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Challenge and Research Trends of Forecasting Financial Energy

Edited by
Tomasz Korol

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Editor

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About the Editor

Tomasz Korol (Ph.D., D. Sc., Eng.). Ph.D. in economics obtained in June 2004, and the degree of habilitated doctor in March 2015 at Gdansk University of Technology (GUT). Principal investigator of two research grants obtained at the National Science Center (NCN) in Poland. He also participated in panel meetings of experts reviewing research applications submitted to the NCN. In 2015–2016, he was a member of accreditation committee at SKVC—Center for Quality Assessment in Higher Education in Lithuania, evaluating four economic universities. In 2015–2020, he was the Chairman of the Faculty Committee for Education Quality Assurance, and since September 2020, he is the Vice-Dean for Science and the Chairman of the Social Sciences Council at the GUT. He won the international competition for the position of "associate professor" twice—at Tecnologico de Monterrey in Mexico (2008–2009) and I-Shou University in Taiwan (2012–2013). Both universities are listed in high positions in the international TOP 500 university rankings in the world. In 2002–2007 he was also a visiting lecturer at the University of Applied Science Stralsund in Germany.

Preface to "Challenge and Research Trends of Forecasting Financial Energy"

The measurement of economic entities' financial strength is one of the significant challenges of modern economic and financial research. With increased financial globalization, faster economic changes, and a new dimension of increased financial risk in the context of the COVID-19 pandemic crisis due to its biological nature and broad scope, affecting the whole world simultaneously, the issue of forecasting financial energy is gaining much more importance currently.

This Special Issue entitled "Challenge and Research Trends of Forecasting Financial Energy" is devoted to the broad research area of forecasting financial energy of economic units such as enterprises, households, local governments, etc. Conceptualizing the term of financial energy, we aim to capture a wide spectrum of predicting and evaluating the financial standing, including various aspects of corporate finance, personal finance, and public finance.

Tomasz Korol
Editor

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Article

Evaluation of the Macro- and Micro-Economic Factors Affecting the Financial Energy of Households

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Abstract: This paper is an evaluation of the common macro-economic, micro-economic, and social factors affecting households' financial situations. Moreover, the author's objective was to develop a fuzzy logic model for forecasting fluctuations in the number of nonperforming consumer loans in a country using the example of Poland. This study represents one of the first attempts in the global literature to develop such a forecasting model based on macro-economic factors. The findings confirm the usefulness of the proposed innovative approach to forecasting the volume of household insolvencies in a country.

Keywords: economics of family; personal finance; financial energy; forecasting; bankruptcy of households; financial health; consumer finance; consequences of COVID-19

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1. Introduction

The paper is an attempt to contribute to evaluating the macro- and micro-economic factors affecting the financial energy of households. Conceptualizing the term "financial energy of households," the author of this research aimed to capture the broad aspects of households' financial standing and the factors directly and indirectly affecting consumers' solvency. The paper is an investigation of the links between the economic and social factors determining households' financial situations and their vulnerability to changes in the macro-economic situation of their country.

It is important to study the vulnerabilities of the household sector for at least two reasons. First, the household sector holds the largest share of wealth in developed economies. As wealth is one of the most important factors in determining a household's consumption patterns throughout its lifecycle, the consumption decisions of households are influenced by their degree of solvency, thereby impacting overall economic activity. Second, vulnerable households pose a threat to a country's financial stability due to their tenuous ties to financial institutions [1].

The financial crisis from 2007–2012 and the current global coronavirus pandemic have dramatically increased the risk of consumer insolvencies throughout the world. Many households are reporting financial distress and feel constrained by debt repayment obligations. Financial distress is a state in which an individual is unable to maintain their customary standard of living [2,3]. This means that anyone, regardless of wealth or level of education, can become financially vulnerable. While there are extensive studies on the effects of gender, level of education, age, and cultural background on consumers' financial decisions [4–10], households' level of financial distress and the factors affecting it have received little attention. Therefore, the author of this study formulated three research questions:

- What are the main macro- and micro-economic factors affecting households' risk of insolvency?
- What macro-economic factors can enable effective forecasting of the changes in the volume of nonperforming consumer loans in the country?

- Is fuzzy logic an effective technique to forecast the changes in the macro-economic risk of nonperforming household loans?

Thus, the contribution of this paper complements the existing literature in an important fourfold manner. First, it is an evaluation of the micro-economic, macro-economic, and social factors affecting households' risk of insolvency. Second, the four most common consumer profiles from the perspective of the factors determining financial vulnerability are identified. Third, the influence of specific macro-economic variables on the volume of personal bankruptcies within a country is identified. Fourth, a fuzzy logic model is proposed for forecasting changes in the macro-economic risk of nonperforming household loans.

This research should enable scholars to better situate the phenomenon of consumer bankruptcies within the literature. It should also result in a better understanding of the process of becoming insolvent, and it includes practical solutions for identifying the volume of household bankruptcies while considering the macro-economic, micro-economic, and social factors affecting the phenomenon.

Scientifically, the term "bankruptcy", which has a pejorative connotation, can be replaced by terms such as "insolvency" and "low financial energy." During the last two decades, personal bankruptcies have become increasingly central to debates on poverty, inequality, and quality of life. Consumption, income, and wealth are three main measures of a household's economic situation and reflect the stability and strength of its finances. The advantage of using the consumption measure is that it not only captures the objective aspects of a household's economic condition but also involves a social and comparative component, which accounts for deprivation that is disproportionate to resources [11]. In turn, consumers' income directly affects their purchasing power and determines their creditworthiness, which indirectly influences their consumption choices. For many individuals, taking out a bank loan may be the only way to afford a house, car, or other amenities that are vital for a person's welfare. Therefore, consumers' consumption decisions are influenced by their households' degree of solvency. Such a multidimensional understanding of the financial energy of households fully reflects the economic resources of income and wealth along with the resources available for consumption under specific cultural and socio-economic conditions.

Besides micro-economic variables, the macro-economic and social factors affecting households' financial energy and the overall scale of bankruptcies within a country's economy are examined. The macro-economic environment influences the availability of loans and their cost to households, the degree of prosperity of consumers, and the stability of the labor market, which affects consumers' earnings prospects. Therefore, in this research, variables such as the unemployment rate, inflation rate, growth rate of the GDP, and interest rates are identified. In the case of social factors, there are two dimensions—objective and subjective. Among the subjective factors, we can identify a consumer's level of awareness of their financial vulnerability, the degree to which they pay attention to their finances, their level of self-control, and their degree of impatience within the context of a materialistic culture. These factors can be used to predict a person's pursuit of possessions and material goods in the hope of reaching a desired state [12]. Materialists believe that the acquisition of material goods is a prime indicator of success and a key to self-definition, happiness, and the achievement of life goals [13]. Among the objective variables, we can identify one's level of education, the condition of one's health, and even the possession of retirement investments and plans as influential.

This paper consists of five sections. In the introduction, the author provides the basis for exploring the topic, the study's objectives, and the study's contributions and innovations to the literature. Section 2 is a literature review covering the causes of household insolvency in various countries, including the USA, Malaysia, the UK, Lithuania, the Czech Republic, Germany, and Chile. Section 3 is an introduction to this study's assumptions. In Section 4, the author presents the conceptual framework for evaluating the risk factors for insolvency, and a forecasting model is constructed. Section 5 is the conclusion, with implications for policy-making efforts and future research.

2. Literature Review

The author of this paper studied the literature on the causes of financial distress in households in European, North and South American, and East Asian countries. The literature review showed that the causes of personal bankruptcy do not depend on the region where consumers are located. In Figure 1, a classification of causes that considers the influence of macro-economic, micro-economic, and social factors on personal bankruptcy risk is presented. The proposed classification considers the entire spectrum of factors leading to an increased risk of consumer bankruptcy as discussed in detail in literature review below.

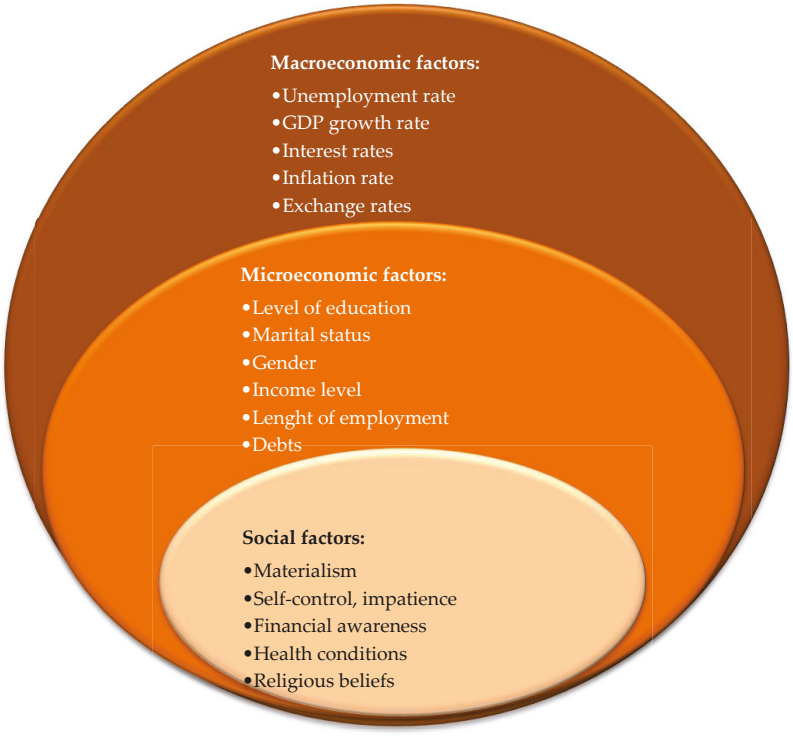

Figure 1. The classification of personal bankruptcy causes. Source: based on the author's own studies.

Generally, the causes of bankruptcy can be divided into two groups. The first consists of exogenous causes. These are the factors shaping the economic conditions affecting a country's households. Households do not have any influence over them and must adapt to the rules they are given for functioning within their country's economy. There is no doubt that the macro-economic situation directly affects the financial standing of consumers, as it influences the availability and cost of credit and the prospective income levels and wealth of households. The second group of causes of bankruptcies includes endogenous causes that can be divided into micro-economic and social factors. Both types of endogenous factors are shaped by the decisions of households, which is why it is important to identify them, as they can then be managed by consumers, leading to a reduced risk of insolvency. It is also important to note that both groups of risk factors overlap, as shown in Figure 1. The social factors are also overlapped by micro- and macro-economic factors, because in the majority of cases these factors are strongly influenced by the environment. The level of education of the consumer is correlated to financial awareness. The health condition of consumer can be shaped by such factors as age, gender, and to some extent even income

level. The level of debts can be affected by religious beliefs as proved in the literature review below.

The results of many studies (e.g., [14–18]) have confirmed the existence of a strong relationship between households' level of financial vulnerability and the unemployment rate, as increasing unemployment results in borrowers being unable to meet their repayment obligations. Shocks to the GDP are the second factor among the macro-economic variables affecting households' insolvency risk. They disrupt the sources of household income, which decreases households' ability to repay their debts. This condition gradually increases the probability of experiencing financial distress, causing foreclosures on the collateral used for securing bank credit, such as homes or cars [19–22]. The third macro-economic factor is the interest rate. When the lending rate increases, the cost of credit card payments, purchase loans, and personal loans also increases, becoming a significant financial burden for borrowers [21,23,24]. The inflation rate directly affects the interest rate, but by influencing the financial situation of enterprises, it can also affect the unemployment rate, as has been discussed [25,26]. The last, most common macro-economic variable affecting the global risk of personal bankruptcy is the exchange rate. The exchange rate clearly has a direct impact on the economic situation of enterprises (both exporters and importers), but it should also be noted that households are also under its influence, either directly (in case of, for example, incurring debts in foreign currencies) or indirectly (through increases in the cost of living in the case of countries dependent on imported goods, e.g., petrol or gas).

Social scientists have long been interested in the determinants of individuals' financial well-being [27]. Most studies have highlighted the following six factors, which are believed to have the biggest influence on an individual's risk of personal bankruptcy [28–33]: level of education, marital status, gender, income level, length of employment, and degree of indebtedness. Caputo [34] studied the influence of marital status and gender on households' risk of financial distress in the USA. He found that formerly married persons (i.e., those who had separated or divorced) were 3.6 times as likely to declare bankruptcy as married persons and that single persons were 4.4 times less likely to declare bankruptcy than married persons. In his study, it was also proven that women were more likely than men to declare personal bankruptcy between 1986 and 2004 in the USA. Traditionally, a person's level of education, income level, and degree of indebtedness have been studied in the literature, with there being clear evidence to support the influence of these factors on an individual's probability of declaring insolvency [35].

Financial vulnerability may also be driven by factors other than macro- and micro-economic ones, including materialism and lifestyle behaviors that may be induced by irresponsibility or short-sightedness on the part of consumers. These may, in turn, dramatically increase the risk of consumers declaring personal bankruptcy. Household attitudes and behavioral characteristics are known to be related to debt-related decisions (e.g., the likelihood of carrying debt and the amount of debt) [36]. For example, spending behaviors, compulsive shopping, saving for a goal, expectations about future income and the economy (e.g., the interest and inflation rates), and credit-related attitudes are commonly reported to be associated with debt-related decisions [36–38]. Among the social factors that may cause personal bankruptcy are health issues, as consumers are sometimes unable to cover huge medical expenses, forcing them to mortgage their homes [11]. Several studies have also been focused on specifically analyzing the relationship between religion and risk-taking attitudes. One of the latest studies conducted in Germany showed that religiously affiliated individuals were, in general, more risk-averse than non-religious people. Furthermore, it was proven that Muslims in Germany exhibited fewer risk-taking behaviors in general than Catholics and Protestants [39].

