the objectives are achieved as the authors Lin and Ullah (2024) point out. In addition to the management and advancement of the use of technologies, the use of appropriate renewable energy technologies has an important impact. Gibson et al. (2017) examine the functioning of renewable energies and highlight some strategies for mitigating their negative effects such as wind, solar and water energy. Wind energy has a lower impact, solar energy is better if it is designed with advanced technology, water energy has greater risks in ecological environments. These technologies are growing globally and are an influential indicator in the growth and use of green energies. Song et al. (2019) highlight the need for increased and regionally-adapted investments in research and development (R&D) to achieve green economic growth. Aydin and Degirmenci (2024) suggest a link between investment freedom and environmental quality, citing examples from Belgium, Croatia, Denmark, Italy, and Spain. Oyebanji et al. (2022) emphasize the importance of promoting patenting, as strong patent protection can encourage environmentally friendly technologies and economic development (e.g.,reducing CO2 emissions). Fedajev et al. (2024) recent study finds that Western Balkan countries lack innovation compared to Central and Eastern European (CEE) countries. This puts them at a disadvantage. The study recommends adopting best practices from other countries to improve innovation in the region.

3. Research methodology and data

In order to investigate the impact or effect of innovation on green economic growth, quantitative methodology was used, which is based on secondary data. The data for the research includes the six countries of the Western Balkans (Kosovo, Albania, Montenegro, Serbia, North Macedonia and Bosnia and Herzegovina), while the research period is 13 years, specifically from 2010 to 2022, so The data consists of panel data type.

Since the region of the Western Balkans is characterized by a lack of statistical data, then the study period is only 13 years (2010-2022), limitations in the data have also determined some of the variables of the study along with the measurement units.

The econometric models that were executed are; first the ordinary least squares (OLS) model, then the Fixed Effect (FE) model, the Ranom Effect (RE) model and the Hausman Taylor (HTH) model(Clark & Linzer, 2015).The reason for using the Hausman-Taylor model, unlike most of the conducted research, also solves the problem of endogeneity, since it is considered that green economic growth can be influenced by the variable itself in the following year (Baltagu& Bresson, 2012).

The model, Hausman - Taylor, is defined as follows:

$$Yit = c + \beta 1\ (yit{-}1) + \beta 2\ (\text{INV}) + \beta 3\ (\text{R\&D}) + \beta 4\ (\text{ITE}) + \beta 5\ (\text{PA}) + \beta 6\ (\text{MAN}) + \beta 7\ (\text{BFI}) + \beta 8\ (\text{IFI}) + \beta 9\ (\text{EFI}) + uit$$

Where yit is the dependable variable, which in this case is green economic growth, i = 1….6 (countries), t = 2010…2022 (years); c is constant; the explanatory variables include: $yit{-}1$, which is the first lagged of dependent variable, *INV* (Innovations index); *R&D* (rResearch and development expenditure); *ITE* (Information technology exports); *PA* (Patent applications by residents); *MAN* (Manufacturing); *BFI* (Business freedom index); *IFI* (Investment freedom index); *EFI* (Economic freedom index) and *uit* is the exogenous disturbance.

Table 1. Definition of variables

Nr	Variable	Abbreviations	Unit
1	Green Growth	GGDP	%
2	Innovations	INV	Index (0-100)
3	Research and development	R&D	Percent of GDP
4	Information technology exports	ITE	percent of total goods exports
5	Patent applications	PA	By Residents
6	Manufacturing	MAN	Percent of GDP
7	Business freedom	BFI	Index (0-100)
8	Investment freedom	IFI	Index (0-100)
9	Economic freedom	EFI	Index (0-100)

3.1. Descriptive statistics

The data in table 2 offers insights into various economic indicators for Western Balkan countries over the period of 2010-2022. Firstly, the mean value of Green Growth Domestic Product (GGDP) indicates an average growth rate of 4.07%, reflecting the region's overall economic performance in terms of environmentally sustainable economic activities. This suggests a positive trend towards environmentally friendly economic development within the Western Balkans.

The Index of Inovation (INV) stands out with a mean value of 33.85, which shows a value below the average of this index and that the countries of the Western Balkans should try to offer more innovations that are related to green economic growth.

Thirdly, Research and Development (R&D) expenditure, with a mean value of 0.41% of GDP, highlights the region's investment in innovation and technological advancement. While this figure may seem relatively low compared to more developed economies, it signifies a growing emphasis on fostering innovation within the Western Balkans.

Additionally, Information Technology Exports (ITE) as a percentage of total goods exports, with a mean value of 0.54, suggest a modest yet noteworthy contribution of the IT sector to the region's export portfolio. This indicates a potential for further growth and

development in the technology sector, driving future economic expansion. Patent Applications (PA) by residents in the region, with a mean value of 52.33, reflect a moderate level of innovation activity. This indicates a budding entrepreneurial spirit and a willingness to protect intellectual property rights within the Western Balkans.

Manufacturing (MAN) as a percentage of GDP, with a mean value of 8.57, underscores the significance of the manufacturing sector in the region's economy. This indicates a diverse economic base with substantial contributions from the manufacturing industry.

Business Freedom (BFI), Investment Freedom (IFI), and Economic Freedom (EFI) indices, with mean values of 78.11, 67.48, and 63.10 respectively, reflect the overall regulatory environment and ease of doing business within the Western Balkans. While these indices show a relatively favorable business climate, there may still be room for improvement to attract more investment and foster economic growth.

Table 2. Descriptive statistics of variables

Variable	Obs	Mean	Std. Dev.	Min	Max
GGDP	78	4.076	1.648	1.18	7.04
INV	78	33.859	3.243	27.1	41.2
R&D	78	.413	.203	.19	.92
ITE	78	.547	.466	.02	2.13
PA	78	52.333	61.717	1	290
MAN	78	8.573	4.509	2.34	16.119
BFI	78	78.115	80.786	46	777
IFI	78	67.487	6.958	50	83
EFI	78	63.103	5.832	45	78

4. Empirical results

In this part, the empirical results are presented, where first the correlation analysis is presented to present the relationship between the variables of the study. Based on the presented data of the correlation coefficient (Table 3), there is a positive relationship between innovation and economic growth with coefficient r=0.22. So, in addition to the growth of innovation in the countries of the Western Balkans, we also have green economic growth.

Table 4 displays findings derived from various regression models, including Ordinary Least Squares (OLS), fixed effects, random effects, and the Hausman-Taylor model with instrumental variables (IVs). Appendix Table A1 contains the results of the Hausman test. The Hausman test statistic is reported as 60.64, yielding a p-value of 0.0006. This indicates a rejection of the null hypothesis (H0) in favor of the alternative hypothesis (Ha). Consequently, both the random effects and fixed effects models are dismissed in favor of the Hausman-Taylor model, which is deemed more efficient. Moreover, Hausman-Taylor IVs are employed to address the issue of endogeneity in the analysis.

Table 3. Correlation results

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(1) GGDP	1.00								
(2) INV	0.22	1.00							
(3) R&D	0.29	0.30	1.00						
(4) ITE	0.34	0.42	0.82	1.00					
(5) PA	0.60	0.18	0.74	0.72	1.00				
(6) MAN	0.62	-0.02	0.48	0.45	0.66	1.00			
(7) BFI	-0.04	0.09	-0.07	-0.06	-0.09	-0.18	1.00		
(8) IFI	-0.06	-0.07	-0.03	-0.11	-0.11	-0.23	0.12	1.00	
(9) EFI	-0.28	0.06	-0.02	-0.05	-0.15	0.11	0.13	0.21	1.00

Table 4. Regression results

Variables/Models	OLS	FE	RE	HTH
INV	0.172***	-0.0334	0.172***	0.416***
	(4.41)	(-1.44)	(4.41)	(-4.74)
R&D	2.630*	-0.424	2.630*	0.341**
	(2.54)	(-0.53)	(2.54)	(2.45)
ITE	-0.431	-0.288	-0.431	-0.367
	(-0.92)	(-1.28)	(-0.92)	(-1.57)
PA	0.990**	0.11	0.990**	0.244**
	(2.88)	(0.43)	(2.88)	(3.11)
MAN	0.258***	0.00317	0.258***	-0.0101
	(6.99)	(0.05)	(6.99)	(-0.17)
BFI	0.186	0.129*	0.186	0.147**
	(1.33)	(2.09)	(1.33)	(2.36)
IFI	0.465**	-0.116	0.465**	0.849***
	2.73	(-1.20)	(2.73)	4.87
EFI	0.114***	0.432	0.114***	0.268
	(5.38)	(0.34)	(5.38)	(2.21)**
GGDP_ln_Lag				0.146**
				(2.81)
CountryID				0.687**
				(2.58)
_cons	0.775	5.866***	0.775	3.417**
	(0.41)	(5.26)	(0.41)	(2.59)
N	78	78	78	78
VIF	2.35			
Breusch-Pagan Test	P=0.7381			
Hausman Test	P=0.0006			

t statistics in parentheses

* p<0.05, ** p<0.01, ***p<0.001

The innovation coefficient (B=0.41) shows a positive impact on green economic growth. So, for every 1 additional value in the innovation index, we will have green economic growth for 0.41% on average. Impact of innovation is statistically significant on green economic growth in 1% level.

Research and development expenditures have a positive impact (B=0.34) on green economic growth. So, for every 1% of the value of the gross local production, an increase in research and development expenses, we will have a green economic growth of 0.34% on average. The impact of research and development expenditures is statistically significant for green economic growth at the 5% significance level.

The application of patents, which is related to the variable of expenses for research and development and innovation, also has a positive impact on green economic growth (B=0.24). So, for every 1 application more for patents from the citizens of the countries of the Western Balkans, we will have a green economic growth of 0.24% on average. Patent application is statistically significant at the 5% level for green economic growth.

All three indices (Index of doing business B=0.14, Index of investments B=0.84 and Index of economic freedom B=0.26) have a positive impact on green economic growth. So, the growth of these indices has a positive impact on green economic growth, where the impact is greater on the investment index, while the smallest positive impact is on the doing business index. The doing business index and the economic freedom index are statistically significant at the 5% significance level, while the investment index is statistically significant at the 1% significance level.

5. Discussion

The analysis highlights several key factors that contribute to green economic growth in the Western Balkans. Notably, innovation emerges as a significant driver, with a positive impact on green economic growth. This underscores the importance of fostering a culture of innovation and investing in technological advancements within the region. Additionally, research and development expenditures are found to positively influence green economic growth, indicating the value of allocating resources towards scientific and technological research to support environmentally sustainable initiatives. Moreover, the positive impact of patent applications further emphasizes the role of intellectual property rights and innovation in driving green economic development.

The study identifies three indices—business freedom, investment freedom, and economic freedom—that also play a crucial role in promoting green economic growth. These indices serve as indicators of the regulatory environment, ease of doing business, and overall economic policies within the region. The positive impact of these indices suggests that favorable business conditions, coupled with investment-friendly policies and economic freedom, contribute significantly to fostering green economic growth in the Western Balkans. Notably, the strongest impact is observed in the investment index, highlighting the critical role of investment in driving sustainability initiatives.

Our findings highlight innovation as a critical driver of green economic growth in the Western Balkans. Its statistically significant impact demands that policymakers and stakeholders prioritize initiatives that foster innovation, research, and development. By nurturing an innovation-friendly environment through R&D incentives, patent support, and collaborative ecosystems, countries in the Western Balkans can unlock long-term green growth. Furthermore, fostering favorable business environments with supportive regulations for entrepreneurship, accessible green capital, and academia-industry-government collaboration will be crucial for maximizing the impact of innovation.