Nowadays, households encounter an environment characterized by a high level of financial complexity, which requires not only financial knowledge but also appropriate consumption decisions depending on both the macro-economic situation and the consumer's predisposition to make decisions that do not increase their risk of insolvency. Figure 2 presents the common profiles of consumers' financial risk behaviors. This classification

considers a broad spectrum of factors, from level of education, income, and marital status to impatience, snobbery, and financial literacy. Based on consumers' demographic resources (low vs. high) and consumption behaviors, such as self-control and financial awareness (low vs. high), four quadrants to classify the risk-taking behaviors of households were identified.

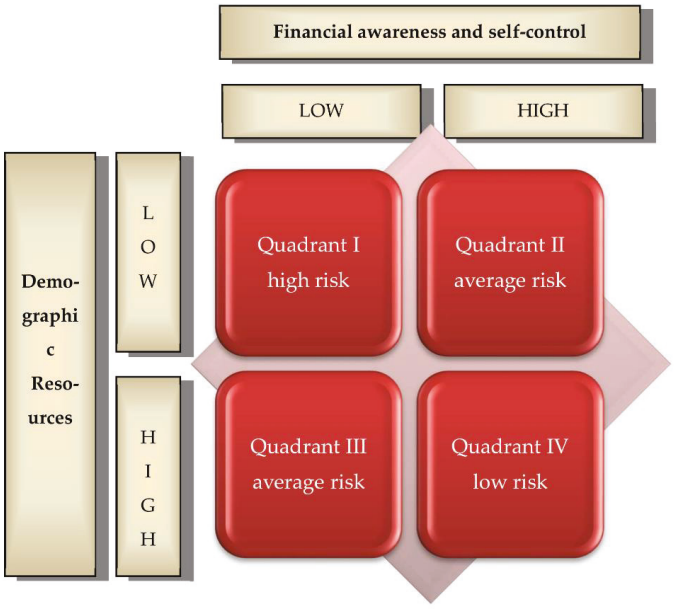

Figure 2. The common profiles of consumers' financial risk behaviors. Source: based on [17].

The first quadrant (Figure 2) represents the consumers burdened with high-risk behaviors. Such households are characterized, on the one hand, by low levels of financial awareness and self-control, and, on the other hand, by the availability of few demographic resources (e.g., poor education, low income, undesirable jobs, etc.). Thus, quadrant I represents the worst situation for consumers. The opposite of quadrant I is quadrant IV, which represents the group of households that is the least financially vulnerable. The consumers in this group are well-educated, high-income persons with good financial knowledge and reasonable, controlled attitudes toward consumerism.

Although the consumers who fall into quadrants II and III are not as risk-prone as those in quadrant I, these households are also of key interest for risk analysts because of the disconnect between their levels of financial literacy and demographic resources, which leads to moderately risky behaviors. For example, the consumers who fall into quadrant III lack financial awareness, which can present an increased risk of experiencing financial hardships regardless of their demographic status (e.g., level of education or income) because they have a low degree of self-control in the context of consumerism. In turn, the households classified as belonging to quadrant II may have an abundance of demographic resources, but they may still be subject to the risk of insolvency when they lack financial awareness of their uncontrolled consumption.

3. Research Assumptions and Forecasting Method

The objective of this research was to develop a model for forecasting changes in the volume of nonperforming consumer loans in the specific country studied. The analyzed country was Poland. The forecasting horizon spanned twenty years: from 2000 to 2020. The main limitation of this research was the prevalence of changes in personal bankruptcy

laws. In Poland, consumer bankruptcy legislation was only introduced in 2014. Thus, the definition of bankruptcy in this research was broadened to include so-called nonperforming loans. In banking, commercial loans are considered nonperforming if a borrower's payment is 90 days past due. Nonperforming loans are also a good measure of household insolvencies. Such a broad definition is often used in studies of countries where personal bankruptcy laws have recently been introduced.

To address the complexity of the households' insolvency phenomenon, in forecasting the financial risk of consumers, the methodology of fuzzy logic was chosen for the model's development.

Most of the methodologies in use nowadays, in all areas, must have advanced decision-rendering capabilities (e.g., engineering, finance, law, etc.). They must have the ability to provide an answer to a complex question. Some of them are based on classical (conventional) logic, which will always correspond to either affirmative or non-affirmative answers such as "white" or "black," "no" or "yes," "high" or "low," etc. These sets of answers are considered sets of truth values {0, 1} [40]. The idea behind the fuzzy logic theory is to replace the set of truth values {0, 1} with the entire interval (0, 1) as a practical approach to addressing a complex problem.

The fuzzy set of universe X is represented by a membership function that maps each element according to its degree of membership within the interval (0, 1). The membership function is a generalized form of the characteristic function, and it is associated with fuzzy logic. Considering the "high"/"low" example, a sentence in this universe according to the classical logic theory can have two possible values, but, using the fuzzy logic theory, the provided answer may have any of a large number of values, which are evaluated in the following manner: "how high/low regarding the highest/lowest value." The fuzzy sets, therefore, solve the problem of quantifying vague linguistic terms.

Membership functions can be present in any form and may be arbitrarily determined by the analyst. In the literature, the most common functions take one of three forms: triangular, trapezoidal, or Gaussian.

The general issues to be taken into consideration before designing a forecasting model based on fuzzy logic are as follows [40]:

- an expert is always needed in the design phase;
- using fewer rules makes it easier to understand the model's behavior;
- it is unnecessary to implement all the possible rules;
- the model may be fine-tuned by modifying the membership functions.

The developed model is based on five different entry variables and it forecasts the number of non-performing loans with the use of macro-economic factors. For each entry variable in the model, the author identified three fuzzy sets (which are subsets of a set of values of the entry variable) and their corresponding membership functions. The fuzzy sets and the thresholds for all the membership functions are presented in Table 1. It is important to note that the author developed the model using the entry variables in the dynamic form (the rate of change), not in the static form (the value of a variable during a specific period). There are two advantages to employing such a research approach. First, it increases the usefulness of the proposed model when discussing various countries. Most countries are characterized by varied combinations of economic conditions and of economic variables. Implementing the rate of change instead of using the static form of economic data increases the universality of the model. Second, the volume of personal bankruptcies is determined within a dynamic system. It is difficult to define a reference state that has been influenced by the static values of other economic variables. For example, the value of the interest rate itself at a specific moment may not influence changes in the volume of nonperforming loans, but an increase/decrease in interest rates can increase/decrease the macro-economic risk of consumer insolvencies. Thus, it is more reliable and representative of the actual situation to explore and forecast this phenomenon from a dynamic perspective. Figure 3 presents an example of fuzzy sets defined with membership functions for the growth rate of the GDP (variable "X4" in the model).

Table 1. The entry variables in the forecasting model. Source: based on the author's own studies.

Symbol	Description of Variable	Thresholds for Individual Membership Functions
X1	The percentage change of interest rate	Membership functions and its values: -"Decrease"—Sigmoidal function: less than 0% (values less than −10% belong to the fuzzy subset "decrease" with the degree of membership of 1, values from −10% to 0% belong to both fuzzy subsets "decrease" and "steady"); -"Steady"—Gaussian function: from −10% to +10% (values from −10% to 0% belong to both fuzzy subsets "decrease" and "steady"; and values from 0% to 10% belong to fuzzy subsets "steady" and "increase"); -"Increase"—Sigmoidal function: more than 0% (values greater than +10% belong to the fuzzy subset "increase" with the degree of membership of 1, values from 0% to +10% belong to both fuzzy subsets "steady" and "increase")
X2	The percentage change of inflation rate	Membership functions and its values: -"Decrease"—Sigmoidal function: less than 0% (values less than −20% belong to the fuzzy subset "decrease" with the degree of membership of 1, values from −20% to 0% belong to both fuzzy subsets "decrease" and "steady"); -"Steady"—Gaussian function: from −20% to +20% (values from −20% to 0% belong to both fuzzy subsets "decrease" and "steady"; and values from 0% to +20% belong to fuzzy subsets "steady" and "increase"); -"Increase"—Sigmoidal function: more than 0% (values greater than +20% belong to the fuzzy subset "increase" with the degree of membership of 1, values from 0% to +20% belong to both fuzzy subsets "steady" and "increase").
X3	The percentage change of unemployment rate	Membership functions and its values: -"Decrease"—Sigmoidal function: less than 0% (values less than −10% belong to the fuzzy subset "decrease" with the degree of membership of 1, values from −10% to 0% belong to both fuzzy subsets "decrease" and "steady"); -"Steady"—Gaussian function: from −10% to +10% (values from −10% to 0% belong to both fuzzy subsets "decrease" and "steady"; and values from 0% to +10% belong to fuzzy subsets "steady" and "increase"); -"Increase"—Sigmoidal function: more than 0% (values greater than +10% belong to the fuzzy subset "increase" with the degree of membership of 1, values from 0% to +10% belong to both fuzzy subsets "steady" and "increase").
X4	GDP growth rate	Membership functions and its values: -"Decrease"—Sigmoidal function: less than 0% (values less than −2.4% belong to the fuzzy subset "decrease" with the degree of membership of 1, values from −2.4% to 0% belong to both fuzzy subsets "decrease" and "steady"); -"Steady"—Gaussian function: from −2.4% to +2.4% (values from −2.4% to 0% belong to both fuzzy subsets "decrease" and "steady"; and values from 0% to +2.4% belong to fuzzy subsets "steady" and "increase"); -"Increase"—Sigmoidal function: more than 0% (values greater than +2.4% belong to the fuzzy subset "increase" with the degree of membership of 1, values from 0% to +2.4% belong to both fuzzy subsets "steady" and "increase").
X5	The percentage change of exchange rate PLN/EUR	Membership functions and its values: -"Depreciation"—Sigmoidal function: less than 0% (values less than −15% belong to the fuzzy subset "decrease" with the degree of membership of 1, values from −15% to 0% belong to both fuzzy subsets "decrease" and "steady"); -"Steady"—Gaussian function: from −15% to +15% (values from −15% to 0% belong to both fuzzy subsets "decrease" and "steady"; and values from 0% to +15% belong to fuzzy subsets "steady" and "increase"); -"Appreciation"—Sigmoidal function: more than 0% (values greater than +15% belong to the fuzzy subset "increase" with the degree of membership of 1, values from 0% to +15% belong to both fuzzy subsets "steady" and "increase").

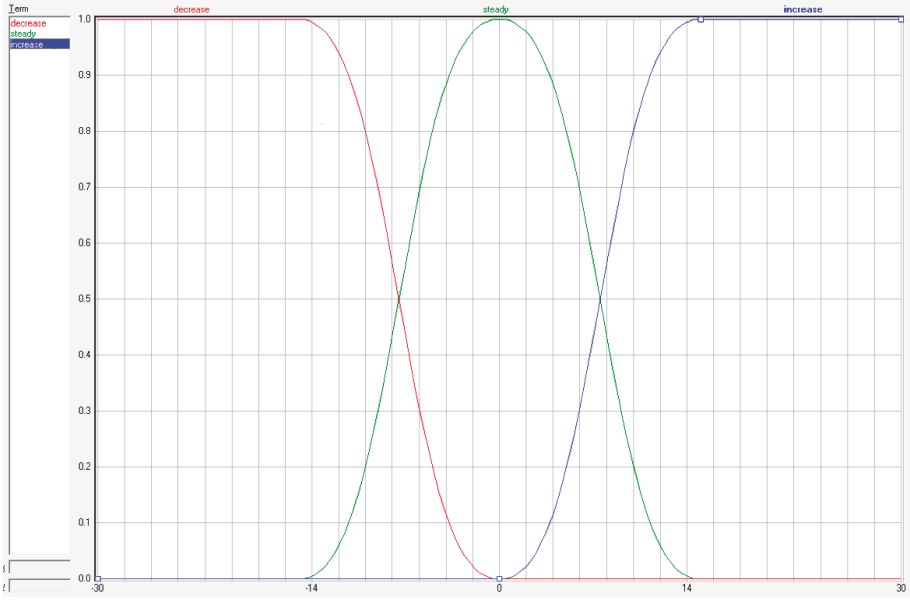

Figure 3. Fuzzy sets for the variable "X4"—the growth rate of the GDP with membership functions. Source: based on the author's own studies.

With such defined subsets, the boundary between the values believed to have a positive or negative effect on the volume of nonperforming loans is fuzzified—specific variable values are "partially positive" and "partially negative." There is no such possibility in the case of classical logic, which is bivalent.

The output of the model is a variable representing the forecast of trends in the volume of nonperforming loans (consumer insolvencies) in the country studied. This variable has a value from −30% to +30%, and it is represented by three membership functions (Figure 4):

- "Decrease"—sigmoidal function: under 0% (values under −15% belong to the fuzzy subset "decrease" with a degree of membership of 1; values from −15% to 0% belong to both the fuzzy subsets "decrease" and "steady");
- "Steady"—Gaussian function: from −15% to +15% (values from −15% to 0% belong to both the fuzzy subsets "decrease" and "steady"; values from 0% to +15% belong to both the fuzzy subsets "steady" and "increase");
- "Increase"—sigmoidal function: above 0% (values greater than +15% belong to the fuzzy subset "increase" with a degree of membership of 1; values from 0% to +15% belong to both the fuzzy subsets "steady" and "increase").

In other words, the function "increase" represents a worsening situation for the credit market, showing an increase in nonperforming consumer loans within a country. The function "steady" indicates the stabilization of the credit market, with a more-or-less stable risk of customer insolvencies. The function "decrease" represents an improvement in a country's situation from the perspective of the number of nonperforming loans and households at risk of bankruptcy.

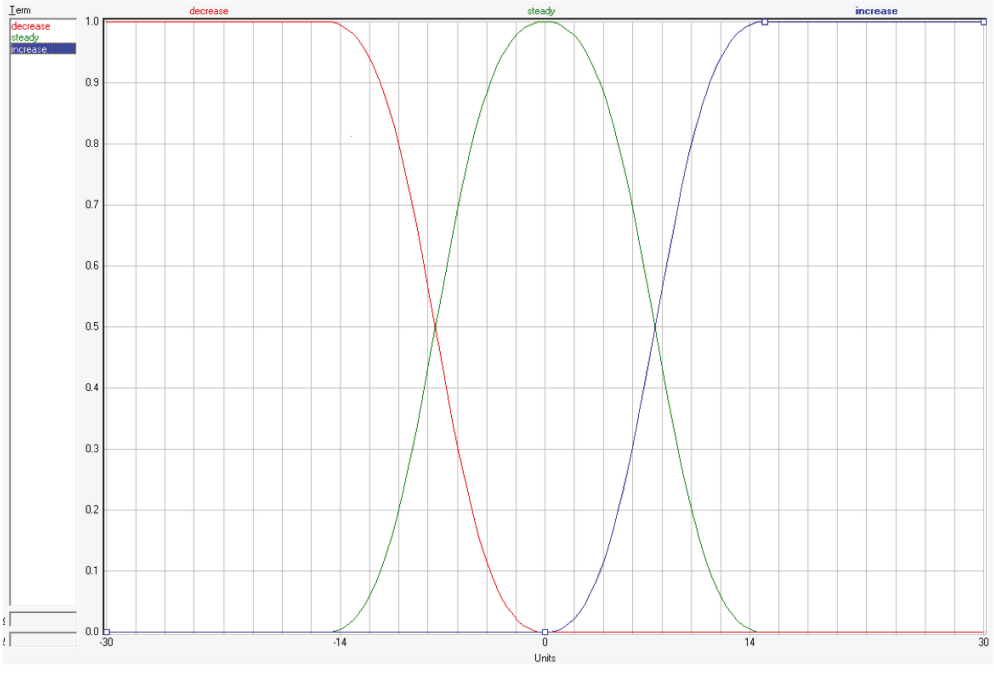

Figure 4. Defined membership functions for the variable "output" representing the forecast of the trends in the volume of nonperforming loans. Source: based on the author's own studies.

4. Results and Discussion

To conduct this study, the author programmed the fuzzy logic model with the structure presented in Figure 5. The model consisted of five inputs (the variables presented in Table 1) and one rule block where the set of decision rules was stored. The model's output was a variable representing a forecast of the fluctuations in the volume of nonperforming household loans within the country studied. The model was based on a set of rules written by the author in the form of "IF—THEN," in which expert knowledge was encapsulated. As there were five entry variables (X1, X2, X3, X4, and X5) with three possible states ("decrease," "steady," and "increase"), and there was a set of 243 possible decision rules. Due to space constraints, only the 30 most important decision rules are presented in Table 2.

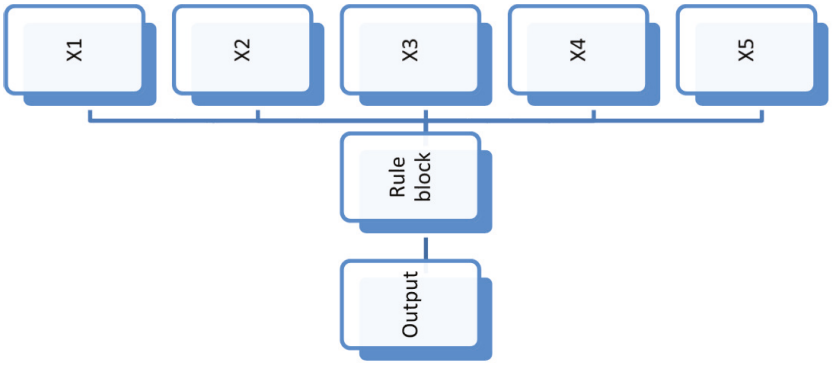

Figure 5. The structure of the fuzzy logic model. Source: based on the author's own studies.

Table 2. The exemplary set of decision rules of the fuzzy logic model. Source: based on the author's own studies.

No.	IF X1 Is	IF X2 Is	IF X3 Is	IF X4 Is	IF X5 Is	THEN Output Is
1	Increase	Increase	Increase	Decrease	Appreciation	Increase
2	Increase	Increase	Decrease	Increase	Depreciation	Decrease
3	Steady	Increase	Decrease	Increase	Steady	Decrease
4	Increase	Increase	Steady	Steady	Appreciation	Increase
5	Steady	Increase	Increase	Decrease	Appreciation	Increase
6	Steady	Steady	Increase	Decrease	Appreciation	Increase
7	Increase	Increase	Increase	Steady	Steady	Increase
8	Decrease	Decrease	Decrease	Increase	Steady	Decrease
9	Decrease	Decrease	Decrease	Steady	Steady	Decrease
10	Steady	Decrease	Steady	Increase	Depreciation	Decrease
11	Steady	Steady	Decrease	Steady	Steady	Steady
12	Steady	Steady	Steady	Steady	Depreciation	Steady
13	Steady	Steady	Steady	Increase	Appreciation	Steady
14	Steady	Steady	Steady	Steady	Appreciation	Steady
15	Increase	Steady	Decrease	Increase	Appreciation	Steady
16	Increase	Increase	Increase	Steady	Appreciation	Increase
17	Increase	Increase	Increase	Decrease	Depreciation	Increase
18	Increase	Increase	Steady	Decrease	Depreciation	Increase
19	Increase	Increase	Steady	Decrease	Appreciation	Increase
20	Increase	Steady	Increase	Steady	Appreciation	Increase
21	Decrease	Decrease	Decrease	Increase	Depreciation	Decrease
22	Decrease	Decrease	Decrease	Steady	Depreciation	Decrease
23	Steady	Decrease	Decrease	Increase	Steady	Decrease
24	Decrease	Decrease	Steady	Steady	Depreciation	Decrease
25	Decrease	Decrease	Steady	Increase	Steady	Decrease
26	Decrease	Steady	Steady	Decrease	Steady	Steady
27	Increase	Steady	Steady	Increase	Appreciation	Steady
28	Steady	Steady	Increase	Steady	Steady	Steady
29	Steady	Steady	Increase	Steady	Depreciation	Steady
30	Increase	Steady	Decrease	Steady	Deprecation	Steady

Based on the set of decision rules, the model was used to evaluate the country's macro-economic situation, which had a direct influence on households' credit-related decisions. There are five variables analyzed in the rule block, and the rules are constructed in consideration of the specific influence that each variable has on the risk of consumer insolvencies. An increase in the interest rate (variable X1) has a negative influence on consumers' degree of solvency. The bigger the increase in the interest rate is, the greater its negative influence on the volume of nonperforming consumer loans is (causing an increase in the number of such loans). In the same negative way, an increase in the inflation rate (variable X2) affects the output of a rule block. We must also remember that these two variables are very strictly dependent on each other. The third factor, changes in the unemployment rate (variable X3), negatively influences the financial situation of households as it increases. This variable often is negatively correlated with the fourth variable, which is the growth rate of the GDP. Variable X4 is believed to have a positive influence on the creditworthiness of households (the higher the increase in the GDP, the better). The last factor affecting the volume of nonperforming consumer loans in the country examined was fluctuations in the exchange rate. In this model, the fluctuation of PLN against EUR was represented. It was assumed that the appreciation of EUR against PLN would cause a higher risk of consumer insolvencies, as it could be expected to lead to an increase in the cost of living and is also often positively correlated with CHF. In Poland, there is a large group of consumers holding credits denominated in CHF, which has a direct, negative influence on their creditworthiness.

The author tested the developed fuzzy logic model using the data representing the fluctuations in the number of nonperforming household loans in Poland from 2000–2020. To evaluate the effectiveness of the model, two measures were considered—the mean absolute error (MAE) and mean absolute percentage error (MAPE). In Figure 6, the real and forecasted yearly fluctuations in the volume of nonperforming loans are presented. Based on the obtained data (Figure 6), the first measure (MAE) was 8.29%, and the second (MAPE) was 33.01%. The idea of using such a fuzzy logic model for predicting the macro-economic risk of consumer insolvencies in a country is a new development in the literature. Thus, the author could not find any data to compare with the obtained results; however, looking at Figure 6, it can clearly be seen that, during the entire analyzed period, the real and forecasted lines representing the percentage change in the number of nonperforming loans always conformed to the same positive/negative trend. This finding indicates that the model correctly predicted the trends in the volume of such loans in the country for all years. The observed MAE and MAPE values also made it possible to draw the conclusion that the errors generated were small and acceptable.

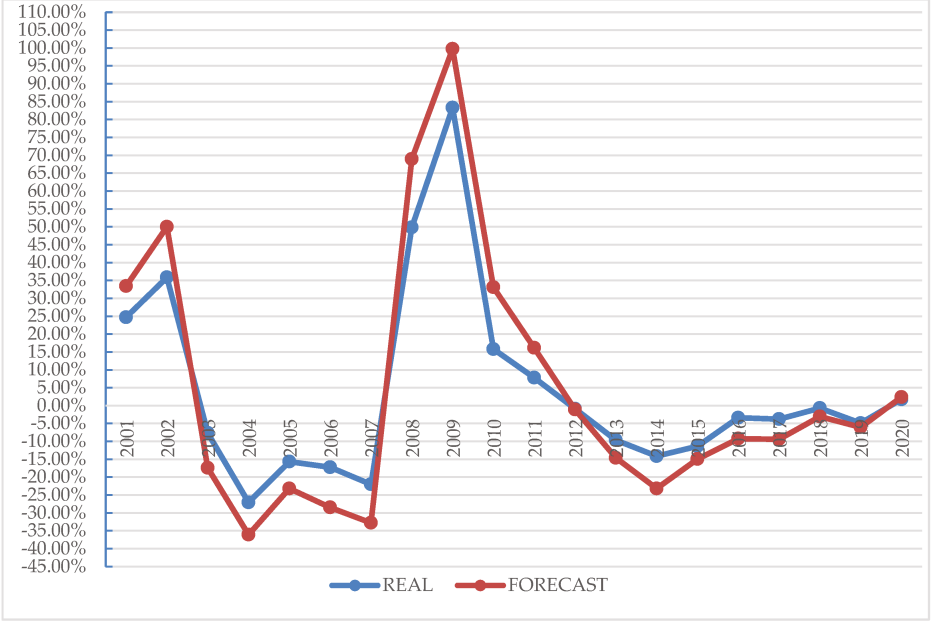

Figure 6. Yearly fluctuations in the volume of nonperforming loans in Poland (real versus forecasted). Source: based on the author's own calculations.

It is also worth underlining a few unique features of the proposed fuzzy logic model:

- it presents explicit knowledge;
- it has the ability to explain how to solve the problem (as opposed to the artificial neural network model that operates on a "black box" principle);
- it has the ability to solve problems not based on an algorithm written explicitly but using different methods of inference (reasoning); and it has the ability to use mainly the processing of symbols and, to a lesser degree, of numerical calculations.

Concluding the results and discussion, in the presented study there are three types of scientific deliberations that constitute direct contribution to the literature:

- theoretical discussion—the author presented an assessment of the main macro- and microeconomic factors affecting the risk of consumer insolvency and explained the

phenomenon of overlapping social factors. Based on these theoretical considerations, four common profiles of consumer behavior related to financial risk have also been proposed.
- methodological considerations—the author developed a forecasting model using fuzzy logic with explicit knowledge in the form of IF-THEN rules and the described membership functions for all used variables. The study also includes the identification of the most predictive macroeconomic factors.
- application considerations—as a final result of this study, the presented model can be used by managers, bankers, financial analysts, researchers, students, etc. The presented study allows readers to freely use the model in other countries.

5. Conclusions

In this paper, a novel approach to evaluating the macro-economic, micro-economic, and social factors affecting the financial situations of households worldwide was presented. Based on a review of the literature, the study's author identified the common factors affecting consumers' risk of insolvency and proposed that there were four common profiles of consumers' financial risk behaviors.

Moreover, in the present study, the author developed a fuzzy logic model that could be used for forecasting the fluctuations in the number of nonperforming loans in a specific country, using the example of Poland. It is worth highlighting that the forecasting methodology of fuzzy logic that was used was employed in an open application form that allows users to modify the model according to their needs; for example, the model could be used for a different country while taking into account various fluctuations in exchange rates or while adding a new variable that could influence the macro-economic risk of household insolvencies.

This study is one of the first attempts in the literature to forecast this phenomenon from the macro-economic perspective. The main limitation of the research is the prevalence of changes to consumer bankruptcy laws, which have made it impossible to thoroughly analyze the number of bankruptcies, as such data tend to be strongly affected by legal modifications. This limitation presents a complication when attempting to construct forecasts for this phenomenon. The author is going to continue the research towards the use of macro- and micro-economic factors combined into one early warning system. Such system will enable the prediction of not only the effect, namely the risk of bankruptcies of households (in annual terms), but also the reasons affecting the number of bankruptcies of consumers (for example, level of unemployment, exchange rates in the case of borrowers with debts in foreign currencies, etc.).