Our findings, aligned with theory and evidence from other contexts, underscore the universal importance of innovation for driving economic growth, especially in environmental sustainability sectors. Innovation acts as a catalyst, fostering green technologies, processes, and practices that boost resource efficiency, reduce environmental impact, and propel green industries. This robust relationship underscores the critical need to prioritize innovation policies for effective sustainable economic development in the Western Balkans.

By emphasizing the pivotal role of innovation, our research underscores the need for targeted efforts to foster a culture of innovation and entrepreneurship within the region. Policymakers can accelerate innovation-driven growth by strategically investing in research and development, particularly in [targeted areas], fostering supportive regulations and collaboration between various stakeholders. These endeavors hold the potential not only to spur economic prosperity but also to propel the Western Balkans toward a more sustainable and resilient future.

These results provide empirical support for the hypothesis that the increase in innovation positively impacts green economic growth in the countries of the Western Balkans. Policymakers and stakeholders in the region can use these findings to inform strategies aimed at fostering innovation ecosystems, investing in research and development, and promoting entrepreneurship to drive sustainable economic growth and address environmental challenges.

6. Conclusions

While innovations and the growth of the green economy are closely related to each other, the research shows that any increase in innovations in the Western Balkan countries results in the growth of the green economy in general. So the impact of innovation is statistically significant in green economic growth at the level of 1%. This paper analyzed the main determinants of the growth of the green economy in order to create certain investment policies that will help in its growth. The results of the analysis of the econometric models complement the results of the literature and are in line with the expectations. According to the results of the econometric models and the reviewed literature, the greatest impact is observed in the index of investments, which play an important role in promoting the green economic growth.

The average rate of the Domestic Product of Green Growth (GGDP) is expressed with values of an average growth rate of 4.07%, contributing to a positive trend of economic

development activities in the countries of the Western Balkans.From the data analysis, innovation, research and development, patent applications, and favorable business and economic environments all contribute to sustainable economic development in the Western Balkans. Stakeholders in the region and policymakers can use these findings to make strategies aimed at promoting innovation, investment in research and development and promoting entrepreneurship to foster sustainable green economic growth and addressing environmental challenges.

The empirical analysis underscores the pivotal role of innovation in driving green economic growth within the countries of the Western Balkans. The positive impact of innovation, as evidenced by the statistically significant coefficients derived from various regression models, highlights the importance ofm prioritizing policies and initiatives that foster innovation across different sectors.Additionally, the findings suggest that increased investment in research and development (R&D) activities, promotion of patent applications, and improvements in the overall business and investment climate can significantly contribute to sustainable economic development in the region. Moreover, the emphasis on regional collaboration and knowledge sharing underscores the potential for leveraging collective resources and expertise to address common challenges and maximize the impact of innovation-driven strategies on green economic growth.

The study acknowledges several limitations. Firstly, while the Hausman-Taylor model is employed to address endogeneity concerns, residual endogeneity may still persist, particularly regarding variables such as innovation and research and development expenditure. Despite efforts to mitigate this issue, the potential influence of unobserved factors remains a concern and could introduce bias into the estimated relationships. Moreover, the model may not fully capture the complex interplay between variables, such as simultaneous causality, which could affect the robustness of the findings and undermine the validity of the conclusions drawn. Secondly, the study may suffer from omitted variable bias due to the exclusion of important factors that could influence green economic growth, such as environmental regulations, energy prices, or political stability. The failure to account for these variables could limit the explanatory power of the model and lead to biased estimates. Additionally, measurement errors in key variables, such as the innovation index and green economic growth, may affect the accuracy of the results. Further validation of the selected variables through additional references or detailed explanations of the methodological procedures from data providers could enhance the credibility of the findings. Overall, while the study provides valuable insights into the relationship between innovation and green economic growth in the Western Balkans, these limitations should be carefully considered.

Based on these results, policymakers are recommended to prioritize the formulation and implementation of evidence-based policies aimed at promoting innovation-led green economic growth in the Western Balkans. This includes allocating resources towards R&D initiatives, providing incentives for patent applications, and implementing reforms to enhance the business and investment climate. Moreover, efforts should be made to strengthen regional collaboration and knowledge sharing mechanisms to facilitate the exchange of best practices and promote growth among countries within the region. By

adopting these recommendations, policymakers can effectively harness the potential of innovation to drive sustainable economic development and improve the overall well-being of the citizens in the Western Balkans.

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https://www.theglobaleconomy.com/indicators_list.php
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Appendix

Table A1. Hausman (1978) specification test

Hausman Test	Coef.
Chi-square test value	60.64
P-value	0.0006

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The Effect of Direct and Indirect Taxes on Economic Growth in Developed Countries

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Abstract. This paper examines how the economic growth in advanced countries is affected by various types of tax revenue. Ten developed countries were chosen based on the Human Development Index, and data from 1995 to 2020 were examined using the feasible generalized least squares method. A total of 260 observations spanning 26 years were available for analysis. The purpose of this paper is to investigate the influence of direct and indirect taxes on economic growth in selected developed countries. According to our results, the growth of these countries was positively influenced by corporate income taxes and taxation on specific goods and services. However, there are adverse impacts from taxes on personal income, contributions to social security, and a tax on value-added. For a beneficial impact on these nations' growth, we suggest policymakers concentrate on taxes on corporations and specific services and goods. Furthermore, it is important to consider the adverse impacts of personal taxation and value-added taxation on growth.
Keywords: Economic Growth; Personal Income Tax; Corporate Income Tax; Value Added Tax; Social Security Contribution; Labor Tax; Property Tax; Tax on Specific Goods and Services

1. Introduction

For decades, there has been an increase in research interest in the influence of taxation on economic performance (Alinaghi & Reed, 2021). Governments can use tax policies as fiscal policy instruments to finance their investments and carry out certain expenditures (Korkmaz & Yilgor, 2019). Also, taxes can be used by governments to achieve multiple goals, such as growth and development, encouraging savings and investments, and increasing production, consumption, and employment (Korkmaz & Korkmaz, 2023).

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Tax revenue is a crucial component of a nation's growth since it represents one of the greatest contributors to total national income. If tax revenues are insufficient, a rise in the budget deficit, both domestically and abroad borrowing or servicing of debt can have an adverse effect on growth (Nazir, Anwar, & Nasreen, 2020). The need for additional revenue to finance increased public expenditure is often caused by economic developments, but it also increases the country's fiscal burden to meet these needs (Nguyen & Darsono, 2022).

The greater the state's engagement in economic activities, the greater the revenue its government will require, with taxes providing the majority of this revenue (Tanzi, 2011). According to Besley and Persson (2013), the average tax revenue in low-income nations is from 10 to 20% of GDP, whereas it exceeds 40% in wealthy ones (Elshani & Pula, 2023).

Plenty of discussions have taken place on comparing the advantages of various types of tax revenue, direct and indirect, with a focus on their potential to assist growth (Stoilova, 2017). The decision to use a combination of indirect and direct taxes plays a critical role in ensuring the optimal distribution of tax income and improving the economy's performance (Hakim, 2020). Martinez-Vazquez et al. (2011) show that across the 116 states, the average ratio of direct taxes to indirect taxes has increased during the previous three decades.

The ability of decisions concerning the tax structure to be effective is based on knowledge about how increases in taxes affect other factors. This paper's main goal is to examine how various taxes influence growth in wealthy nations to identify which kinds of direct and indirect taxes have a higher or lower impact on their growth. In our models, we have included personal income tax (PIT), value-added tax (VAT), corporate income tax (CIT), tax on specific goods and services (SGST), and some types of taxes with a smaller share of the GDP. It is important to understand the direction in which these types of taxes will influence economic growth so that optimal tax structures can be determined.

The remaining sections of the paper are arranged as follows. The following part is a review of the available literature. The third section illustrates the data and variables used in the econometric models, as well as the technique used in the article. The fourth section provides the research's outcomes and its discussions. Lastly, the fifth section presents the conclusions reached.

2. Literature review and hypothesis development

There is a wealth of literature on the tax-growth relationship. Based on panel data from 26 OECD nations from 1965 to 2007, Furceri and Karras (2008) discovered that higher taxes showed a negative influence on real GDP per capita. In contrast, Vintila et al. (2021) found a positive correlation between fiscal factors and GDP growth in OECD nations from 2002 to 2017. In a similar vein, the findings of Spulbar et al. (2021) imply that the amount of tax in EU-28 member countries is playing an increasingly crucial role in GDP dynamics. Furthermore, Hoang et al. (2021) revealed that the majority of taxes are favorable to growth in nations with low incomes, whereas taxation on services and goods can help increase growth in wealthy nations, after analyzing 63 countries' data between 2003 and 2017.

Much emphasis has been dedicated to the way taxes that are both direct and indirect affect development. Utilizing panel data from 51 nations from 1992 to 2016, Hakim (2020) discovered that, whereas indirect taxes appear to be a favorable but insignificant element for growth, direct taxes have a considerable and adverse effect on growth. Acosta-Ormaechea et al. (2019) show that increases in consumption and property taxation, along with declining income taxes, increased long-term growth across 70 countries from 1970 to 2009. Stoilova and Patonov (2013) argue that a system of taxation that relies on direct taxes is more beneficial for fostering the growth of EU members. Furthermore, the authors Elshani et al. (2018) observed, using data from 35 European nations from 2002 to 2014, that states using the linear tax had higher growth compared to those using the progressive tax. As such, numerous scholars examined the implications of taxing on growth using data from various nations and periods. Table 1 summarizes the investigations conducted in this area.

Table 1. The influence of taxation on growth

Authors	States	Period of time	The influence of taxation on growth
Hakim et al. (2022)	137 countries	2000–2020	Direct taxes have a beneficial impact on advanced nations but a detrimental impact on developing ones. In both countries, indirect taxes have an adverse connection.
Martinez-Vazquez et al. (2011)	116 states	1972–2005	Growth seemed to be negatively impacted by high direct-to-indirect tax ratios.
Alm & Rogers (2011)	USA	1947–1997	Although statistically important, the link between state tax policies varies greatly depending on the period and the particular collection of regressors used.
Stoilova (2017)	EU Member States	1996–2013	Tax revenue appears to have less harmful effects on growth for EU-28 member states.
Alfo et al. (2022)	21 OECD Countries	1965–2010	Growth is negatively impacted by taxation.
Arnold (2008)	21 OECD Countries	1971–2004	In general, taxes on income are less favorable for growth than consumption and property taxes.
Hakim (2020)	51 Countries	1992–2016	Direct taxes have an adverse effect, but indirect taxes have an insignificant beneficial effect.
Stoilova & Patonov (2013)	EU Member States	1995–2010	To support growth in EU countries, direct taxation is more efficient.

Source: Illustrated by authors.

Personal income taxation and growth

Several studies have been conducted to determine the effect of taxation on personal income growth. Widmalm (2001) discovered that personal income taxes (PIT) have a

detrimental effect on economic growth after researching 23 OECD nations between 1965 and 1990. Using regression analysis conducted on OECD nations between 2000 and 2011, Macek (2015) also discovered a negative correlation. Furthermore, Dackehag and Hansson (2012) examined data from 25 affluent OECD nations from 1975 to 2010 to show that PIT had an adverse effect on growth. Longer term, author Xing's (2011) study reveals that between 1970 and 2004, a rise in PIT income was associated with a decline in per capita GDP among 17 OECD nations. Based on data from 21 OECD states between 1971 and 2004, Arnold (2008) discovered that progressivity in PIT and growth also had an adverse relationship. Following the literature review, a hypothesis could be developed as follows:

H1: Personal income tax has an effect on the economic growth of developed economies.