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Debt as a Source of Financial Energy of the Farm—What Causes the Use of External Capital in Financing Agricultural Activity? A Model Approach

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Abstract: The aim of this study was to identify and assess the factors influencing the increase in the financial energy of a farm through the use of external capital, taking into account the farmer's and farm characteristics. For its implementation, a logistic regression model and a classification-regression tree analysis (CRT) were used. The study was conducted on a group of farms in Central Pomerania (Poland) participating in the system of collecting and using data from farms (Farm Accountancy Data Network—FADN). Data on 348 farms were used for the analyses, obtained through a survey conducted in 2020 with the use of a questionnaire. Based on the analysis of the research results presented in the literature to date, it was established that the use of external capital in a farm as a factor increasing financial energy is determined, on the one hand, by the socio-demographic characteristics of the farmer and the characteristics of the farm, and on the other hand, by the availability of external financing sources. Factors relating to the first of these aspects were taken into account in the study. Using the logistic regression model, it was established that the propensity to indebtedness of farms is promoted by the following factors: gender of the head of the household (male, GEND), younger age of the head of the household (AGE), having a successor who will take over the farm in the future (SUC), higher value of generated production (PROD_VALUE), larger farm area (AREA) and multi-directional production of the farm (production diversification), as opposed to targeting plant or animal production only (farm specialization—SPEC). The results of the analysis carried out with the use of classification and regression trees (CRT) showed that the key factors influencing the use of outside capital as a source of financial energy in the agricultural production process are, first of all, features relating to an agricultural holding: the value of generated production (PROD_VALUE), agricultural area (AREA) and production direction (SPEC). The age of the farm manager (AGE) turned out to be of key importance among the farmer's features favoring the tendency to take debt in order to finance agricultural activity.

Keywords: financial energy; farms; factors determining the propensity to use external capital; logistic regression; classification and regression trees (CRT); Central Pomerania; Poland

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1. Introduction

The interdisciplinary approach to financial energy (cf. [1]) allows for associating it with the general financial condition of the entity [2], which is influenced, among others, by the use of equity and external capital and the treatment of money as a source of energy [3]. Based on Korol [2,4], the paper adopts the concept of "*financial energy of a farm*" understood as its general financial situation. It mainly consists of having capital that enables agricultural activity, which is both the cause and the consequence of the financial and investment decisions of a given entity. Based on this concept, it was assumed that the use of external capital increases the financial energy of a farm, enabling the implementation of investment projects whose scope exceeds the level of the entity's equity.

The appropriate level of financial energy of a farm is essential to start all processes related to agricultural activity.

The selection of the financing sources necessary to run a business, including agricultural activity, is within the scope of the entity's financial decisions. In the process of selecting forms and sources of financing, an agricultural holding may use many selection criteria. Opportunities to increase the financial energy of the farm, therefore access to capital, its cost, possibilities and limitations in acquiring are crucial at every stage of farm development. Both the establishment of a farm and its development require funding. Research shows that the lack of access to capital, including external capital, is the most important limitation in starting agricultural activity [5]. It is related to the low financial energy of the farm. Nevertheless, the relatively low use of external capital may also be related to the reluctance of farmers to incur debt [6]. Thus, the use of outside capital makes it possible to increase the financial energy of a farm and is determined, on the one hand, by its availability, on the other hand, the impact on its use is influenced by the farm's and the farmer's characteristics, with particular emphasis on behavioral aspects.

The aim of the study was to identify and assess the factors influencing the increase in the financial energy of a farm through the use of external capital, taking into account farmer's and farm characteristics. Due to the fact that agriculture is one of the key areas of importance in the context of the plan Transforming our world: the 2030 Agenda for Sustainable Development [7], the research thread concerning the factors determining farmers' tendency to get into debt is considered important. Sustainable development of agriculture requires investments that require capital, including outside capital. Therefore, the investment possibilities of a farm depend on the level of financial energy of a given entity; this energy can be increased by using external capital.

A farm, despite its specific nature, should be treated as an enterprise [8]. However, this specificity significantly affects the farm's financial energy and the selection of the structure of financing sources. In the case of farmers, the theory of the hierarchy of funding sources and the theory of partial adjustment are the most fully applicable to the explanation of financing decisions. The first one was formulated by S.C. Myers [9]. According to it, enterprises prefer internal sources of financing, and use external sources only when the demand for capital increases. This is due to the fact that there is an information asymmetry that can lead to under-investment, over-investment or value transfer. Sources that are lower on the list of preferences are not used until all the sources higher on that list are exhausted. The theory of the hierarchy of sources of financing emphasizes the importance of the asymmetry of information between the capital giver and the capital buyer, which is also noticeable in the case of entities from the agricultural sector [10]. This theory, however, does not take into account the advantage of outside capital over own capital, resulting from the existence of the financial leverage effect or the tax shield. Due to the specific nature of farm taxation, it is considered that they use the financial leverage effect by supplying their business with external capital when the interest rate on bank deposits is lower than the return on equity [11]. The theory of partial adjustment assumes conscious shaping by farms of the proportion between equity and debt. Benefits from external capital may be higher than from own capital, however, assuming that the tax system in agriculture makes it possible to deduct financial costs from the tax base. Moreover, the asymmetry of information affects the use of equity in the financial strategies of entities from the agricultural sector [8]. The phenomenon of low use of external capital to finance activities is characteristic of agriculture [6,12–15].

Internal sources are of dominant importance, which are determined by the value of the farmer's household income (income from agricultural activities and those collected outside of it) and the tendency of farmers to give up current consumption [16]. The research results confirm that farmers are characterized by a relatively high propensity to save, and the accumulated savings are spent primarily on financing investments carried out on the farm [17]. The size, determinants of creation and factors determining income in agriculture are the subject of research by many scientists (see e.g., [18–23]). In the context of financing

agricultural activity of farms located in the European Union, sources that relate to direct support systems should also be distinguished, because direct subsidies are a significant part of farm income [24,25]. In combination with the possibility of using European Union assistance, they constitute an important source of financing for agriculture [26–28]. These activities, together with domestic aid for financing agriculture, according to Zinych and Odening [29], fit into the concept of soft budget constraints [30]. This concept focuses on the state co-financing of various entities, which helps their development. In terms of external capital, farms mainly use bank loans [31–33], commercial loans [34,35], leasing [36,37], as well as informal loans, most often family ones [38,39].

Financial energy, including the possibility of using external capital, often determine the investment activity of farmers [29,40]. Research on the use of external financing sources in agriculture emphasizes that difficulties in accessing outside capital result from both the characteristics of the potential borrower and the attitude of the lenders. Conditions for taking out and granting external capital (most often it is a bank loan) are related to the specificity of the functioning of farms, which is expressed in high capital intensity in relation to the sales level and the guaranteed cash surplus; lack of flexibility of owned assets and their strict connection with the farm; long production cycles and difficulties in raising capital on the stock market [41]. Moreover, agricultural holdings exhibit features that cause internal credit limitations of these units. These include farmers' conservative attitude to external, returnable sources of financing; lack of sufficient knowledge, skills and experience of farmers in using external financing and perceiving institutions granting loans as unfriendly. Farmers also have a fear of indebtedness, resulting from the fact that the purpose of the operation of many units in the agricultural sector is sustainable existence that allows them to meet basic needs, and not maximizing profit or increasing the value of the farm [42].

The literature emphasizes that access to credit and its use in agriculture contribute to the maintenance of food security, rural development, and affect the production volume and increase productivity, and, consequently, determine the level of agricultural income, contributing to poverty reduction [43–47]. Farms with greater financial possibilities also make greater investment expenditures, which contributes to an increase in labor productivity and in land productivity [48].

Among the studies on the factors influencing the use of external capital, the importance of both the characteristics of a farm and the personal characteristics of the person managing it is emphasized. Zulfiqar et al. [46] verified the impact of factors belonging to both of these groups on credit availability. They showed that the factors conditioning access to credit related to the farm manager are: the farmer's age, education and the fact of having income from outside agriculture, while the characteristics of the farm include: the size of the entity and the level of mechanization. Mądra [49] included the following factors influencing the amount of debt per hectare of agricultural land: the degree of financial leverage, change in the value of equity, inventory turnover, share of net working capital in total assets and the ratio of the ability to generate cash flows from operating activities. In turn, the studies by Kiplimo et al. [50] shows that farmers' decisions regarding the use of external capital are determined by the following factors: education level, occupation, access to extension services, total annual household income and the distance to the credit source. The first three factors had a positive impact on the access of the surveyed farmers to external sources of financing, while the last two factors had a negative impact. Datta et al. [51], conducting research in this area, proved that principal occupation, use of modern technology, the rate of interest, household medical expenditure and source of loan are significant variables affecting the debt.

The research also shows that a barrier to changing the structure of farm liabilities is the belief that equity is a cheap and safe source of financing [52]. The size of a farm, measured by its area or the value of its production, has a positive effect on the use of external financing sources and the level of debt of a farm [53–58]. Having a larger farm gives the opportunity to achieve a higher production value, which increases income. Therefore, it allows both to

incur greater investment expenditures from own sources, and to supplement them with outside capital, because it increases creditworthiness, and thus financial energy.

The factor that influences the economic situation of farms, including the production potential and the structure of financing sources, is the specialization of agricultural production. The research results show that farms that focus on plant or animal production use external capital to a greater extent to finance their activities [59,60].

There are also dependencies between farmers' access to outside capital and the share of non-agricultural income in total farm income. Higher revenues from outside the farm may increase access to credit, which results, among others, from an increase in creditworthiness. This is particularly important in the case of young farmers, therefore age, combined with an increased share of income from non-agricultural activities, has a positive effect on access to external capital and, consequently, also on the increase in farm size, the ability to create economic surplus and productivity of production factors [61]. Wu et al. [62] also draw attention to the fact that incomes from outside the farm can contribute to an increase in creditworthiness and reduce the probability of default. On the other hand, they can be a source of internal financing, thus contributing to reducing the demand for external sources, as proved, among others, by Datta et al. [51].

Apart from the features relating to the farm, the socio-demographic features of the farm manager are of significant importance for the tendency to indebtedness. The age, gender, education, professional status of a farmer and their experience are important in making decisions about the use of outside capital in financing agricultural activities [53,55,58,63,64]. The results of studies on the influence of age on the propensity to incur debt are not clear; however, most of them prove that the farmer's propensity to use outside capital decreases with age [53,65]. Subash and Ali [64] have shown that the incidence of indebtedness increases with age, but after attaining a certain age, the relationship between age and indebtedness becomes inverse. The older a farmer is, the less inclined they are to make innovative investments, which affects credit constraints. Credit institutions are more willing to grant loans to young farmers [66,67]. It was also found that male-run farms used loans more often [63,64].

The level of education is a determinant of human capital, which is important in independent business management [68]. A higher level of education, as shown by research results, is conducive to the use of external capital [50,55,58], thus contributing to the increase of the financial energy of the agricultural holding. The level of economic knowledge of the decision-making entity in the selection of financing sources is also important. This is related, among others, to financial literacy and financial capabilities of a given entity and their use in the process of making decisions regarding the selection and use of individual financial products and services [69]. Educated people more consciously use the opportunities provided by the financial market; they understand the mechanisms of modern economy to a greater extent, including the role of the credit market, and they want to use it [70]. The condition for making a correct loan decision is, first of all, access to relevant information and having financial knowledge and skills that allow this information to be properly used [71]. In addition, credit institutions may have greater confidence in farmers with higher education due to their greater potential to work in the non-agricultural sector, should the need arise, which will contribute to obtaining additional income to pay off debt [65].

Having a successor who will take over the farm in the future, encourages farmers to increase investment expenditures, which was proved by Wright and Brown [72]. It is related to the expectations of the continuation of agricultural activity, especially for family farms. Thus, this fact should positively influence the tendency to incur debt in order to obtain capital for additional investments. The lack of a successor is one of the barriers to the modernization of agriculture [73]. Harris et al. [74] proved that farms with succession plans have higher profit margins and higher returns to equity, therefore succession planning is positively related to farm business performance. At the same time, it was found that farms

which increase financial energy through the use of external capital to finance agricultural activity have higher production and economic results [14].

The rest of the paper is structured as follows. Section 2 presents the survey methodology and data sources. Section 3 presents the results of empirical research. First, the characteristics of the researched farms were established (Section 3.1). Then, the identification of farm characteristics and socio-demographic characteristics of the farm manager were made, which affect the propensity to use outside capital in financing agricultural production, as a form of improving the financial energy of a farm (Section 3.2). For this purpose, a logistic regression model and a classification-regression tree analysis (CRT) were used. The last section summarizes the obtained results and sets out the directions for further research.

2. Materials and Methods

The study uses primary data obtained in the course of a survey conducted in the second quarter of 2020 among farms covered by the European Farm Accountancy Data Network (FADN). The spatial scope of the study covered the area of Central Pomerania (Poland). 361 farms participated in the study, which constitutes 88% of all entities covered by FADN agricultural accounting in the analyzed area. After substantive verification, the results concerning 348 entities were accepted for analysis. The survey was carried out by advisers from Agricultural Advisory Centers through personal contact with the farmer and supplementary telephone contact (Paper & Pen Personal Interview—PAPI and Computer Assisted Telephone Interview—CATI methods). The data obtained concern 2019 (some questions also related to the period from 2004—i.e., from the moment of Poland's accession to the European Union). A total of 69 questions were included in the questionnaire, divided into three main sections: (A) General information about the household, (B) Information about the financial management of the household, (C) Information about the farm.

The logistic regression model and the classification-regression tree analysis (CRT) were used to identify the features of farms in Central Pomerania which use external capital to improve the financial energy of their agricultural holdings. Based on the results of the logistic regression model, the factors influencing the probability of using external capital by a farm were determined. Then, the classification and regression trees (CRT) analysis was applied, which allowed for the identification of key features of a farmer and a farm affecting the propensity to finance agricultural activity with external capital.

The first method used, logistic regression, allows to study the influence of many independent variables $x_1, \ldots, x_k$ (which can be both qualitative and quantitative) on the dependent variable Y, which is dichotomous (zero-one variable) [75,76]. In this study it was assumed that the dependent variable Y is the use of external capital to finance agricultural activity. This variable, due to its dichotomous nature, takes the value 1 in the case when the researched farm used external capital (130 cases), otherwise the variable takes the value 0 (218 cases).

The probability that an agricultural holding will use outside capital to finance agricultural activity ($Y = 1$) was determined using the following function [77,78]:

$$Prob(Yi = 1) = \frac{e^{\alpha_0+\alpha_1 x_1+\ldots+\alpha_k x_k}}{1 + e^{\alpha_0+\alpha_1 x_1+\ldots+\alpha_k x_k}} \quad (1)$$

where: $Prob(Yi = 1)$—the probability that the dependent variable for an entity with characteristic i will take the value 1; $\alpha_0, \alpha_1, \ldots, \alpha_k$—model parameters; $x_1, \ldots, x_k$—independent variables.

The selection of independent variables for the logistic regression model was made using the backward elimination method. The model parameters were estimated using the maximum likelihood (ML) method [79]. The significance of the obtained model was verified using the Likelihood Ratio (LR) [79]. The significance of individual model parameters was verified on the basis of z^2 Wald Test [80]. The Akaike Information Criterion (AIC) was analyzed as the criterion of the model's optimality [81]. Cox-Snell R^2, Nagelkerke R^2 and Count R^2 statistics were used to assess the fit of the model to the observed data [79,82].

Goodness of model fit was also assessed using the AUC—Area Under Curve index, calculated on the basis of the Receiver Operating Characteristic (ROC) [77]. The Odds Ratio was used to interpret the obtained results of the logistics model [83]. Statistical analyzes were performed using the Statistica 13.3 software.

The second of the methods used in the study, the analysis of classification and regression trees, is used to determine whether objects belong to classes on the basis of measurements of one or more explanatory variables, determining their impact on the qualitative dependent variable Y [84]. Decision trees are a graphic form of presenting possible decisions and their consequences [85]. The analysis of classification-regression trees consists in the sequential partitioning of the L-dimensional space of X^L variables into subspaces R_k (segments), until the dependent variable Y reaches the minimum level of differentiation in each of them, which is measured by the appropriate loss function (more on this topic: [86–88]). This partitioning is displayed in a tree structure which is called a decision tree, with the root node at the top of the tree [89]. In the study, the dependent variable was the use of external capital by a farm to finance agricultural activity. As in the case of logistic regression, this variable can take two values: $Y = 1$—when the researched farm used external capital to increase their financial energy (130 farms), and $Y = 0$ otherwise (218 farms). The assessment of the degree of differentiation of the subspace R_k was based on the Gini index [86,90]. In order to obtain a simplified form of a classification and regression tree and to identify the key features influencing the use of external capital by farms, the recursive splitting was stopped before achieving segment homogeneity, for this purpose the FACT—Fast Algorithm for Classification Trees rule was applied for a given object fraction [91]. Cross-validation was used in the classification and regression trees (CRT) analysis [89,92]. Statistical analyses were performed using the Statistica 13.3 software (C&RT algorithm).

The explanatory variables used both in the logistic regression model and in the classification and regression tree analysis were selected on the basis of the literature studies. Eight independent variables relating to the socio-economic characteristics of the farmer and the characteristics of the farm were used to assess the probability tested. Their characteristics and their hypothetical impact—established on the basis of the research results presented in the literature—on the inclination of the researched farms in Central Pomerania to finance agricultural activities with external capital are presented in Table 1.

Table 1. Set of potential variables adopted for the study.

Variable	Description of the Variable and Its Categories	Expected Sign	Impact Confirmed by Scientific Research
DEB	Dependent variable: Farm debt: yes; no		
AGE	Age of the head of the households (years)	−/+	Amjad and Hasnu (2007) [53] Kata (2012) [55] Kumar and Saroj (2019) [65] Subash and Ali (2019) [64]
GEND	Gender of the head of the household: female = 1, male = 2	+	Kata (2013) [63] Subash and Ali (2019) [64]
EDU	Education of the head of a household: 1—basic; 2—basic vocational; 3—secondary; 4—post-secondary; 5—higher	+	Kata (2012) [55] Kiplimo et al. (2015) [50] Chandio et al. 2020 [58]
EDU_EC	Economic education of the head of the household: yes; no	+	Wałęga (2012) [70] Solarz (2014) [71] Kuchciak (2020) [69]

Table 1. *Cont.*

Variable	Description of the Variable and Its Categories	Expected Sign	Impact Confirmed by Scientific Research
SUC	Having a successor who will take over the farm: yes, no	+	Harris et al. (2012) [74] Wright and Brown (2019) [72]
PROD_ VALUE	Annual production value of an agricultural holding: ≤PLN 100,000; >PLN 100,000	+	Kata (2012) [55] Zawadzka et al. (2015) [59] Zawadzka et al. (2019) [93]
AREA	Farm area (ha)	+	Kata (2012) [55] Zawadzka et al. (2015) [59] Strzelecka et al. (2018) [94] Subash and Ali (2019) [64] Thorat et al. (2020) [57]
SPEC	Farm specialization: yes, no	+	Zawadzka et al. (2015) [59]

Source: Own study based on: [50,53,55,57–59,63–65,69–72,74,93,94].

3. Results

3.1. Characteristics of the Surveyed Farms

In the surveyed group of farms in Central Pomerania, nearly 38% of entities, apart from equity capital, used external sources of financing for agricultural activities, in order to improve their financial energy. Liabilities constituted on average 14.4% in the structure of financing sources of the analyzed entities. This is confirmed by the results of studies conducted so far on the high degree of self-financing of farms and their low inclination to (see e.g., [6,95]).

Table 2 presents descriptive statistics of the variables included in the analysis, on the basis of which, the characteristics of the researched farms were made.

Table 2. Descriptive statistics of independent variables considered in the model.

Continuous Variables					
Variable	**Average**	**Median**	**Minimum**	**Maximum**	**Standard deviation**
AREA	56.75	38.02	0.88	430.00	56.53
AGE	46.93	47.00	23.00	73.00	11.66

Discrete variables											
Variable	**Average**	**Number of households in particular classes of net income per one person in a household**									
		1 basic		2 basic vocational		3 secondary		4 post-secondary		5 higher	
		No.	Share	No.	Share	No.	Share	No.	Share	No.	Share
EDU	3.0	15	4.31	123	35.35	129	37.07	10	2.87	71	20.40

Dichotomous variables				
Variable	**Occurrences 0**		**Occurrences 1**	
	No.	Share	No.	Share
EDU_EC	326	93.68	22	6.32
GEND	61	17.53	287	82.47
SUC	177	50.86	171	49.14
SPEC	99	28.45	249	71.55
PROD_VALUE	192	55.17	156	44.83

Note: No.—number of farms; Share—share of farms in total number of farms (%). Source: Own study.

The average area of a farm was 56.57 ha, with half of the studied population having an area not exceeding 38.02 ha. The minimum area of a farm was 0.88 ha, while the maximum area was 430 ha. The surveyed entities were characterized by a higher average area of agricultural land than the average area of a farm in Poland, which in 2019 amounted to

10.95 ha [96]. The most numerous group were farms with a production value between PLN 32.001 and PLN 100,000 (37.8%). Farm whose production value exceeded PLN 500,000 (6%). More than half of the population (55.2%) had a production value not exceeding PLN 100,000. Most entities were clearly focused on plant production—they constituted almost half of the surveyed group. 28.4% of the surveyed units were multi-directional farms, diversifying their production.

The surveyed farms were managed mainly by men (82.5%). The average age of the farm manager was 47 years. With regard to the level of education, it was found that farms managed by managers with secondary (37.1%) and basic vocational education (35.3%) dominated. One in five respondents declared having higher education. It was also noted that 17.5% of the surveyed farmers had economic education. Almost half of the respondents (49.1%) indicated that they have a successor who will take over the farm in the future.

3.2. The Use of External Capital and the Features of a Farm—A Model Approach

Based on the adopted research assumptions, first, a logistic regression model was constructed, in which eight explanatory variables were included (Table 1). Then, using the backward elimination method, successive predictors were eliminated and the assessment of change in the value of criteria adopted for the model quality assessment was made. Finally, two independent variables related to the farmer's education level were eliminated from the initial model: EDU and EDU_EC, whose impact on the probability of using external capital by the farm, as a source of financial energy, was not statistically significant. Six variables remained in the final model (Table 3), the matrix of case classification is presented in Table 4.

Table 3. Results of estimation of model parameters—final model.

Variable	Variable Parameter	Standard Error	z Wald Test	Significance Level	Odds Ratio
AREA	0.012	0.003	16.649	0.000	1.012
AGE	−0.037	0.012	8.951	0.003	0.964
GEND_Male	0.766	0.370	4.300	0.038	2.152
SUC	0.568	0.279	4.141	0.042	1.764
SPEC	−0.678	0.281	5.803	0.016	0.508
PROD_VALUE	1.221	0.277	19.494	0.000	3.392
Intercept	−0.553	0.637	0.752	0.386	0.575
		AIC = 384.06			
		Cox-Snell R^2 = 0.228			
		Nagelkerke R^2 = 0.310			
		count R^2 = 0.73			
		AUC = 0.785			
		LR = 89.87 (df = 6; $p \leq 0.001$)			

Source: Own study.

Table 4. Matrix of case classification.

Classification of Objects Based on the Logit Model	Real Belonging of Objects		Sum
	y_i=1	y_i=0	
$\hat{y}_i = 1$	75	55	130
$\hat{y}_i = 0$	39	179	218
Sum	114	234	348

Source: Own study.

The estimated model of the probability of financing agricultural activity with external capital is as follows:

$$\text{Prob(DEB = 1)} = \Lambda(0.012\text{AREA} - 0.037\text{AGE} + 0.766\text{GEND\_Male} + 0.568\text{SUC} - 0.678\text{SPEC} + 1.221\text{PROD\_VALUE} - 0.553)$$

where: $\Lambda(x) = \frac{e^x}{1+e^x}$ logistic distribution function.

Based on the model, 73% of cases were correctly classified (Count R^2 = 0.73). The quality of the constructed model was assessed on the basis of Cox-Snell R^2 (0.228), Nagelkerke R^2 (0.310) and the ROC curve (Figure 1).

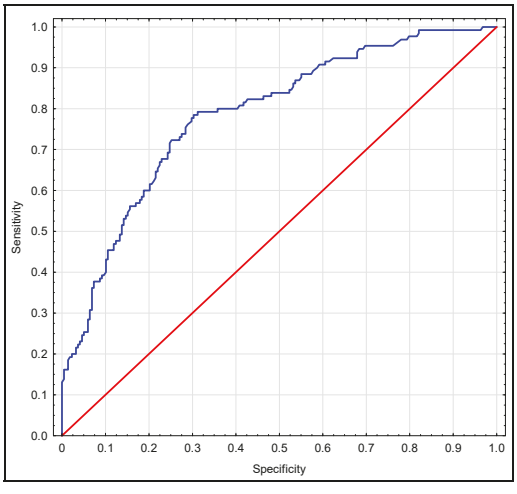

Figure 1. ROC curve for the model of the tendency to indebtedness of farms in Central Pomerania. Source: Own study.

The area under the ROC curve (AUC) is 0.785, which indicates a good quality of the constructed model (AUC > 0.5). The *LR*-statistic value is 89.87 ($p < 0.001$), the critical value of this statistic for 6 degrees of freedom is 16.81.

The results of the study show that the following characteristics of the farmer had a statistically significant positive impact on the probability of using external capital as a form of improving financial energy by farms in Central Pomerania: gender (**GEND_Male**) and having a successor who would take over running the farm in the future (**SUC**), as well as the following characteristics of a farm: farm area in ha (**AREA**) and annual production value (**PROD_VALUE**). On the other hand, the farmer's age (**AGE**) and farm specialization—targeting one type of crop or animal production (**SPEC**) had a statistically significant negative impact on the tested probability. The direction of the impact of the variables: **AGE**, **GEND**, **EDU**, **EDU_EC**, **SUC** and **PROD_VALUE** and **AREA** turned out to be consistent with the assumed one, thus confirming the research results presented so far in the literature (e.g., [50,55,57,58,64,72,74]). In the case of the **SPEC** variable, the results of our research showed a different than assumed impact of production specialization on the use of external capital in order to improve the financial energy of the farm.

In accordance with the established methodology of the study, in the next stage of the analysis, the key features of the farmer and the farm that affect the propensity to use external capital were identified. For this purpose, classification and regression tree analysis (CRT) was used. The results of the classification of the researched farms in Central Pomerania according to the criterion of using external capital to increase financial energy based on classification and regression trees (CRT) and the importance of independent variables included in the analysis are presented in Figures 2 and 3.