Corporate income taxation and growth

Some scholars have identified a negative association between corporate income taxes and growth. Lee and Gordon (2005) found a substantial negative association between growth and the corporate tax rate after studying data from 70 nations between 1970 and 1997. According to their calculations, a ten percent corporation tax rate cut would be sufficient to increase the annual growth rate by roughly 1.1%. Oz-Yalaman (2019) discovered that corporation tax rates have considerable adverse effects on growth after examining data from 29 OECD nations between 1998 and 2016. Authors Nazir et al. (2020) examined data from 20 Asian nations with average incomes from 1990 to 2017 and found that corporate taxes have a detrimental effect on growth.

Other authors, however, discovered favorable associations. Stoilova (2017) discovered that corporation taxes have a favorable effect on growth; however, the association is not very strong. Corporate revenue tax rates are linked positively (significantly, though not strongly) with growth, according to the authors Angelopoulos et al. (2007). Kate and Milionis (2019) studied 77 OECD nations between 1965 and 2014. The association between capital taxes and growth is generally positive for advanced countries but statistically insignificant for developing countries in most circumstances, according to the authors' findings. Given that we take into analysis 10 developed economies over a long period, and this research focus has yielded that there are positive effects of corporate income tax on economic growth, the following hypothesis is put forth:

H2: Corporate income tax has an effect on the economic growth of developed economies.

Value-added taxation and growth

Chiricu (2019) examined how value-added tax (VAT) affects growth. The study's data for Southern European nations from 1996 to 2017 demonstrated that VAT has a significant favorable impact on growth. Elshani and Ahmeti (2017) contend that VAT has a favorable impact on European nations' growth that implement progressive taxes. Acosta-Ormaechea and Yoo (2012) also noted, after examining 69 nations with different income levels from

1970 to 2009, that VAT and sales taxes are significantly favorably connected with growth.

On the other side, Stoilova (2017) demonstrated how the implementation of VAT negatively impacts the EU-28 economies. Alm and El-Ganainy (2012) demonstrate that a 1% increase in VAT would cause a short-term, roughly 1% fall in overall consumption, followed by a longer-term, somewhat more substantial decline. The study covered 15 EU nations between 1961 and 2005. Most studies covering developed economies covered in our study report a negative impact of value-added tax on economic growth. Therefore, we can put forward the following hypothesis:

H3: Value-added tax has an effect on the economic growth of developed economies.

Customs duties, excise duties, and growth

According to empirical research by Elshani and Pula (2023), the GDP of nations in the Euro region is negatively impacted by customs and excise duties. The authors Elshani and Ahmeti (2017) reached the same outcome. Additionally, Aliyu and Mustapha (2020) concluded that between 1981 and 2017, customs and excise duties harmed Nigeria's growth.

Customs duties and excise have a favorable correlation with Nigeria's growth, according to research by authors Ibadin and Oladipupo (2015), who examined data from 1981 to 2014. Owino (2019) discovered similar findings after examining data for Kenya from 1973 to 2010. Given that extant studies investigating this relationship overlook developed economies, in our case, we postulate a positive relationship, given the obvious differences with emerging economies. Hence, we formulate the following hypothesis:

H4: Customs and excise duties have an effect on the economic growth of developed economies.

3. Methodology

This section presents the econometric models that were applied to examine the connection between revenue from taxes and growth. The Panel Data method is used for data analysis. We rely on this method due to its demonstrated feature of evaluating temporal and cross-country changes (Petranov, Zlatinov, & Atanasov, 2022). In this paper, two econometric models have been built, where the response variable is economic growth, namely the GDP growth rate for model 1 and the GDP per capita growth for model 2, the data for which were taken from the World Bank database. These variables were also used by other authors, including Widmalm, 2001; Martinez-Vazquez et al., 2011; Stoilova, 2017; Elshani & Pula, 2023; Lee & Gordon, 2005; Johansson et al., 2008; Stoilova & Patonov, 2013; Hakim et al., 2022; Hoang et al., 2021; and Elshani & Ahmeti, 2017. Whereas the regressors in the model are Income from personal income tax (PIT), corporate income tax (CIT), social security contributions (SSC), labor force taxes (TPW), property tax (TP), value-added tax (VAT), and tax on specific goods and services (SGST). Data for all explanatory variables are taken from a database of the OECD and given as a percentage

of GDP. VAT and SGST are examples of indirect taxes among the taxes included as explanatory variables in our models; direct taxes make up the remaining tax categories.

The study includes ten developed nations, namely: Australia, Denmark, Finland, Germany, the Netherlands, Ireland, Norway, Sweden, the United States of America, and Switzerland. The Human Development Index (HDI), a development indicator published by the United Nations Development Program, was used to choose the nations that were part of the study. An HDI value nearer one indicates more development. This indicator has a level greater than 0.9 in each of the nations included in our paper. According to the United Nations Development Program (2021): Australia (0.951), Denmark (0.948), Finland (0.940), Germany (0.942), Ireland (0.945), the Netherlands (0.941), Norway (0.961), Sweden (0.947), Switzerland (0.962), and the USA (0.921).

The following table shows the economic growth and different types of tax revenues to GDP as an average for the years 1995-2020 in the developed nations included in the paper.

Table 2. Tax revenues in % of GDP and economic growth, by country.

Nr	State	GDP	GDP/cap	PIT	CIT	SSC	TPW	TP	VAT	SGST
1	Australia	3.05	1.62	11.38	4.97	0.00	1.42	2.63	2.83	3.43
2	Denmark	1.54	1.10	24.56	2.79	0.15	0.25	1.79	9.37	5.00
3	Finland	2.11	1.78	12.98	3.00	12.04	0.00	1.17	8.47	4.78
4	Germany	1.22	1.14	9.23	1.62	14.02	0.00	0.93	6.67	3.17
5	Ireland	5.85	4.52	8.87	2.98	4.09	0.20	1.69	6.07	3.38
6	Netherlands	1.84	1.35	6.86	3.18	13.59	0.00	1.60	6.60	3.50
7	Norway	1.98	1.14	10.15	7.49	9.56	0.02	1.11	8.15	3.59
8	Sweden	2.37	1.73	14.00	2.84	11.24	3.24	1.24	8.66	3.13
9	Switzerland	1.71	0.88	8.23	2.50	6.45	0.00	2.14	3.28	1.71
10	USA	2.27	1.37	9.97	2.02	6.31	0.00	3.11	0.00	1.76

Source: OECD, compiled by authors, average data for the period 1995-2020.

From the table above, Denmark has the largest share of revenues from TAP in GDP with 24.56%, followed by Sweden with 14% and Finland with 12.98%. However, the Netherlands has the lowest share of this tax with 6.86%, followed by Ireland with 8.87%. Regarding VAT revenues, Norway has the highest share of these revenues in GDP with 7.49%, followed by Australia with 4.97%. However, Germany had the lowest participation with 1.62%. Denmark has the highest share of VAT revenue in GDP at 9.37%.

The study was conducted for 26 years, starting from 1995 to 2020, resulting in a total of 260 observations (10 countries for 26 years). The FGLS technique was applied for both models because of the correction for the existence of cross-sectional dependency, heteroskedasticity, and autocorrelation.

Table 3. Details and description of variables for model 1 (M1) and model 2 (M2)

Variables	Abbre-viations	Types of variables	Calculation	Source
Gross Domestic Product	GDP	Dependent variable (M1)	Annual growth rate	World Bank Data
Gross Domestic Product per capita	GDP/ cap	Dependent variable (M2)	Annual growth rate	World Bank Data
Personal Income Tax	PIT	Independent variable (M1, M2)	Percentage share of GDP	OECD Data
Corporate Income Tax	CIT	Independent variable (M1, M2)	Percentage share of GDP	OECD Data
Social Security Contribution	SSC	Independent variable (M1, M2)	Percentage share of GDP	OECD Data
Labor Tax	TPW	Independent variable (M1, M2)	Percentage share of GDP	OECD Data
Property tax	TP	Independent variable (M1, M2)	Percentage share of GDP	OECD Data
Value Added Tax	VAT	Independent variable (M1, M2)	Percentage share of GDP	OECD Data
Tax on Specific Goods and Services	SGST	Independent variable (M1, M2)	Percentage share of GDP	OECD Data

Source: Illustrated by authors.

The econometric models used in our research are as follows:

Model 1 (GDP Growth):

$$Y_{it} = \alpha + \beta_1 PIT + \beta_2 CIT + \beta_3 SSC + \beta_4 TPW + \beta_5 TP + \beta_6 VAT + \beta_7 SGST + \mu_{it} + \epsilon_{it}$$

Model 2 (GDP Growth per capita):

$$Y_{it} = \alpha + \beta_1 PIT + \beta_2 CIT + \beta_3 SSC + \beta_4 TPW + \beta_5 TP + \beta_6 VAT + \beta_7 SGST + \mu_{it} + \epsilon_{it}$$

Where:

PIT – Personal income tax
CIT – Corporate income tax
SSC – Social Security contribution
TPW – Labor tax
TP – Property tax
VAT– Value-added tax
SGST– Tax on specific goods and services.

According to the Hausman test, the fixed effects model is better suited to model 1 than the one with random effects. However, the existence of problems with cross-sectional dependence, autocorrelation, and heteroskedasticity has been proven through diagnostic tests. Model 2, in which the Hausman test results showed a model with a random effect

as the best fit, has also shown similar problems. The FGLS approach is used to correct these issues.

4. Results and discussions

To describe the study's variables, descriptive statistics were used. In descriptive statistics, all variables are present.

Table 4. Descriptive statistics for Model 1 and Model 2

	GDP	GDP cap	PIT	CIT	SSC	TPW	TP	VAT	SGST
Mean	2.39	1.66	11.62	3.34	7.74	0.51	1.74	6.01	3.34
Std.Dev.	2.87	2.81	4.86	1.93	4.97	1.09	0.70	2.96	1.15
Min.	-8.07	-8.51	5.6	0.6	0	0	0.8	0	1.6
Max.	24.37	23.20	26.2	12.6	15	5.3	4.3	10	6.3
Obs.	260	260	260	260	260	260	260	260	260

Source: Illustrated by authors.

The table above includes descriptive data for all the variables this study looked at. In terms of average tax revenues, the biggest tax revenues on average are PIT revenues, which account for 11.62% of GDP in the nations studied, followed by the contribution to social security with 7.74% of GDP and the value-added tax with an average of 6.01% participation in GDP.

Next, the correlation analysis is shown. Table 5 illustrates the correlation between economic growth (measured as GDP and GDP per capita) and PIT, CIT, SSC, labor tax, property tax, VAT, and SGST in the advanced nations covered by this study from 1995 to 2020.

Table 5. Correlation analysis

Variables	GDP	GDP/cap	PIT	CIT	SSC	TPW	TP	VAT	SGST
GDP	1.000								
GDP/cap	0.983***	1.000							
PIT	-0.086	-0.051	1.000						
CIT	0.103*	0.043	-0.065	1.000					
SSC	-0.169***	-0.075	-0.447***	-0.143**	1.000				
TPW	0.010	-0.027	0.159**	0.024	-0.078	1.000			
TP	0.060	-0.020	-0.025	-0.111*	-0.582***	-0.086	1.000		
VAT	-0.093	-0.028	0.456***	0.138**	0.285***	0.162***	-0.781***	1.000	
SGST	0.104*	0.161***	0.573***	0.126**	-0.049	-0.045	-0.417***	0.676***	1.000

Source: Illustrated by authors. *Note: *** p<0.01, ** p<0.05, * p<0.1.*

Model 1's dependent variable was GDP growth. The following analysis reveals a positive relationship between corporate income tax (0.103) and tax on specific goods and services (0.104) and GDP growth. However, there is a negative link between PIT (-0.086), SSC (-0.169), and VAT (-0.093) and GDP growth. Additionally, it is seen that there is a positive connection between GDP per capita and SGST (0.161) and CIT (0.043). All other types of taxes, beginning with PIT (-0.051) and VAT (-0.028), show a negative relationship with GDP per capita growth.

Nonetheless, for both models, the correlation analysis discovered that CIT and SGST show a positive influence on the growth of the developed nations involved. Then, according to these results, PIT and SSC have an adverse influence on these states' growth.

The findings of the Breusch and Pagan Lagrangian multiplier test, which was used to evaluate the importance of random effects, are shown in Table 6. Because the null hypothesis was rejected in our case and both models had prob > chi2 values of 0.0000, it was determined that random effects have significance in these models. Because there are significant variations between countries, these findings demonstrate that we cannot depend on straightforward OLS regression estimates. In conclusion, it can be claimed that for both models at this point, a random effect model appears more appropriate than an OLS model.

Table 6. Breusch and Pagan Lagrangian Multiplier Test Results.

Estimated result:					
Test: Var (u) = 0					
M1 (Model 1)			M2 (Model 2)		
	Var	sd = sqrt (Var)		Var	sd = sqrt (Var)
GDP	8.281634	2.877783	GDPcap	7.903981	2.811402
e	6.040608	2.457765	E	6.051313	2.459942
u	2.210371	1.486732	U	1.642833	1.28173
chibar2 (01)	23.76		chibar2 (01)	15.79	
Prob > chi2	0.0000		Prob > chi2	0.0000	

Note: In the table above "e" is the Usual Error term and "u" is the Random Effects term.
Source: Illustrated by authors.

In the case of both models, after demonstrating that a random effect model is superior to the OLS model, the study proceeded toward selecting between the RE (random effects) model and the FE (fixed effects) model. Table 7 displays the Hausman test findings for this purpose.

Table 7. Hausman Test Results.

Test: H_0: difference in coefficients not systematic		
	Model 1	Model 2
	Coef.	Coef.
Chi-square test value	16.104	9.191
P-value	0.024	0.239

Source: Illustrated by authors.

Based on these findings, we determine that, for model 1, the FE model is a better fit than the RE model ($p = 0.0242$, $p < 0.05$). As a result, the null is rejected, and it is demonstrated that the systematic difference in the coefficient favors the FE model. Regarding model 2, the test findings demonstrate that, with $p = 0.239$, the RE model is a better match than the FE model, supporting the null hypothesis and demonstrating the non-systematic nature of the coefficient difference in this model.

Diagnostic tests should be carried out to ascertain whether the models chosen by the Hausman test are free from issues such as cross-sectional dependency, heteroscedasticity, autocorrelation, and multicollinearity. All of this is done to ensure that the econometric model's outputs are as accurate and dependable as possible, as the existence of these issues may lead to deviations in the model's output. Next are the outcomes of the diagnosis tests and the corresponding explanations for each of the aforementioned issues, starting with the Breusch-Pagan LM test to check for cross-sectional dependence before moving on to the Woodridge test for checking autocorrelation and the Modified Wald test to look for heteroskedasticity. To determine whether there is an unacceptable correlation among the regressors included in the model, the testing phase also involves testing for multicollinearity.

According to De Hoyos and Sarafidis (2006), Breusch and Pagan's LM test can be applied to check for the presence of cross-sectional dependency when T (dimension of time) > N (dimension of cross-section). Because in our case, T > N (T = 26 years, N = 10 countries), we can use this test to examine cross-sectional dependence. Table 8 shows the results of this test. The results indicate that we are unable to accept the null hypothesis in any of the models since pr = 0.0000, so pr < 0.05 for both models. As a result, we conclude that the panels are interconnected.

Table 8. Results of the Breusch-Pagan LM independence test

H_0: residuals across entities are not correlated	
Model 1	Model 2
chi2(45) =357.562	chi2(45) = 373.673
Pr = 0.0000	Pr = 0.0000
Based on 26 complete observations over panel units	

Source: Illustrated by authors.

The findings of the Woodridge test for detecting autocorrelation in panel data are provided in the table below. The null states that there is no first-order autocorrelation.

Table 9. Estimated results of the Woodridge Test.

H_0: no first-order autocorrelation	
Model 1	Model 2
F (1,9) = 26.038	F (1,9) = 22.223
Prob > F = 0.0006	Prob > F = 0.0011

Source: Illustrated by authors.

We've rejected the null hypothesis and found that autocorrelation exists in models 1 and 2 based on this test, as Prob > F < 0.05 in both models.

After testing for autocorrelation, from which we concluded that model 1 with fixed effects has the presence of autocorrelation, we continued with tests for heteroskedasticity.

Table 10. Modified Wald test for group heteroskedasticity.

H_0: Sigma (i)^2 = sigma^2 for all i	
Model 1	
chi2 (10)	384.30
Prob>chi2	0.0000

Source: Illustrated by authors.

The modified Wald test for group heteroscedasticity was applied in model 1 with fixed effects to establish whether it is inclusive of homoscedasticity. Homoscedasticity, or constant variation, is the null hypothesis. Since prob > chi2 = 0.0000 and prob > chi < 0.05, we concluded heteroskedasticity. Table 10 gives the results of this test carried out on our model.

To assess whether multicollinearity is present, we use the variance inflation factor (VIF) indicator. The findings of this test apply to both models because the regressors are alike in both. Table 11 displays these outcomes. Given that VIF < 10 and tolerance 1/VIF > 0.1 are true for all variables, we can conclude that multicollinearity does not occur.

Table 11. Testing for multicollinearity through VIF (Variance Inflation Factor).

Model 1 and Model 2		
Constant	1/VIF (Tolerance)	VIF
VAT	0.162	6.167
TP	0.222	4.500
PIT	0.312	3.207
SSC	0.370	2.702
SGST	0.409	2.445
CIT	0.803	1.245
TPW	0.876	1.141
Mean		3.058

Source: Illustrated by authors.

From the above tests, in summary, we can conclude that model 1 with fixed effects contains cross-sectional dependence, autocorrelation, and heteroskedasticity, while model 2 with random effects after testing revealed autocorrelation and cross-sectional dependence. To achieve effective results, all of the issues identified above had to be addressed. The Feasible Generalized Least-Squares method is advised for working with panels where T (dimension of time) is bigger than N (dimension of cross-section). Hoechle (2007) states

that the constraint N<T is required for this regression to be possible. Since we have data for 10 nations for 26 years, in our example T>N, the FGLS approach, which accounts for heteroskedastic panels and the presence of autocorrelation, was thought to be suitable for model 1. Model 2 has also been subjected to the FGLS approach, taking autocorrelation and cross-sectional dependency into account. In line with Bai et al. (2020), when heteroscedasticity, serial, and cross-sectional correlations occur, the proposed FGLS estimator is a better choice than OLS.

Table 12 presents the outcomes of the analysis we conducted, allowing us to determine which tax types influence development. According to both models, corporate income taxes as well as taxes on specific goods and services show a favorable influence on the growth of the advanced nations included in our research, with SGST being significant ($p<0.01$) in the two models and CIT being significant just in the first one. Taxes on personal income and value-added tax, on the other hand, show an unfavorable effect on these countries' growth. In the two models, VAT is significant ($p< 0.05$ in M1, $p< 0.10$ in M2), whereas PIT is significant ($p< 0.1$) only in the second model.

Table 12. Results with FGLS for Model 1 (M1) and Model 2 (M2)

FGLS									
Dependent variables: For M1: GDP For M2: GDP/cap			**Independent Variables**						
		Cons.	**PIT**	**CIT**	**SSC**	**TPW**	**TP**	**VAT**	**SGST**
M1	Coef. Sig.	1.435 (0.470)	-0.064 (0.364)	0.155* (0.071)	-0.012 (0.862)	0.162 (0.440)	-0.201 (0.693)	-0.33** (0.013)	0.912*** (0.000)
	St.Err.	1.985	0.07	0.086	0.072	0.21	0.509	0.133	0.215
	t-value	0.72	-0.91	1.80	-0.17	0.77	-0.39	-2.48	4.24
M2	Coef. Sig.	4.445** (0.041)	-0.156* (0.066)	0.062 (0.640)	-0.132* (0.086)	0.067 (0.770)	-1.032 (0.100)	-0.34* (0.064)	1.077*** (0.000)
	St.Err.	2.172	0.085	0.132	0.077	0.23	0.628	0.184	0.309
	t-value	2.05	-1.84	0.47	-1.72	0.29	-1.64	-1.85	3.49
Significance of the model			**Model 1: FGLS**				**Model 2: FGLS**		
			Wald chi2(7) = 32.34 Prob > chi2 = 0.0000				Wald chi2(7) = 21.31 Prob > chi2 = 0.0033		
*** 1%, ** 5%, * 10%									

Source: Illustrated by authors.

The FGLS approach outcomes were used in this section to assess the hypotheses, and then our outcomes were compared with those of other authors. Firstly, we demonstrated the significance of each of the models M1 and M2, with Prob> chi2 = 0.0000 and Prob> chi2 = 0.0033, respectively.

Hypothesis H1 is confirmed. The outcomes in model 2 showed that the personal income tax has a significant adverse effect ($p< 0.1$) on the growth of developed nations, whereas the effect in model 1 was positive but insignificant. The GDP per capita decreases by an average of 0.16% for every 1% rise in the percentage of PIT income in the GDP. Several studies have shown similar results (Macek, 2015; Widmalm, 2001; Dackehag & Hansson, 2012; Xing, 2011; Elshani & Ahmeti, 2017; Arnold, 2008; Acosta-Ormaechea et al., 2019; Elshani & Pula, 2023; Alfo et al., 2022). A rise in PIT can cause disposable income to reduce, which in turn causes a dip in the rate of savings and consumption and raises the chances of unfavorable effects on growth.

Hypothesis H2 is accepted. Corporate income tax has a beneficial and significant effect on growth. An increase of 1% in CIT's share of the GDP results in an average 0.15% boost in GDP growth. This tax has an insignificant but favorable effect on GDP per capita. Other research revealed similar results (Elshani & Pula, 2023; Stoilova, 2017; Angelopoulos et al., 2007; Kate & Milionis, 2019; Elshani & Ahmeti, 2017; Hoang et al., 2021). This conclusion could be explained by the fact that CIT is an important part of financing tax revenue investment in public services. Consequently, this tax contributes to the growth of the economy (Hoang et al., 2021).

The third hypothesis is accepted. VAT revenues have an adverse and significant ($p< 0.05$) influence on GDP and GDP per capita. According to our findings, a 1% rise in the share of VAT income in GDP indicates a 0.33% decrease in GDP in the developed nations studied. An average reduction of 0.34% in GDP per capita occurs when the participation of this tax in GDP increases by 1%, as the significance of the finding was $p<0.1$. Our findings match those of Alm and El-Ganainy (2012) and Stoilova (2017). One possibility for this result could be that customers' increased prices due to the VAT rise motivate them to consume less. Consequently, when consumption as an element of GDP reduces, an unfavorable effect on growth might occur. It should be noted that some researchers (Elshani & Ahmeti, 2017; Acosta-Ormaechea & Yoo, 2012; Chiricu, 2019; Elshani & Pula, 2023) have been able to determine a favorable effect of VAT on growth.

Hypothesis H4 is fully accepted. Within the revenues from specific goods and services, customs and excise have a beneficial and significant ($p<0.01$) influence on growth. Whereas a rise of 1% in the share of revenues from specific goods and services in the GDP influences GDP growth in these countries by an average of 0.91%. Some authors, like Owino (2019) and Ibadin & Oladipupo (2015), reached similar conclusions. Taxes on goods and services enhance growth in rich nations (Haong et al., 2021).