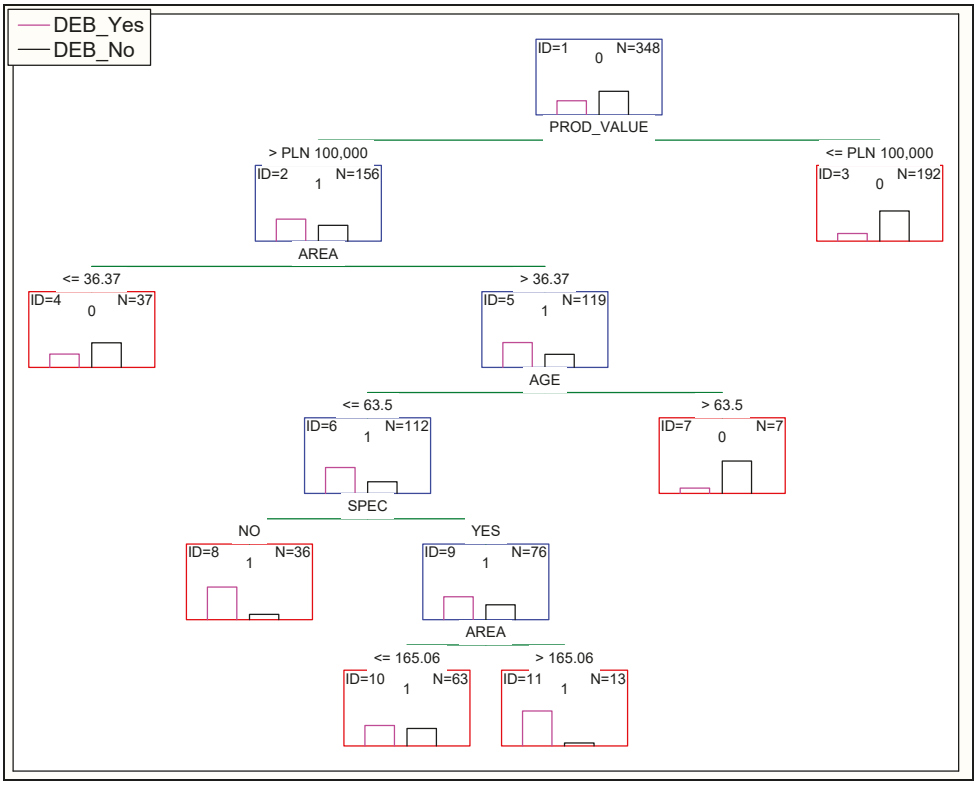

Figure 2. Classification and regression tree (CRT). Source: Own study.

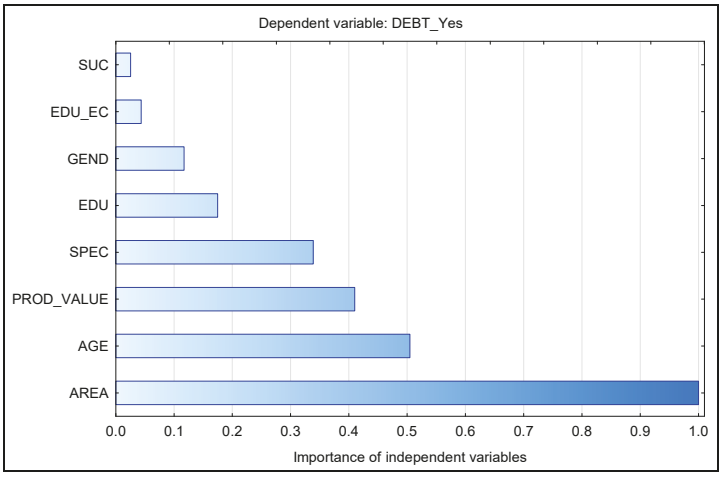

Figure 3. Importance of independent variables. Note: Scale 0–1; 0—variable is no important; 1—variable is very important. Source: Own study.

The decision rules are designed in the root (ID 1), branch (IDs: 1, 2, 5, 6 and 9) and leaves (IDs: 3, 4, 7, 8, 10 and 11) views. The tree consists of five shared nodes and six terminal nodes. The certainty of the forecast is 74.7%.

The first split of the studied population was made on the basis of the **PROD_VALUE** variable. On the basis of this criterion, the surveyed group was divided into two groups: farms with an annual production value of more than PLN 100,000 (ID 2) and those with an annual production value of up to PLN 100,000 (ID 3). It was found that in the case of entities with a lower annual production value, the vast majority (80%) did not use external capital as a form of increasing financial energy. On the other hand, among farms characterized by a higher production value (ID 2), 58% used outside capital. The key variable differentiating the studied population in node 2 (ID 2) was the farm area (**AREA**). As a result of the classification, two groups were obtained: users of farms with an area of up to 36.37 ha (ID 4)—among them 35% were willing to use outside capital, and users of farms with an area exceeding 36.37 ha (ID 5), of which 66% used outside capital. The split of entities in node 5 (ID 5) was made based on the variable **AGE**. As a result of the classification, two groups were obtained: farmers aged up to 63.5 years (ID 6) and 69% of them were characterized by a tendency to indebtedness, and farmers aged over 63.5 years (ID 7), among whom only 14% used external capital. Subsequently, farms from node 6 (ID 6) were divided based on the **SPEC** variable. Among the entities diversifying production (ID 8), 86% used external capital to finance their activities. On the other hand, among specialized farms, 61% were characterized by the use of external capital in order to improve their financial energy (ID 9). Then, the entities from node 9 (ID 9) were further classified using the **AREA** variable and two groups were obtained: users of farms with an area of up to 165.06 ha inclusive (ID 10) and users of farms with an area exceeding 165.06 ha (ID 11). It was found that specialized units were more willing to use outside capital when they used a farm with an area greater than 165 ha (92% of entities in node 11 were characterized by financing agricultural activities with outside capital).

4. Discussion and Conclusions

The aim of the study was to identify and assess the factors influencing the increase of the financial energy of a farm through the use of external capital, taking into account the farmer's and farm characteristics. For its implementation, a logistic regression model and a classification and regression tree analysis (CRT) were used. The study was conducted on a group of farms in Central Pomerania (Poland) participating in the system of collecting and using data from farms (FADN). Data on 348 farms were used for the analyzes, obtained through a survey conducted in 2020 with the use of a questionnaire.

Based on the analysis of the research results presented in the literature to date, it was established that the use of external capital as a source of financial energy in a farm is determined, on the one hand, by the socio-demographic characteristics of the farmer (**AGE**, **GEND**, **EDU**, **EDU_EC**, **SUC**) and the characteristics of the farm (**PROD_VALUE**, **AREA**, **SPEC**), and, on the other hand, by the availability of external financing sources. Factors relating to the first of these aspects were taken into account in the study.

Using the logistic regression model, it was established that the propensity to incur debt of farms is promoted by the following factors: gender of the head of the household (male, **GEND**), younger age of the head of the household (**AGE**), having a successor by the head of the household, who will take over the household in the future (**SUC**), higher value of generated production (**PROD_VALUE**), larger farm area (AREA) and multi-directional production of a farm (production diversification), as opposed to targeting plant or animal production (**SPEC**). The results of the analysis carried out with the use of classification and regression trees (CRT) showed that the key factors influencing the use of external capital in the agricultural production process are, first of all, features relating to an agricultural holding: the value of generated production (**PROD_VALUE**), agricultural area (**AREA**) and production direction (**SPEC**). The age of the farm manager (**AGE**) turned out to be of

key importance among the farmer's features favoring the tendency to incur debt in order to finance agricultural activity.

Among the surveyed entities of Central Pomerania, the chance of using outside capital is 115.2% higher in farms managed by men than in farms managed by women (*ceteris paribus*). The direction of this relationship is consistent with the research results presented in the literature [63,64]. It was also established that in the case of farms with a designated successor, the chance of financing agricultural activities with external capital is 76.4% higher in relation to farms where no successor has been designated (*ceteris paribus*). Moreover, the study proved that the farmer's age has an influence on the propensity of farms to borrow, and this tendency is higher in the case of younger farmers, which is consistent with the results of the research by Amjad and Hasnu [53]. It was also determined that the propensity to use external capital is also determined by the features relating to the farm. The results of the study show that increasing the farm area by one hectare will increase the probability of using external capital by the farm by 1.2% (*ceteris paribus*). This is consistent with the results of the studies by Kata [55], Subash and Ali [64] and Thorat et al. [57]. Moreover, in the case of farms whose annual production value exceeds PLN 100,000, the chance of financing agricultural production with external capital is 239.2% higher than in farms characterized by a lower annual production value (*ceteris paribus*). The direction of the impact of the variables included in the analysis is as predicted, except for the production specialization (**SPEC**). This means that in the case of the researched farms in Central Pomerania, multidirectional farms, diversifying production, are more likely to use outside capital in financing agricultural activities than those focused on one type of animal or plant production. This is probably due to the development processes of farms in the analyzed area. The data of the General Agricultural Census 2020 show that dynamic changes are taking place in agriculture in Poland, which are manifested by an increasingly stronger specialization of farms, with a simultaneous progressive concentration of agricultural production [97]. The studied farms with a multidirectional production profile use outside capital to a greater extent to finance their activities than units focused plant or animal production, because they are probably in the transformation phase, therefore show greater investment activity, and, to finance their investments, they also involve—apart from equity—external sources of financing thus increasing their financial energy. The verification of this hypothesis will constitute the next stage of research.

The results obtained in the course of the research contribute to both literature and practice. With regard to the first aspect, the presented results constitute a thread in the discussion of factors influencing the decisions of farms in the use of external capital in the agricultural production process. They also confirm the thesis about the high degree of self-financing of farms and their relatively low tendency to borrow (see e.g., [6,95]). Moreover, based on Korol [2,4], the paper proposes a conceptual approach to "*financial energy of a farm*", understood as the general financial situation of the farm. It mainly consists of possessing capital that allows for agricultural activity, which is both the cause and the consequence of the determinants of financial and investment decisions of a given entity. With regard to practice—the results of our research may constitute an important source of information, e.g., for financial institutions that deal with preparing offers in the field of external sources of financing for agricultural activities.

The obtained results have become a contribution to determining the direction of further research, which will include, among others, establishing the hierarchy of financing sources for farms and identifying factors that determine it. Assessing farmers' willingness to use leasing as an alternative to credit as a source of investment financing was also planned, as well as identifying factors determining its use. In the next stage of the research, it was also planned to report on the applicability domain of the developed models according to Roy, Kar and Ambure [98] and de Assis et al. [99]. The models will also be built using r^2_m metrics for validation according to Roy et al. [100] and Gajo et al. [101].

For further research, establishing the importance of using external capital in the process of transformation and specialization of agricultural production is also being planned.

This issue is of particular importance in the context of the implementation of target 2.3 of sustainable development [7], which concerns the doubling of agricultural productivity and income of small-scale food producers—thus increasing the financial energy of the agricultural holding, which can be achieved, among others, through the specialization of agricultural production. Also in this context, the financial energy of a farm becomes of great importance, as it can be activated or increased by recapitalization in the form of external capital. This form of energy triggers subsequent processes—both on the micro scale (a farm) and in the resulting macroeconomic processes, including the context of the implementation of global sustainable development goals (SDGs). Agriculture is a sector around which many of the defined SDGs concentrate. This is because farmers manage the vast majority of natural resources. Therefore, activities aimed at eliminating hunger or poverty, as well as those related to environmental protection and adaptation to climate change, are concentrated around them. Thanks to the use of external capital in the farm itself, processes in the form of investment and financial decisions are launched, which improve the financial situation—an increase in the financial energy of the farm, thus improving the financial condition of the farmer's household (increase in the financial energy of households) [2,4]. Moreover, financial energy is transferred from farms to many entities, changing its form. The importance of farms in the food supply chain should be emphasized here.

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Determinants of COVID-19 Impact on the Private Sector: A Multi-Country Analysis Based on Survey Data

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Abstract: Our paper aims to investigate the impact of COVID-19 on private sector companies in terms of sales, production, finance and employment. We check whether the country and industry in which companies operate, government financial support and loan access matter to the behaviour and performances of companies during the pandemic. We use a microdata set from a worldwide survey of more than 15,729 companies conducted between April and September 2020 by the World Bank. Logistic regression is used to assess which factors increase the likelihood of businesses suffering due to the COVID-19 pandemic. Our results show that COVID-19 negatively impacts the performance of companies in almost all countries analysed, but a stronger effect is observed among firms from developing countries. The pandemic is more harmful to firms providing services than those representing the manufacturing sector. Due to the pandemic, firms suffer mainly in sales and liquidity decrease rather than employment reduction. The increase in the number of temporary workers is an important factor that significantly reduces the probability of sales, exports or supply decline. The analysis results indicate policy tools supporting enterprises during the pandemic, such as increasing the flexibility of the labour market or directing aid to developing countries.

Keywords: COVID-19; pandemic; company's performance; logistic regression

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1. Introduction

The coronavirus pandemic has spread to nearly every country on the planet. As policymakers struggle with new lockdown policies to combat the virus's spread, national economies pay the cost. According to the International Monetary Fund (IMF) [1], the global economy contracted by 4.4% in 2020. The volume of international trade in goods dropped by 16% between April and June 2020 compared to the same period in 2019 [2]. The COVID-19 crisis has also had a significant impact on the labour market—overall, an unprecedented global loss of 114 million jobs was observed in 2020 compared to 2019, highest in the both North and South America and lowest in Europe and Central Asia, where job retention programmes have supported reductions in working hours [3]. Apart from statistics, in economic literature, we can find several new studies related to the impact of the COVID-19 pandemic on economic activities. They focus mainly on the macroeconomic effects of pandemics, i.e., a high correlation between the level of restriction and economic downturn [4–9]. The pandemic has also affected investments and consumption patterns [10–13].