Apart from a discussion of the outcomes, we looked at a few more research outcomes. The growth of GDP per capita is negatively and significantly ($p < 0.1$) influenced by social security contributions. Our findings are consistent with those of some authors, such as Acosta-Ormaechea et al. (2019); Furceri & Karras (2008); Vintila, et al. (2021). This is because social security contributions are paid to finance social welfare, which does not generally result in growth (Feldstein, 1974). Our findings show that property taxes have an insignificant but adverse impact on GDP per capita. Additionally, Furceri and Karras (2008) demonstrate that GDP per capita is negatively affected by property taxes, although their findings do not seem to be statistically significant.

5. Discussion and conclusions

In this research, ten advanced nations were chosen based on the Human Development Index, and the influence of taxes, both direct and indirect, on economic growth was examined. The results of several researchers have been provided through this review; these results were then compared to our own. We came up with hypotheses based on the literature review. Regarding how various taxes influence development, we put forth four hypotheses. All hypotheses that have been put forth have been verified.

We concluded that the personal income tax, as a direct tax, has an adverse effect on growth, whereas, in the second model, this effect was statistically significant and, as such, should be kept at low levels to encourage growth through higher consumption. This was found after evaluating the influence of various types of revenues from taxes on the growth of the advanced nations covered by this paper. From our analyses, we conclude that GDP per capita decreases by an average of 0.16% for every 1% rise in the percentage of PIT.

Meanwhile, the economies of these nations were favorably impacted by the corporate income tax, another form of direct tax that was important in the first model. Regarding the value-added tax, we discovered that, in each model, this kind of indirect tax had a significant and adverse effect on growth. Whereas, the growth of these states has been positively and significantly affected by the Tax on Specific Goods and Services, an indirect tax. Regarding our results, an increase of 1% in the CIT reflects on an average 0.15% boost in GDP growth.

According to our findings, a 1% rise in the share of VAT income in GDP causes a 0.33% decrease in GDP in the developed nations included in our study. An average reduction of 0.34% in GDP per capita occurs when the participation of this tax in GDP increases by 1%. With these results, we confirm that VAT has an impact on GDP and GDP per capita. Also, as confirmed in our fourth hypothesis a rise of 1% in the share of revenues from specific goods and services in the GDP influences GDP growth in these countries by an average of 0.91%.

It is obvious that development can be assisted by an optimal tax structure. Thus, to reach the goal of growth, policymakers should concentrate on identifying that structure. The analyzed nations' growth is positively impacted by the rise in SGST and CIT revenue collection. As a result, these taxes need to be considered on the way to attaining economic growth.

We recommend policymakers consider the benefits of corporate income taxation and specific goods and services taxes for growth. To reduce the adverse effect on growth, it is also useful to consider the unfavorable impacts of value-added tax and personal income tax.

Countries should work toward creating a fiscal environment that encourages saving and investment and provides work incentives. The negative impact of income tax means that many other factors can affect the economic growth of a country in addition to tax structures, for example, socio-political factors and technology.

This finding provides additional support and confirmation to the existing research on how different tax structures may impact the economic growth of a particular country

differently. Hence, policymakers are recommended to revisit the tax structures of their countries if they want to enhance the positive impact of taxes on their countries' economic development, explicitly securing more investment and reducing the unemployment rate.

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Predicting Mortgage Loan Defaults Using Machine Learning Techniques

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Abstract. Mortgage default prediction is always on the table for financial institutions. Banks are interested in provision planning, while regulators monitor systemic risk, which this sector may possess. This research is focused on predicting defaults on a one-year horizon using data from the Ukrainian credit registry applying machine-learning methods. This research is useful for not only academia but also policymakers since it helps to assess the need for implementation of macroprudential instruments. We tested two data balancing techniques: weighting the original sample and synthetic minority oversampling technique and compared the results. It was found that random forest and extreme gradient-boosting decision trees are better classifiers regarding both accuracy and precision. These models provided an essential balance between actual default precision and minimizing false defaults. We also tested neural networks, linear discriminant analysis, support vector machines with linear kernels, and decision trees, but they showed similar results to logistic regression. The result suggested that real gross domestic product (GDP) growth and debt-service-to-income ratio (DSTI) were good predictors of default. This means that a realistic GDP forecast as well as a proper assessment of the borrower's DSTI through the loan history can predict default on a one-year horizon. Adding other variables such as the borrower's age and loan interest rate can also be beneficial. However, the residual maturity of mortgage loans does not contribute to default probability, which means that banks should treat both new borrowers equally and those who nearly repaid the loan.
Keywords: machine learning, classification, default prediction, mortgage lending, random forest, extreme gradient-boosting decision tree

1. Introduction

Loan default prediction remains a critical area of research for financial institutions. Accurate prediction of borrower insolvency lowers credit risk and enables correct short- and medium-term provisioning planning. Default rate shocks cannot be prevented, and some borrowers default anyway, but banks should do everything to lower their losses.

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One of the key segments of financial markets, especially in developed countries, is mortgage lending. Mortgages possess special interest because they have two features: significant loan sums and long terms. In case of default, these features correspond to significant financial losses. That is why it is crucial for banks to predict borrowers' default in this segment.

Machine learning (ML) methods open new horizons for default prediction. According to the recent Bank of England report, more than 72% of all financial services in the UK already use machine learning (Bank of England, 2022). ML techniques can provide new insights into economic data and prove that the relationship between factors is more complex than was believed earlier. Large borrower-level datasets are usually used for estimating the probability of borrowers failing to repay their loans and are most suitable for training and testing models.

Financial institutions use a variety of machine learning methods. The central bank of Russia combined logistic regression and random forest to predict the probability of default of non-financial corporations (Buzanov & Shevelev, 2022). Banks in Ecuador use artificial neural networks (Rubio et al., 2020). German financial company Kreditech uses natural language processing for credit scoring (Datsyuk, 2024).

In this paper, we consider two goals. Firstly, we aim to analyse the predictive power of ML models in comparison with traditionally used logistic regression in credit risk assessment. More specifically, we predict which borrowers will become insolvent on a one-year horizon based on macroeconomic, borrower, and loan-specific factors. We expect that ML methods such as random forest, extreme gradient boosting trees and others may perform better than the logit model due to their capacity for capturing non-linear relationships within the data.

Secondly, the goal of this research is to check which factors contribute to the default probability the most. For example, the debt service-to-income ratio indicates the difficulty of repaying debt by the borrower, and we expect that it will significantly influence the default probability irrespective of the model.

Thus, our research questions are:

- Which machine learning modelling techniques can predict the default of mortgage borrowers the best?
- Which factors contribute to the borrower default and which of them have the highest importance?

The paper was organized as follows. In the second section, we described the literature related to both ML modelling as well as data preparation techniques. The third section is devoted to the data analysis, specifically, which variables we used and why. In the fourth section, we described our methodology. The results are described in the fifth section and, finally, in the sixth section. We made conclusions regarding which models are useful for credit risk assessment as well as which variables contribute to default probability and which problems ML methods will solve in credit risk assessment.

2. Literature review

Credit registry data are widely used for credit risk assessment using ML methods across countries since these datasets are large enough to train and test models by various dimensions. In the following text, we describe the two most important streams of literature: ML usage to the probability of default estimation and dataset balancing techniques.

There is extensive literature on the efficiency of ML algorithms in credit risk assessment. One of the most influential papers by Doko et al. (2021) presented the application of different ML techniques to create an accurate model for credit risk assessment using the data from the credit registry of the Central Bank of the Republic of North Macedonia. The authors estimated several approaches to find the most optimal model. They used the following: logistic regression, support vector machines, random forest, neural network, and decision tree, and concluded that the decision tree is the most efficient in their case.

Turkson et al. (2016) tested 15 ML algorithms both supervised and unsupervised on the University College London dataset to find that except Naïve Bayes and Nearest Centroid all other algorithms perform well and close to each other (accuracy rate of 76-80%). They also examined and selected the most important features that contribute to the default probability. The results in this paper show that the age of the borrower is one of the most important variables that have a positive relationship with default probability.

Dumitrescu et al. (2022) developed the original idea – penalized logistic tree regression. They combined lasso logistic regression with predictions extracted from the decision tree. The authors tested this approach on three real-life datasets and Monte Carlo simulations and found that with an increasing number of predictors the efficiency of this method is better than for logistic and random forest models.

Filatov and Kaminsky (2021) used unique granular data from the Ukrainian credit registry to suggest a scoring model for default monitoring. The authors proved that a simple logistic model is useful for calibrating macroprudential instruments such as DSTI or DTI. Another valuable finding is that contributions of certain factors to the default probability were not linear, and sometimes it is essential to use quadratic terms (for credit risk, interest rates, and confirmed income in their case). This study used only one ML method – XGBtree – that proved to be slightly better than the logistic regression.

Liashenko et al. (2023) used ML methods to predict bankruptcies of US firms. They found that neural networks and decision trees outperform other models. The authors also dealt with another issue – an unbalanced dataset.

Usually, the credit registry data is highly unbalanced – the number of defaults is very small. In that regard, some researchers suggest using balancing techniques to improve model quality. One of the most popular approaches is the synthetic minority oversampling technique (SMOTE), the idea behind which is to create an additional number of observations based on features in the dataset. Doko et al. (2021) used it to prove that ML estimation results are much better than on unbalanced data. Shen et al. (2019) reinforce this point and insist that for neural networks SMOTE is necessary. Batista et al. (2004)

used 13 UCI repository datasets with different class imbalances to test four oversampling methods. They came up with more difficult versions of the SMOTE algorithm to show that they increased the performance of the decision tree model in comparison to the original dataset. Gupta et al. (2023) compared how the XGBoost classifier would perform on SMOTE-synthesized, Random Over Sampling (ROS), and Random Under Sampling (RUS) credit card fraud data. They concluded that ROS is slightly better than SMOTE based on precision and accuracy scores.

Another way of dealing with data imbalances is weighting data. When estimating model coefficients or splitting trees the relative importance of certain classes can be increased. This idea was highlighted by Xu et al. (2020). According to the authors, the weighting leads to a higher precision of predicting minority class but may lower overall accuracy since the majority class will be wrongly classified. Bakirar and Elhan (2023) used several weighting methods and proved that for random forests the weighting based on the square root of class frequency works better than other methods.

There are also methods of improving the data quality. Costa et al. (2022) built a model of isolation forest that detected anomalies in the credit registry data. Li et al. (2021) tested different ways of data cleaning and proved that removing missing values and fixing mislabelled data is likely to improve the classifier prediction.

This paper contributed to the existing literature in two ways. Firstly, we applied data-weighting and SMOTE algorithms to the unbalanced data. Then we estimated ML models and compared the results based on the accuracy and precision of default prediction. Secondly, we used a variety of variables for modelling both borrower-specific and macroeconomic and checked whether they were useful for predicting default.

3. Data

Currently, banks calculate the probability of default under Regulation 351, which is the main regulation on credit risk estimation in Ukraine. It sets strict rules on how banks should calculate the probability of default, loss given default, and exposure at default which together combine into credit risk metric. Banks should take into account debt burden to income, credit history and days overdue to compute PD. Banks may assess other information such as the income of other household members, but the verification of that data may be challenging. Financial institutions still face obstacles, such as confirmation of borrower's stable income and checking credit history, especially for new borrowers. Regulation 351 does not contradict International Financial Reporting Standards 9 (IFRS 9) but rather complements them. Banks still assess both lifetime and one-year horizon probability of default in line with the IFRS 9. Since the data is limited to 2020–2023, we assess only one-year horizon probability, which is in line with IFRS 9 and is reflected through a dependent variable. Besides a significant number of mortgages in the data were issued during 2021–2022, so that assessing lifetime PD is impossible for them.

In this study, we used unique data from the Credit registry developed and supported by the National Bank of Ukraine (NBU) between 2020 and 2023. Since the floor for being registered in the Credit registry is an initial loan sum of 50,000 hryvnia (UAH) equivalent (currently, around 1200 euro), the data for mortgages are presented fully. The frequency of data for this study is quarterly, which was transformed into annual because the probability of default according to Regulation 351 is calculated on a one-year horizon.

We subset only data on households, which have at least one mortgage denominated in national currency (UAH) and issued after 1 January 2005. The data have been cleaned from both denominated in foreign currency mortgages and restructured foreign currency into UAH mortgages since they do not reflect market rates and quality. The restructured mortgages have very different structures across banks, which means that loans with the same formal characteristics (term, interest rate, and sum) may actually be very different in accounting. We also excluded borrowers without any registered income and those who are in default on the mortgage for the whole timespan.

We define the dependent variable as a binary default indicator, which was calculated as follows. If the household was in default on its mortgage on 1 January of a given year, such a borrower was excluded for this year. If the borrower was not in default on its mortgage on the 01 January of a given year and then did not default during the year, the default indicator equals 0. Otherwise, if the borrower was not in default on its mortgage on 1 January of a given year and then defaulted during the year, the dependent variable equals 1. As a result, we obtained a dataset with only 6% of defaults, that is, highly unbalanced. This number corresponded to banks' assessment of the probability of default on the given time horizon. Consequently, we used a maximum of four data points for each borrower (corresponding to default status in 2020, 2021, 2022, and 2023). The schematic representation of the construction process of the dependent variable is shown in Figure 1.

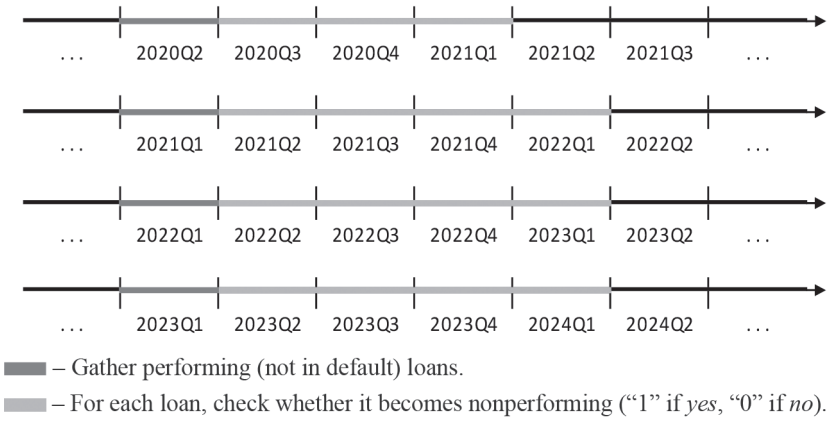

Figure 1. Construction of the Dependent Variable

Source: own elaboration based on Dirma and Karmelavičius (2023).

Borrower-specific variables were taken as of 1 January of the respective year. The macroeconomic variable was set to be equal to the actual GDP growth of the year. That is done to distinguish the effect of general macroeconomic conditions on all borrowers from individual metrics.

One of the most important metrics for credit risk models is a debt-service-to-income ratio (DSTI), which points out the ability of the borrower to serve their debt. The idea of DSTI inclusion is that borrowers with higher DSTI will default more often. In countries where DSTI is an active policy instrument, values around 40% are believed to be a limit after which the borrower may possess additional credit risk for banks. Following Nier et al. (2019), we got rid of DSTI values higher than 300%. The reason for such high DSTIs lies in the field of income confirmation. Banks in Ukraine do not pay much attention after loan issuance to income verification and updating. As long as the borrower pays on time, there is a chance that banks will not update data. The DSTI was calculated for each loan and then aggregated on the borrower level as a simple sum.

The borrower's age is another crucial indicator that influences the probability of default. For example, in Slovakia, policy measures are different for different age groups. It is more difficult for elderly people to find the new job if needed. In Ukraine, mortgages are provided only if the person is under 60 years old as of the maturity date. That is why we expect that a higher age would contribute to a higher default probability.

One more popular variable in credit risk studies is income. Filatov and Kaminsky (2021) used the quadratic term of this variable. Interestingly, their results imply that after a certain critical point income contributes positively to default. They indicated that the reason for this result is that the data quality of the Ukrainian credit registry is low, and data points with high income cannot be fully trustworthy.

We also included the loan characteristics, such as residual maturity in years and interest rate. Nier et al. (2019) proved that residual maturity is a very powerful and robust predictor of default. They found that the more time is left to pay the loan, the higher the probability of default. Moreover, Doko et al (2021) found that both maturity and interest rate have high and significant information values for default prediction.

This study also incorporated credit risk metrics assessed by banks. Filatov and Kaminsky (2021) findings show that credit risk indicator based on Ukrainian Credit registry data has a hump-shaped impact on default probability.

Since all borrowers are influenced by general macroeconomic conditions, we incorporate the real GDP growth. We expect that the GDP growth is positively associated with the default probability: when the economic crises hit in 2020 and especially in 2022 in Ukraine, we observed higher default rates than in relatively calm 2021.

The final list of indicators for modelling and their descriptive statistics are presented in Table 1. The number of observations is 35828, with a unique number of borrowers equal to 18057. Annex A presents additional statistics for each variable.

The multicollinearity could be an issue for this ML study since we were interested in variable importance. From Table 2 we can conclude that no variables correlate much, and we can use them in the model.

Table 1. List of variables.

Variable	Level	Unit of measurement	Min	Max	Median	Mean	Proportion of zeros, %
Annual income	Borrower	Thousand UAH	0	320983	340	749	0
DSTI	Borrower	%	0	300	22	34	2
Age	Borrower	Years	21	72	39	40	0
Mortgage interest rate	Loan	%	0	60	14	13,6	5
Aggregate borrower credit risk	Borrower	Thousand UAH	0	23906	3,4	18,5	6
Residual maturity of mortgage	Loan	Years	0	32	13,6	12,6	0,3
GDP growth	Macroeconomy	%	-29,1	5,2	-3,45	-7,5	0

Source: own calculations based on the NBU's Credit registry

Table 2. Correlation matrix of variables

	DSTI	Age	Credit risk	Annual income	Mortgage interest rate	Residual maturity of mortgage	GDP growth
DSTI		0,05	-0,0008	-0,09	0,11	-0,03	-0,12
Age	0,05		0,02	0,0009	0,04	-0,37	0,005
Credit risk	-0,0008	0,02		0,01	-0,07	0,002	0,01
Annual income	-0,09	0,0009	0,01		0,0006	-0,01	0,01
Mortgage interest rate	0,11	0,04	-0,07	0,0006		-0,08	0,03
Residual maturity of mortgage	-0,03	-0,37	0,002	-0,01	-0,08		-0,01
GDP growth	-0,12	0,005	0,01	0,01	0,03	-0,01	

Source: own calculations based on the NBU's Credit registry

4. Methodology

For classification tasks, the distribution of classes is crucial. As discussed above, our dataset is unbalanced, and it will be challenging for models to capture this nature. Moreover, it is more important for the bank to predict default in advance and act, rather than to believe that the borrower will continue to pay. There are two ways of handling the imbalance problem without changing the dataset: weight assignment and cost-sensitive

learning. Setting efficient costs for type 1 and type 2 errors is an exercise that demands another research. The reason for that is that banks, after classifying the borrower as risky, are required to form reserves. For loans accounted on a group basis (most popular for mortgages) it means that reserves must be equal to 100% of the estimated risk, which is costly. That is why in this study, we used the weight assignment technique. To check the robustness of weighting, we also used the SMOTE algorithm, which is a popular method in credit risk studies.

4.1. Data preparation

The idea of weight assignment is that in the training phase of the model observations of different classes are assigned different weights. Since banks care more about default (the ones in our data), we assigned a higher weight to them. The advantage of this method is that it is simpler than other ones and does not change the sample. The disadvantage is the difficulty of assigning efficient weights that will maximize true positive values and minimize loss in overall accuracy. The weight of defaults was chosen to be inversely proportional to their number in the original dataset.

$$w_k = \frac{1}{n_k} \tag{1}$$

where
w_k – weight of unit in class k
n_k – number of units in class k

Sample manipulation is a widespread group of methods in ML. One of the most popular methods that are used for credit risk modelling is SMOTE. It artificially creates an additional number of "defaults" and makes data balanced. The algorithm finds the difference between the given point and its nearest neighbour. This difference is multiplied by a random number in the interval from 0 to 1. The obtained value is added to the given point to form a new synthesized point in the feature space. Similar actions continue with the next nearest neighbour, up to the point when the sample will become balanced.

4.2. Modelling techniques

The classical classification methods are binary choice models, in particular a logistic regression (hereinafter logit). The main advantage of this model is its simplicity and easy interpretability. However, there are many disadvantages including linearity between dependent and independent variables and problems to work with datasets containing many features. That is why in this study we applied other methods as well. ML methods suggest new ways of separation between classes and as a result, provide high efficiency classification. The logit model would be the basis for comparison.

The models were chosen based on several papers that also studied credit risk. Doko et al. (2021) used logistic regression, decision trees, random forests, support vector ma-

chines, and neural networks. Kaminsky and Filatov (2021) applied XGBTree. Turkson et al. (2016) also applied linear discriminant analysis.

Linear Discriminant Analysis (LDA) is a statistical method aiming to find optimal linear combinations of features that maximize the separation between different classes. By projecting data onto a lower-dimensional space, LDA seeks to capture essential information while minimizing class overlap. Assumptions include multivariate normality and equal covariance across classes, rendering LDA effective when these assumptions hold. It is widely utilized in classification tasks where interpretability and dimensionality reduction are paramount (James et al., 2013).

Support Vector Machines (SVM) aim to find an optimal hyperplane that maximizes the distance (called margin) between different classes in feature space. SVM excels in high-dimensional spaces and can handle non-linear relationships through kernel functions. By focusing on the most critical data points, or support vectors, SVM delivers robust classification performance. For this research we used a linear model, leaving more complex ones for future studies. Mathematically, the optimization problem that is solved by this kind of model is given as follows (James et al., 2013):

$$\max M \; s.t. \sum_{j=1}^{p} \beta_j^2 = 1; \; y_i \left(\beta_0 + \sum_{j=1}^{p} \beta_j x_{i,j} \right) \geq M(1 - \epsilon_i)$$
$$\epsilon_i \geq 0, \sum_{i=1}^{n} \epsilon_i \leq C \tag{4}$$

where
M – margin to optimize
ϵi – errors allowing observations to be on the wrong side of the plane
C – nonnegative tuning parameter

Classification and Regression Trees (CART) construct binary trees by recursively partitioning data based on feature splits. The algorithm optimizes impurity measures, such as the Gini index. CART's simplicity, interpretability, and ability to handle both categorical and continuous data make it a versatile tool for classification tasks. For this method, it is especially crucial to make a trade-off between interpretability and accuracy. The more complex trees may produce better-classifying properties but are very difficult to understand.

Random Forest (RF), which is a more complicated version of CART, builds an ensemble of decision trees using bootstrap sampling and feature randomness. By aggregating predictions from multiple trees, it mitigates overfitting and enhances overall model accuracy. Random Forest excels in capturing complex relationships and interactions in diverse datasets. The significant plus of the RF models is that they overfit less than methods. The

algorithm works by calculating the weighted Gini index and optimizing it to find the minimum one (Saini, 2022). For the binary data like in this study, the formula looks like this:

$$Gini_i = f_{left} * (1 - (P^2_{+,left} + P^2_{-,left})) + f_{right} * (1 - (P^2_{+,right} + P^2_{-,right})) \quad (2)$$

Where:
$Gini_i$ – Gini index at node i
f_{left} – fraction of values that went to the left on the split
f_{right} – fraction of values that went to the right on the split
P_+ – probability of getting positive class
P_- – probability of getting negative class

XGBoost, an implementation of gradient boosting, focuses on maximizing computational efficiency and predictive accuracy. The XGBtree variant employs tree-based models, combining multiple weak learners to form a robust classifier. Through gradient boosting, XGBoost sequentially corrects errors of preceding models, showcasing superior performance in various domains. Its versatility, scalability, and adaptability to diverse datasets make XGBtree a popular choice for complex classification challenges. According to Beeravalli (2018), it is one of the most balanced methods for credit risk assessment. Filatov and Kaminsky (2021) also concluded that this method is applicable to credit risk assessment using Ukrainian data.