Our paper aims to examine the impact of COVID-19 on private sector firms, and it is in line with quickly expanding studies on COVID-19 implications at the micro-level. Previous papers are mainly related to the implications of COVID-19 on management and marketing activities [14]. They analyse how the COVID-19 pandemic influence human resources management [15], research and development activities [16], corporate social responsibility (CSR systems [17], consumer behaviours [18], manager behaviours [19] and even gender equality in pandemic situations [15]. The researchers in this area have worked rapidly to find alternative solutions and facilitate the transformation of companies to adapt to the new

scenario and ensure their survival. The results of these works are guidelines for managers, especially indications of how to find uncertainty in businesses and develop strategies [20], tools for creating new marketing strategies [21,22], new strategies for organisations [17], practical advice on financial management [23] and guidelines on marketing innovation strategies of firms under crisis [22]. In addition, some of the papers show how to implement the interventions in public laws and policy, and national and local regulations [24].

Far fewer analyses relate to the impact of the COVID-19 pandemic on the economic activities of companies. The majority of studies focus on the three aspects. First, they try to identify channels through which firms adjust to the economic disruption caused by COVID-19 and try to overcome the pandemic [25]. The firms struggle with broken supply chains, discontinuity of services (both public and commercial), availability of staff, transport and logistics [26]. This is not just the result of the disease but also of how people or businesses respond to the circumstances. These analyses show that firms try to overcome the crises mainly by accelerating their adoption of digital, automation and other technologies [27,28] and shifting business activities to remote/hybrid work [29].

The second group of papers concentrates on the firm's expectations, i.e., how long did businesses expect the crisis to last and how do expectations affect their decisions. Research shows that a company's market condition before the pandemic determines its expectations regarding the pandemic duration. Weak companies are more affected; they expect further difficulties and are the first to limit employment and investments [30]. On the other hand, the higher liquidity firm has and the more prominent the firm is, the greater the belief in the ability to survive the crisis [25]. Additionally, Ref. [31] finds that despite international firms being more exposed to the COVID-19 pandemic, they have more resilient actions and better expectations for future domestic firms due to their global connectedness.

The last group of analyses relates to the implication of demand and supply shocks caused by COVID-19 on enterprises' operational and financial activity. According to [32], companies worldwide have been or still are forced to suspend some of their operations, partly due to temporary job closures ordered by some governments and partly due to supply chain disruptions. In some cases, changing demand patterns have forced companies to relocate or realign their production processes. In other cases, companies have had to find entirely new ways to operate in a challenging and uncertain environment. Severe effects of the COVID-19 pandemic have been documented in various countries in the form of lost sales, business closures, mass layoffs and liquidity shortages (for US firms: [25,33,34]; for firms from high and middle-income countries [35]; for selected European companies: [36]; for firms from developing countries [37]; for firms from selected Asian countries: [38–41]). However, few studies analyse the determinants of the impact of the COVID-19 pandemic on the economic activity of firms.

In this regard, our article fills the research gap by identifying determinants of the COVID-19 pandemic in enterprises. Few previous studies indicate firm size as a significant factor that determines the pandemic effects on the economic activities of firms. Despite large companies and small and medium-sized enterprises (SMEs) affected by the pandemic, all studies show that the impact on SMEs is much more significant [25,42]. Among SMEs, according to [38], faster-growing firms experience the demand shock somewhat less severely but are more affected by international trade disruptions, supply and financial shocks. Additionally, Ref. [39] find that better skills protect against the effects of a pandemic, i.e., employees with medium to high professional qualifications are less affected by the crisis. The weakness of the above analyses is that they are often based on data from one country and a limited set of determinants (size, employee skills, susceptibility to supply shocks). Our paper analyses whether the country and industry in which firms operate, government financial support and access to credit impact their behaviour and performance during the pandemic. We use a microdata set from a global survey of more than 15,720 firms conducted by the World Bank in 37 countries. In our work, we wanted to investigate the following research hypotheses:

Hypothesis 1 (H1). *Financial aid granted by commercial banks will most strongly reduce the probability of the company's performance drop.*

Hypothesis 2 (H2). *Increasing online business activity reduces the likelihood of a decline in sales more than increasing remote working.*

Hypothesis 3 (H3). *Declines in supply were the most difficult to cover with financial aid or changes in the work organisation.*

Hypothesis 4 (H4). *Regardless of the sector and the measure of economic activity, companies in developing countries were more exposed to losses.*

To summarise, our contribution to the empirical literature is that we, based on a large sample of firms worldwide, provide insight into the economic impact of the COVID-19 on the private sector. The results illuminate the strong economic impact of COVID-19 on private firms in the first weeks following the onset of COVID-19-related disruptions. We concentrate on the identification of factors, which determine the strength of this influence. The paper is organised as follows. The subsequent section outlines the description of the survey and the dataset. Section 2 introduces the empirical part of the paper by presenting the methodology used to measure the impact of COVID-19 on the activities of firms. The following section offers the results of our analysis, and the last one presents our conclusions.

Description of the Survey and the Data Set

The World Bank has developed a short company survey instrument, called Follow-up COVID-19, to measure the impact of the COVID-19 pandemic on the private sector. This survey is part of the Enterprise Survey (ES.), a flagship firm-level survey of a representative sample of an economy's private sector that the World Bank has conducted since the 1990s [43]. The Enterprise Survey is aimed at companies with five or more employees and answered by business owners and top managers. It covers a wide range of business environment issues, such as performance, finance, competition and corruption. The ES concerns manufacturing firms (with ISIC (International Standard Industrial Classification of All Economic Activities) codes 15–37, 45, 50–52, 55, 60–64 and 72) and services companies from construction, retail, wholesale, hotel, restaurant, transport, storage, communications and IT sectors. The Enterprise Survey is carried out in 42 countries, but the number of interviews depends on the economy's size, i.e., from 150 in small countries to 1200–1800 in large economies.

After the COVID-19 outbreak, follow-up surveys on the impact of COVID-19 under the ES methodology were conducted. The World Bank has two rounds of follow-up surveys. Our research is based on data obtained during the first completed round, between April and September 2020. The topics covered include changes in sales, demand for products or services, supply of inputs, workforce, cashflow availability and government supports. The survey was conducted using mainly computer-assisted telephone interviewing (CATI), i.e., a telephone surveying technique in which the interviewer follows a script provided by a software application. Telephone interviews are supported by email for self-administration if needed. The exceptions are three African countries (face-to-face interviews) and Russia, where an online survey was applied.

The sample covers micro, small, medium and large enterprises from 37 countries, including companies from Europe (62.7%), Asia (10.2%), Africa (21%) and Central America (6.2%) (Figure 1). Almost half (45.5%) are from the European Union countries, and nearly the same percentage (45.2%) are from developed countries. Firms from developing countries and transition economies represent 32.8 % and 22%, respectively.

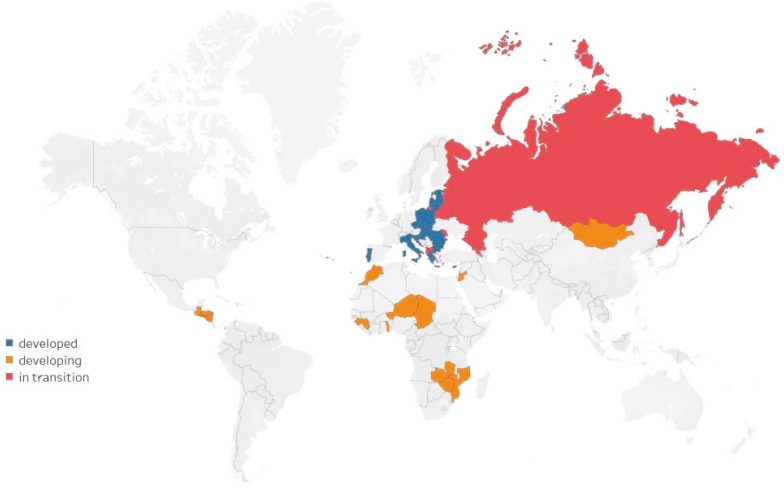

Figure 1. List of countries in the sample.

A representative sample of the private sector excluding agriculture and extractive industries covers companies dealing in manufacturing (49.4%), retail (19.6%) and other services (31%). Small and medium-sized firms account for 60% of the sample in the manufacturing sector and almost 88% in retail (Figure 2). The largest share of large companies can be observed in manufacturing (10%).

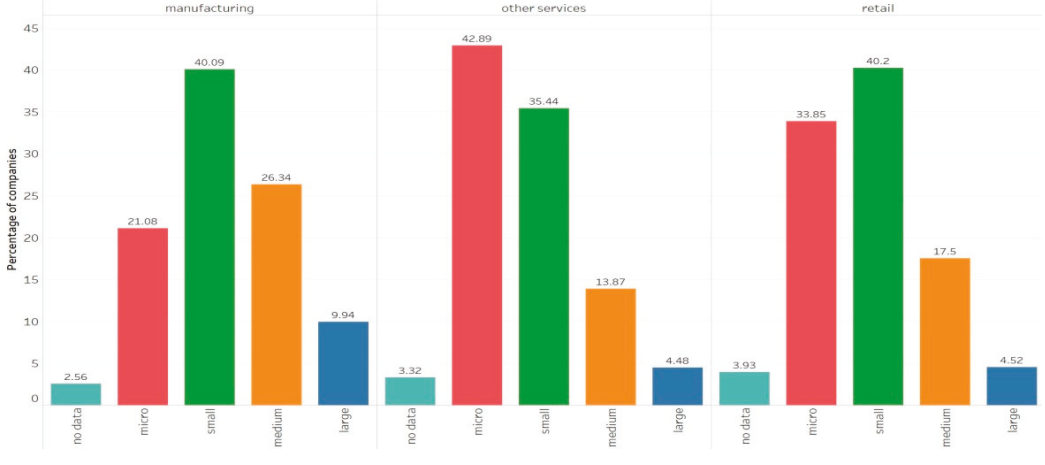

Figure 2. The sample in the term of firm size.

2. Research Methodology

The analysis covers survey data obtained from the World Bank's Enterprise Surveys—COVID-19 Survey, Round 1 from 2020 [43]. The research sample includes 15,720 companies from 37 countries. However, it should be noted that not all respondents answered every question; hence, the number of observations at individual stages of the analysis may differ.

Logistic regression was used to assess which factors increase the likelihood of companies suffering due to the COVID-19 pandemic. It is an excellent tool for modelling binary dependent variables [44]. In our case, it was the fact that there was a decrease in sales,

exports, demand, supply or liquidity. Therefore, we wanted to find factors that increase the probability that a given dependent variable would take the value of 1:

$$y_i = \begin{cases} 1, \textit{ analysed phenomenon decreased (e.g., sales, export or liquidity)} \\ 0, \textit{ analysed phenomenon remain the same or increased} \end{cases} \quad (1)$$

The following formula expresses this probability:

$$p_i = \frac{e^{\beta_0+\beta_1 x_{1,i}+\beta_2 x_{2,i}+\cdots+\beta_k x_{k,i}}}{1+e^{\beta_0+\beta_1 x_{1,i}+\beta_2 x_{2,i}+\cdots+\beta_k x_{k,i}}} \quad (2)$$

where p_i, the probability the dependent variable y_i, equals 1, $\beta_{1,i}$; $\beta_{2,i}$, …, $\beta_{k,i}$ represent the regression coefficient and $x_{1,i}$; $x_{2,i}$, …, $x_{k,i}$ represent the independent variables.

The positive sign of the parameter indicates that the increase in the variable increases the probability of taking the value of 1, while the negative sign of the parameter decreases this likelihood. Models were estimated using the MLM—maximum likelihood method [45]. In order to determine the strength and direction of the impact of the variables, odds ratios were determined:

$$\frac{p_i}{1-p_i} = e^{\beta_0+\beta_1 x_{1,i}+\beta_2 x_{2,i}+\cdots+\beta_k x_{k,i}} \quad (3)$$

The e^{β_k} is the fold change in the odds ratio; if $e^{\beta_k} > 0$, the increase in the odds ratio (3) can be observed, and for $e^{\beta_k} < 0$, we can observe the decrease in the odds ratio. The set of variables used in the analysis is presented in Table 1.

Table 1. Variables used in the study.

Variable	Description
Man	1 if it is a manufacturing company, 0 otherwise
Retail	1 if it is a retail company, 0 otherwise
Service	1 if it is an "other services" company, 0 otherwise
SalesD	1 if the sales decreased (comparing to the same month in 2019), 0 otherwise*
ExportD	1 if the exports decreased (comparing to the same month in 2019), 0 otherwise*
DemandD	1 if the demand decreased (comparing to the same month in 2019), 0 otherwise
SupplyD	1 if the supply decreased (comparing to the same month in 2019), 0 otherwise*
CFD	1 if the cash flow decreased (comparing to the same month in 2019), 0 otherwise*
LCB	1 if the primary aid source was a loan from a commercial bank, 0 otherwise
LNB	1 if the primary aid source was a loan from a non-banking financial institution, 0 otherwise
EF	1 if the primary aid source was equity finance, 0 otherwise
DP	1 if the primary aid source was delaying payments to suppliers or workers, 0 otherwise
GG	1 if the primary aid source was a government grant, 0 otherwise
OBA	1 if the company started or increased business activity online, 0 otherwise
DA	1 if the company started or increased delivery online, 0 otherwise
RW	1 if the company started or increased remote work, 0 otherwise
TW	1 if the company increased the number of temporary workers, 0 otherwise
Developed	1 if a developed country, 0 otherwise
Developing	1 if a developing country, 0 otherwise

Source: Authors' investigation. * Constant included but not reported. *p*-values are given in parentheses.