Comprising layers of interconnected artificial neurons, Neural Networks (NNET) leverage backpropagation to iteratively adjust weights, adapting to intricate patterns. Their capacity for hierarchical feature learning and representation makes them highly effective in capturing non-linear dependencies, making Neural Networks suitable for classification tasks where intricate relationships exist. The main definitions for Neural networks are weights and biases. Weights are coefficients that are multiplied by indicators. Bias is the constant that is added to the product of features and weights. The formulas for updating the network at each step are the following:

$$w_{new,i} = w_{old,i} + learning\ rate * error * x_i,$$
$$bias_{new,i} = bias_{old,i} + learning\ rate * error, \quad (3)$$

where
w_{new} – new weight of variable i
w_{old} – old weight of variable i
$bias_{new}$ – new bias of variable i
$bias_{old}$ – old bias of variable i
learning rate – parameter that determines the size of the update step

4.3. Variable importance

One of the goals of this study was to assess which variables can be used as the best predictors for the default. This will be done through variable importance analysis. Since we used several ML methods, we should go through what is variable importance (VI) for each of them.

In Logit and LDA models, VI is based on the magnitude of the estimated coefficients. Larger coefficients suggest a stronger impact on the response variable. This method does not cause problems if we use linear models, however, adding interactions or polynomials may lead to "borrowing" importance between variables. In SVM models, coefficients are called "weights", but the idea is the same: larger weights suggest a more important role in determining decision boundary.

In CART and RF models, VI is calculated based on the decrease of the Gini index at each split. The bigger in magnitude is the decrease in the Gini index, the more significant the variable is.

VI in XGBtree models provides a score that shows how useful a variable was in the construction of the tree. The more an attribute is used to make split decisions, the higher would be VI.

The VI analysis can also be applied to neural networks. We applied the methodology first proposed by Garson (1991). The basic idea is that the relative importance is calculated as a sum of all weighted connections between nodes that correspond to the variable of interest.

All variable importance scores were normalized in such a way that the most important variables would have a score value of 100, and the least important - 0. Where coefficients can have different signs (like in Logit or SVM), the absolute value was used for calculation.

4.4. Final methodological considerations

To test the efficiency of each method, we split the data into training and testing sub-samples. There are no direct rules for the ratio of data split into training sets; however, standard practices use 70%/30%, 67%/33%, or 80%/20%. We chose the 70%/30% rule as the main one and other rules as robustness checks. We used the training sub-sample to estimate the parameters and the testing sub-sample to see the out-of-sample effectiveness. Cross-validation was included in the training phase with some folds equal to 100. Based on the test sample we calculated AUROCs and made a DeLong's test for statistical difference between them. We followed the simple DeLong's methodology as in DeLong et al. (1988). All variables have been scaled in a preprocessing stage, so the impact of different variables on the default outcome was comparable.

All models were compared via three dimensions. The first one is classification metrics such as accuracy, F-score, AUROC, and precision. The second dimension lies in the field of variable importance. There we concluded which variables play the most important role in default prediction. If the variable turned out to be important for several models, then it was robust to specifications, and we concluded that a change in that variable would

lead to a change in default probability. Finally, we repeated this exercise for the weighted original sample and the sample after the SMOTE algorithm, to compare which method is more accurate for default prediction.

5. Estimation results

In this section, we presented the results for 7 ML models estimated on two datasets.

5.1. Weighted data

We started by analysing weighted original sample results. Figure 2 presents ROC curves with respective AUROC values. We observed that the logit model performed well both in terms of overall accuracy and precision of default prediction. However, it is worth mentioning that despite only 564 defaults in the test sample, the logit model predicted more than 3000. This result highlights the necessity to use more complex models because the model overshooted even though the data has been weighted there. The SVM and LDA models showed the worst results since they could not predict any defaults at all. Random Forest and XGBtree had significantly better performance in comparison to logit based on the AUROC metric and it was tempting to say that they would be the best for credit risk assessment.

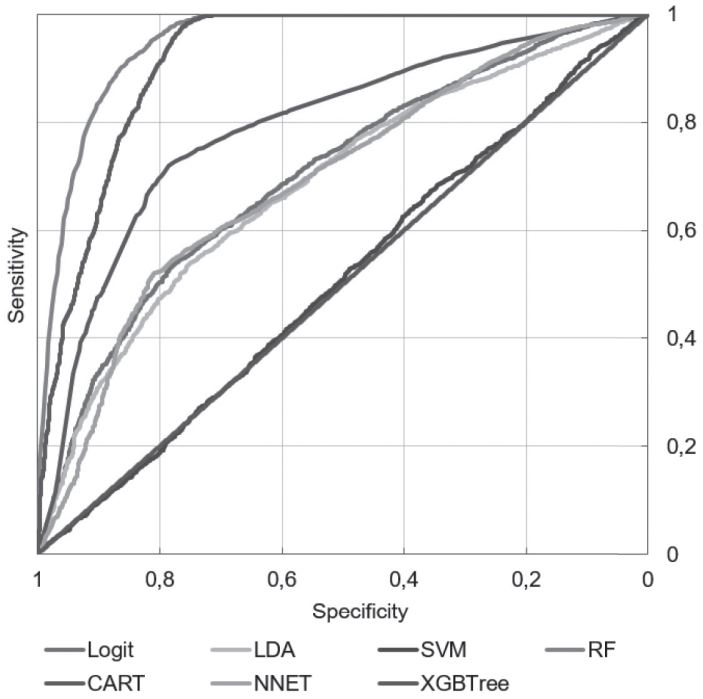

Figure 2. Efficiency of selected models on the weighted original sample
Source: calculated by authors

According to the results in Table 3, Models like Neural Net, CART, and logit due to a much higher number of predicted defaults in general, predicted a high number of correct defaults. However, since the correct number of defaults was only 564 it means, that usage of these models will predict thousands of excess defaults, which is also too risky for financial institutions. RF and XGBtree predict more correct defaults, with a lower number of false defaults. They do not overshoot with type 1 errors that much. These models provided the essential balance. It is also important to mention that all pairs of models except the NNET-LDA pair passed DeLong's test for statistical difference between ROCs. From here, we conclude that RF and XGBtree showed the most accurate results based on predictive metrics not only in comparison to baseline logit but also among all presented models.

Table 3. Prediction results of selected models on the weighted original test sample

Model	Logit	LDA	CART	RF	SVM	NNET	XGBtree
Predicted number of 0	6990	10745	6377	8694	10747	6673	8973
Predicted number of 1	3757	2	4370	2053	0	4074	1774
Proportion of correct default prediction (precision), %	67	0,2	77	92	0	72	96
F1 - score	0,18	0,004	0,18	0,89	0	0,17	0,9

Source: calculated by authors

Table 4 presents results of variable importance. For the logit model GDP growth, credit risk, and age showed the biggest in magnitude impact on the probability of default. If we take a broader look at all models, it was quite expected that GDP growth would be a good predictor of default because in four models it turned out to be the most important one. However, in RF and XGBtree models it turned out the least important variable. The reason for that lies in the field of how VI is calculated for these models. Zero for tree-based models means that there are very few nodes in which GDP participates. The dataset includes only 4 years, so there is not enough variation for the model to make decisions based on macroeconomic conditions. Rolling window approach as well as gathering more data in the future is going to solve this problem.

According to the models' results, DSTI also contributed a lot to default probability, especially in the XGBtree model (most important) and RF (second most important), which proved to be the best in the previous analysis step. It means that NBU can use it for its policy purposes. In contrast to similar studies, residual maturity did not play an important role in causing defaults. This means that banks' monitoring policy should treat equally borrowers with high residual maturity as well as those who nearly repaid the debt.

As an interim summary, we could say that RF and XGBtree models suit better than Logit to estimate the default probability on a one-year horizon. They perform well in terms of overall accuracy and precision in insolvency prediction. The results of models slightly contradict which variables contribute more to the default probability, so let's see how SMOTE estimations performed.

Table 4. Variable importance scores for selected models on the weighted original sample

Variable	Logit	LDA	CART	RF	SVM	NNET	XGBtree
DSTI	10,31	25,07	25,92	83,18	25,07	0	100
Income	8,66	30,08	32,26	81,90	30,08	0,06	93,74
Age	29,03	28,27	35,97	81,35	28,27	29,01	87,05
Interest rate	20,82	30,79	36,01	53,97	30,79	31,01	76,75
Credit risk	49,24	69,89	100	100	69,89	44,32	65,69
Residual maturity	0	0	20,9	67,78	0	28,51	55,88
GDP growth	100	100	0	0	100	100	0

Source: calculated by authors

5.2. SMOTE-synthesized data

According to Figure 3, the ROCs looked nearly the same as on the unbalanced sample, except for the LDA model. DeLong's test for the difference between AUROCs failed for LDA-SVM pairs, which is interpreted as that their overall accuracy was very close.

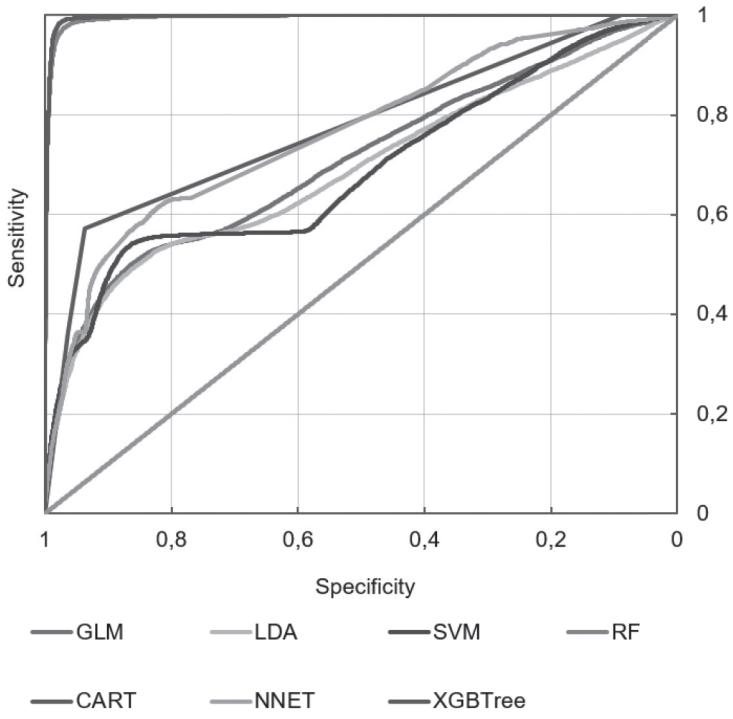

Figure 3. Efficiency of selected models on the SMOTE sample

However, when we checked the precision (Table 5), we observed that all models except for RF and XGBtree again overshoot with the total number of defaults. Moreover,

even though RF and XGBtree predicted fewer defaults than other models, they predicted more defaults that were correct this time, which is especially crucial for banks. Because SMOTE made the sample balanced, the precision of all models increased.

Table 5. Prediction results of selected models in the test sample

Model	Logit	LDA	CART	RF	SVM	NNET	XGBtree
Predicted number of 0	9935	10305	8896	10390	10196	10335	10415
Predicted number of 1	10416	10046	11455	9961	10155	10016	9936
Proportion of correct default prediction (precision), %	70	66	80	90	67	77	92
F1-score	0,68	0,66	0,76	0,91	0,67	0,77	0,93

Source: calculated by authors

Now let us check which variables contribute to the default probability on the balanced synthesized data. Models on these data were not much different from the previous ones. GDP growth, Credit risk, and DSTI variables turned out to be the best predictors. Surprisingly XGBtree and RF models that showed the best results on the weighted original sample, revealed contradictive results after SMOTE. While XGBtree was in line with its previous conclusion that DSTI was the most important variable, the RF model showed that it was among the least important ones. That is also counterintuitive because for the RF model partial dependency of default outcome on DSTI was high on both original data and SMOTE, which is illustrated in Annex B. The reason for that is that in this kind of model, importance means taking part in splitting trees. Partial dependence, on the contrary, shows how changing the predictor by 1 unit will change the probability of the outcome. Therefore, even though there are not many nodes where DSTI took part in the decision, it is still significant in general.

Table 6. Variable importance scores for selected models on the SMOTE sample

Variable	Logit	LDA	CART	RF	SVM	NNET	XGBtree
DSTI	9,75	47,31	11,96	2,79	47,31	58,67	100
Income	0	14,7	0	2,22	14,7	0	60,28
Age	28,61	28,42	0,99	0	28,42	38,02	45,15
Interest rate	19,44	31,26	14,05	20,08	31,26	61,65	38,93
Credit risk	49,15	100	35,13	8,39	100	26	14,23
Residual maturity	1,84	0	9,1	10,16	0	57,17	13,52
GDP growth	100	79,26	100	100	79,26	100	0

Source: calculated by authors

Annex C presents the robustness checks based on other train-test splittings, namely, 80%/20% and 67%/33%. We compared the overall performance of the models and concluded that the results are not much different for both weighting and SMOTE-synthesized datasets, which means that the current specification is robust. XGBtree model still shows the best accuracy and precision results.

6. Conclusions and recommendations

In this study, we examined how Credit registry data can predict the default of borrowers with mortgages using machine learning techniques.

First, we showed that Random Forest and XGBtree models were the most suitable for insolvency prediction among ML modelling techniques and showed better performance than logistic regression. They provided the essential balance between correct default classification and minimizing false defaults. These models showed robust results and predicted defaults most efficiently on both weighted data and SMOTE-synthesized.

Second, GDP growth and DSTI turned out to be the best predictors of mortgage default on a one-year horizon independent of the data sample and its transformations. This result is useful for both banks and policymakers. On one hand, it means that banks in general adequately measure credit risk, and on a one-year horizon borrowers become insolvent if the risk increases. On the other hand, DSTI is an effective policy instrument that can mitigate risk accumulation. For example, the National Bank may introduce new capital measures for borrowers with high DSTI. Furthermore, adequate GDP forecasting can lead to increased accuracy in default probability.

Third, the study explored data balancing techniques. The findings are that models estimated on the SMOTE sample showed better performance than those on data weighted sample. In further studies, the authors will investigate other balancing techniques.

As policy recommendations for the regulator, we suggest that NBU may accelerate with DSTI introduction as a macroprudential instrument. This could potentially decrease the number of defaults in the future. As to recommendations for commercial banks, they should pay close attention to all borrowers irrespective of their loan maturities. It is essential for them to direct their focus to income verification because it is the key to correct DSTI calculation. Using DSTI as a proper instrument could help NBU monitor the systemic risk in household lending, while commercial banks will do provisioning on time.

Further borrower insolvency studies can help banks detect the realisation of credit risk in advance and take action. Machine learning will play a key role here since traditional logistic regression is limited in its capabilities to capture complex relations. ML methods can maximize the accuracy of forecasting, at the same time minimizing false default predictions. Moreover, machine learning models can offer insights into patterns within the data that traditional methods might overlook. Incorporating in future collateral characteristics in the study may also provide insights not only into the PD estimation but also its relationship with a loss given default, which is still a question for Ukrainian banks.

ML methods can explain this relationship better than traditional linear or logistics models.

The dataset used in this research used the period of 2020–2023. As a further extension, the authors will broaden the horizon to 2024. Further studies will also include testing other time periods like 2021–2023 or 2021–2022. This could potentially lead to other factors playing a role, which in turn can change the predictive power of the model.

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Annexes

Annex A. Additional statistics of data (without 5% of outliers)

Variable	Skewness	Kurtosis
Annual income	1,5	1,89
DSTI	1,14	1
Age	0,54	0,06
Mortgage interest rate	-0,09	2
Aggregate borrower credit risk	2,08	4,3
Residual maturity of mortgage	-0,15	-1,05
GDP growth	-0,66	-1,44

Annex B. Partial dependency plots (PDP)

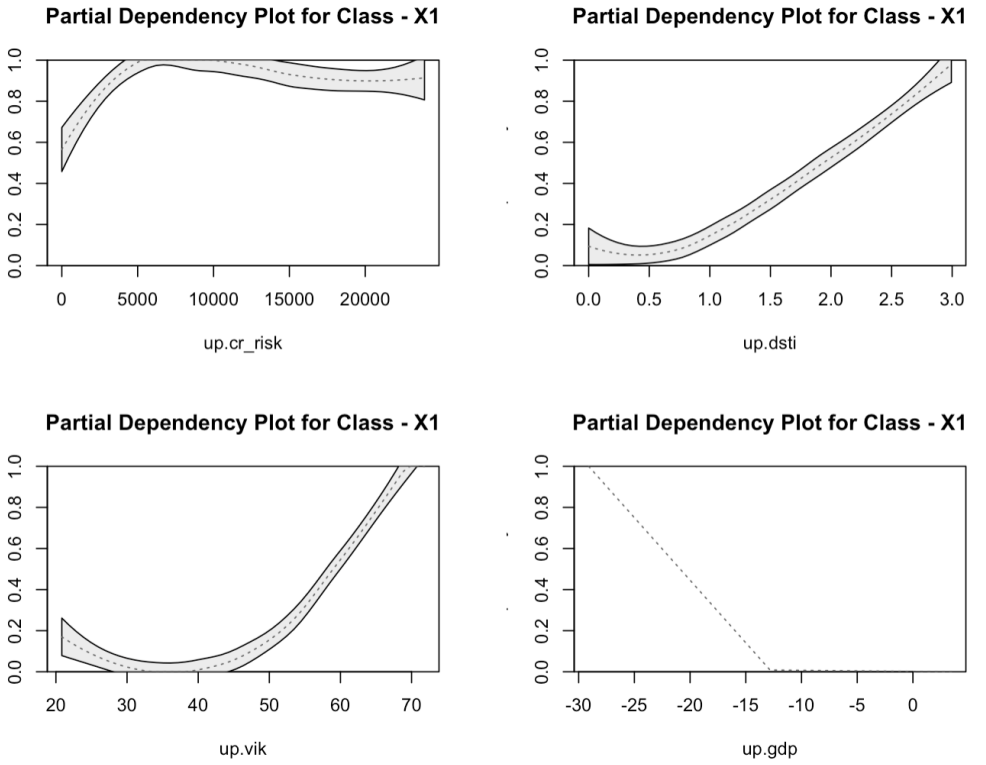

Figure 1. PDP of default outcome on selected variables for RF model on the original data (left-to-right – Credit risk, DSTI, age, GDP growth).

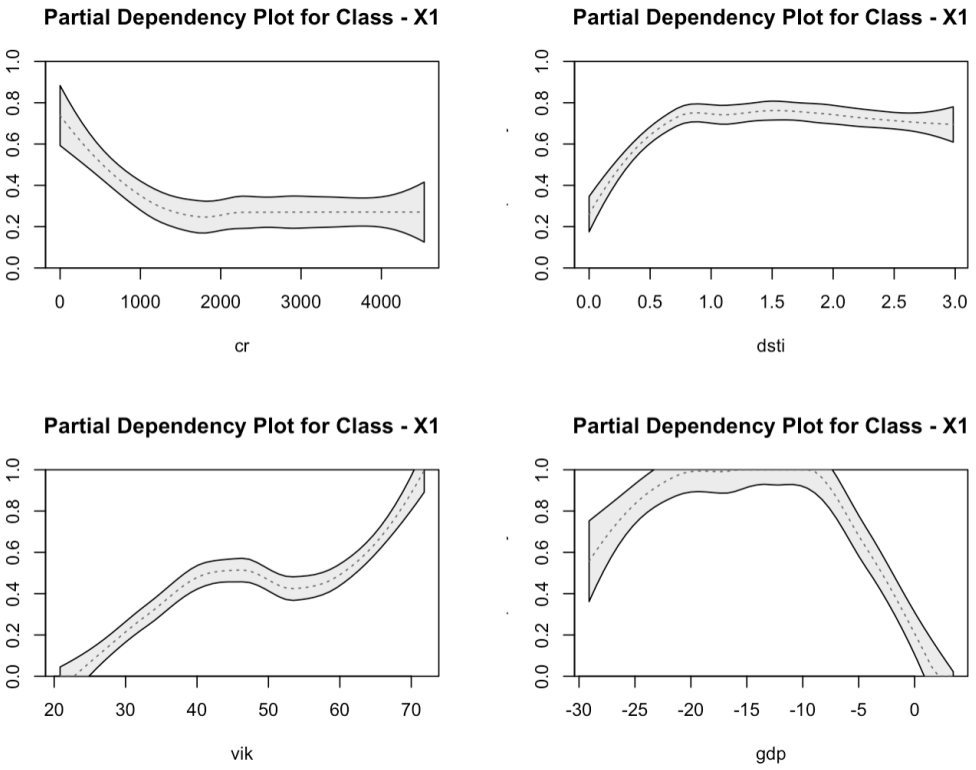

Figure 2. PDP of default outcome on selected variables for RF model on the SMOTE-synthesized data (left-to-right – Credit risk, DSTI, age, GDP growth).

Annex C. Robustness checks of models based on 80%/20% and 67%/33% splitting

Weighted sample model results on 80%/20% split

Model	Logit	LDA	CART	RF	SVM	NNET	XGBtree
Predicted number of 0	4618	7163	4830	5773	7165	4439	5598
Predicted number of 1	2547	2	2335	1392	0	2726	1567
Proportion of correct default prediction (precision), %	70	0,003	69	96	0	75	97
F1 - score	0,18	0,005	0,19	0,88	0	0,18	0,88

Weighted sample model results on 66%/33% split

Model	Logit	LDA	CART	RF	SVM	NNET	XGBtree
Predicted number of 0	7772	11939	7156	9701	11942	7379	10280
Predicted number of 1	4170	3	4786	2241	0	4563	1662
Proportion of correct default prediction (precision), %	66	0,003	78	96	0	73	94
F1 - score	0,17	0,006	0,18	0,89	0	0,18	0,90

SMOTE-synthesized sample model results on 80%/20% split

Model	Logit	LDA	CART	RF	SVM	NNET	XGBtree
Predicted number of 0	6565	6868	5906	6859	6742	6914	6839
Predicted number of 1	7002	6699	7661	6708	6825	6653	6728
Proportion of correct default prediction (precision), %	70	66	75	97	67	78	98
F1 - score	0,69	0,66	0,75	0,97	0,67	0,78	0,98

SMOTE-synthesized sample model results on 66%/33% split

Model	Logit	LDA	CART	RF	SVM	NNET	XGBtree
Predicted number of 0	11032	11486	9930	11397	11309	11561	11403
Predicted number of 1	11581	11127	12683	11216	11304	11052	11210
Proportion of correct default prediction (precision), %	69	66	80	97	68	77	97
F1 - score	0,69	0,67	0,76	0,97	0,68	0,78	0,98

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