The quality of the model was assessed using McFadden's pseudo-R2, the log-likelihood for the entire model and the likelihood ratio test [46].

3. Results

In the first step of the analysis, the descriptive characteristics of the analysed entities were established, mainly in terms of the sector in which they operate. We assumed that

services and manufacturing were not equally affected by the effects of the pandemic, as the restrictions introduced in these sectors were different.

Table 2 shows the percentage distribution of constantly operating companies and temporarily or permanently closed ones, depending on the type of business. When analysing the data contained in Table 2, it can be seen that the percentage of permanently closed companies was similar in each sector. Nevertheless, other services are evidently disadvantaged, as the ratio of companies closed temporarily was almost twice as high as in the case of manufacturing or retail.

Table 2. Percentage of companies that remained open or were temporarily or permanently closed.

Sector	Remained Open	Temporarily Closed	Permanently Closed
Manufacturing	90.2%	5.9%	4.0%
Retail	89.6%	6.4%	4.0%
Other services	84.1%	10.7%	5.2%

Source: Authors' investigation based on the World Bank's Enterprise Surveys—COVID-19 Survey. Produced based on data taken from [43], World Bank, 2021. The World Bank approved the access to the World Bank Enterprise Survey Portal.

Figure 3 suggests that the type of business activity influences individual elements of the company's operations. In each case, the yellow colour means that the variable is at the same level as in the corresponding month of 2019; green means an increase and red a decrease. In Figure 3, in all aspects, the red dominates, so all aspects of business activities have been adversely affected by the pandemic. In many manufacturing companies, supply and demand have not changed. Retail turned out to be the sector in which the highest percentage of companies recorded an increase in sales and demand. At the same time, it shows the most significant decrease in sales, demand and financial liquidity in other services sectors. The graphical analysis suggests a certain relationship between the type of business activity and performance during the pandemic. This finding was further confirmed by the chi-square test of independence, which showed for each of the six analysed aspects that achievements in a given field are associated with the type of economic activity.

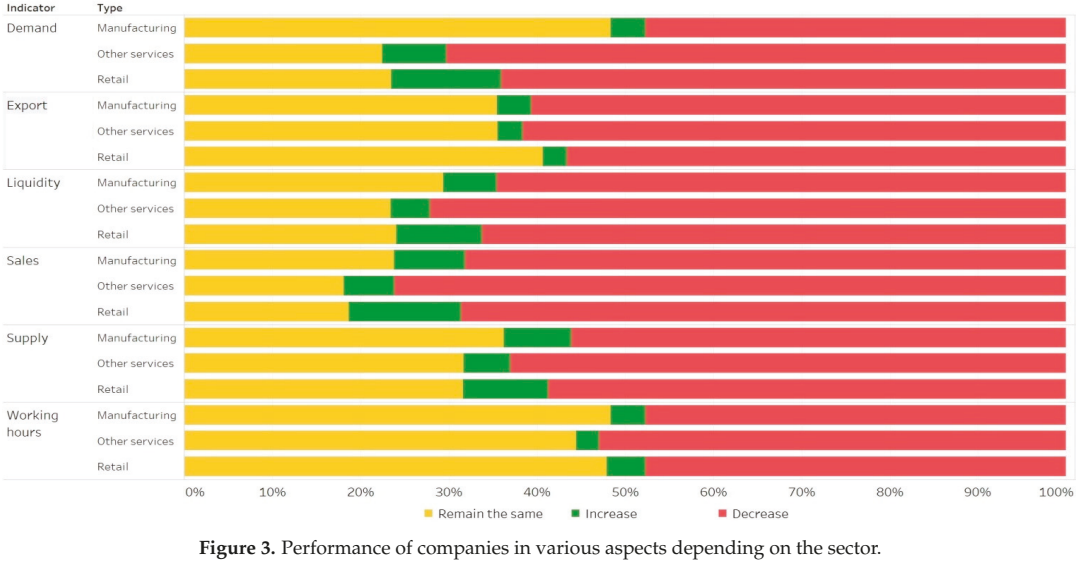

Figure 3. Performance of companies in various aspects depending on the sector.

The preliminary analysis showed that many aspects of enterprises' activity shrank compared to the corresponding month of 2019. By analysing the basic descriptive statistics,

we wanted to know the depth of these declines. Quantitative data from the World Bank survey [43] concerned only the sales volume and the number of laid-off employees. Table 3 presents basic descriptive statistics for these factors. When analysing the data on the decline in sales volume, it can be seen that it was significant. In manufacturing, half of the firms recorded a decline of 40% or higher, and the majority indicated a decrease of 30%. In retail, the median was also 40%, but in this case, most companies reported that sales fell by half; most companies from the other services sector revealed a similar decrease in sales. There is quite a strong differentiation and right-handed asymmetry in all sectors, which means that most companies recorded declines below the average, which was the highest for other services—52%. There are also significant differences in the case of 10% of companies affected by the highest sales drops. They amounted to at least 80% in manufacturing, but the decrease reached 100% in other services. Interestingly, looking at the data on the number of laid-off employees, the median and mode were 0 in each case; taking into account the positive skewness sign, it can be concluded that most companies did not reduce the number of employed staff, and those that did so reduced employment on average by 3.3 (retail) to 5.3 (manufacturing) workers. However, attention should be paid to the enormous values of the coefficient of variation and the range between the maximum and minimum values. At least one company in the manufacturing and retail sectors dismissed 600 people, while many companies issued no lay-offs. Thus, not only the industry itself but also other factors forced the reduction of staff.

Table 3. Percentage of companies that remained open or were temporarily or permanently closed.

	Mean	Median	Mode	Coefficient of Variation	Skewness	Min.	Max.	90th Percentile
Decrease in Sales (in Percentage Points)								
Manufacturing	43.05	40	30	57.51	0.69	1	100	80
Retail	46.83	40	50	55.98	0.45	1	100	90
Other services	52.16	50	50	53.96	0.29	1	100	100
Number of laid-off workers								
Manufacturing	5.33	0	0	478.60	14.01	0	600	10
Retail	3.30	0	0	677.43	21.12	0	600	6
Other services	4.06	0	0	363.83	7.94	0	250	10

Source: Authors' investigation based on the World Bank's Enterprise Surveys—COVID-19 Survey Produced based on data taken from [43], World Bank, 2021. The World Bank approved the access to the World Bank Enterprise Survey Portal.

Because all sectors were most severely affected by sales declines, we decided to show the scale of the problem in more detail. Figure 4 (box plot—dark red represents values between first quartile and the median, light red represents those between the median and third quartile) shows the declared decrease in sales in analysed sectors, taking into account the region as well. Not only were most companies from the other services sector affected by sales declines (Figure 3), but also the volume of this decline was the most severe in this sector (Figure 4), mainly if the business was run in a transition (median 40%, mode 100% sales drop) or developing country (median 55%, mode 50% sales drop). The manufacturing sector in developed countries (mode and median 30%) experienced the relatively mildest decline. However, it should be borne in mind that the analysed set of enterprises is characterised by high differentiation (long boxes) and the presence of extreme values (lower and upper whiskers). In each sector/region combination, some companies declared a 100% sales decline, but in some, it was practically unnoticed (1–2%). It most likely results from the industry in which the company operates and the degree of flexibility of operations.

The models presented in Table 4 have satisfactory properties, both in terms of predictive properties and the model's fit to empirical data. In the sales decline (SalesD) case, seven diagnostic variables turned out to be statistically significant. The estimated parameters

showed a negative value for three of them, which indicates that the sales drop is less likely to occur as the predictor takes the value of 1. In this case, the odds of recording a decline in sales decreased if it was a manufacturing company (Man), which increased the number of temporary employees (TW), and if its headquarters were in a developed country (Developed). At the same time, the remaining variables indicate characteristics that increase the chance of recording a drop in sales (a positive coefficient value and odds ratio above 1). Such factors turned out to be EF, DP, Support and Developing. This means that companies that received any form of government support had a better chance of observing a drop in sales. However, it should be considered whether this phenomenon is not due to the fact that the government aid (at least in Poland) was directed to a greater extent to entrepreneurs who were able to document an actual drop in sales and revenues compared to the periods before the pandemic. Moreover, the factors increasing the chances of recording a decline in sales included two forms of primary aid: equity finance and delaying payments to suppliers and employees. Doing business in developing countries was also a factor increasing the chance of recording a drop in sales.

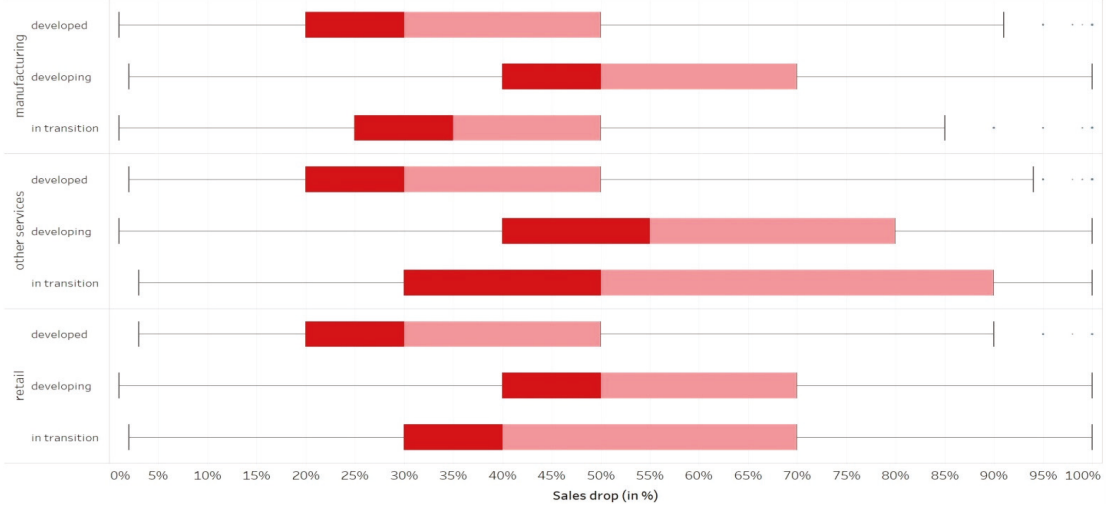

Figure 4. Distribution of the decline in sales by sector and region–dark red represents values between first quartile and Table 4.

In the case of another dependent variable—a decrease in exports (ExportD)—in the estimated model, 6 out of 14 proposed diagnostic variables turned out to be statistically significant. However, it should be borne in mind that in this case, the number of observations was almost two times lower, as not all of the analysed companies conducted export activities. The variable Man turned out to be among the factors reducing the odds of recording a decline in exports, so again companies from the broadly understood services sector fared worse than manufacturing companies. TW (an increase in the number of temporary workers) reduced the chance of recording a decline in exports, as in the case of sales. Moreover, the LCB variable also turned out to be statistically significant. Hence, companies whose primary source of aid were loans offered by commercial banks had less chance of reducing exports. Factors increasing this chance turned out to be running a business in developed and developing countries, which means that they fared worse than companies operating in countries belonging to the "in transition" group. In addition, surprisingly, the variable DA, i.e., starting or intensifying online deliveries, was a factor increasing the odds of export reduction.

Table 4. Logit binary model's estimation results *.

Variable	SalesD		ExportD		DemandD		SupplyD	
	Coef.	Odds Ratio	Coef.	Odds Ratio	Coef.	Odds Ratio	Coef.	Odds Ratio
Man	−0.022 (0.017)	0.8057	−0.934 (0.005)	0.393	−0.074 (0.308)	0.928	0.060 (0.318)	1.062
Retail	−0.074 (0.531)	0.9281	−0.461 (0.333)	0.630	0.057 (0.558)	1.059	0.081 (0.301)	1.084
LCB	0.132 (0.260)	1.1409	−0.680 (0.049)	0.506	0.042 (0.666)	1.043	−0.021 (0.797)	0.978
LNB	0.452 (0.662)	1.5719	**		−0.189 (0.766)	0.828	−0.357 (0.522)	0.699
EF	0.447 (0.0000)	1.5643	−0.064 (0.859)	0.937	0.316 (0.0003)	1.375	0.052 (0.473)	1.054
DP	0.462 (0.0009)	1.5878	−0.488 (0.219)	0.613	0.351 (0.0017)	1.421	0.009 (0.913)	1.010
GG	0.235 (0.146)	1.2644	−0.382 (0.442)	0.682	0.230 (0.099)	1.258	0.171 (0.136)	1.187
OBA	−0.029 (0.783)	0.9714	−0.106 (0.714)	0.899	0.132 (0.132)	1.141	0.096 (0.188)	1.101
DA	−0.045 (0.667)	0.9554	0.595 (0.086)	1.813	−0.140 (0.104)	0.869	0.060 (0.411)	1.062
RW	−0.034 (0.691)	0.9658	−0.364 (0.135)	0.694	−0.104 (0.147)	0.901	−0.130 (0.029)	0.877
TW	−1.177 (0.0000)	0.3080	−1.747 (0.0000)	0.174	1.068 (0.0000)	0.344	−0.861 (0.0000)	0.422
Support	0.224 (0.018)	1.2514	−0.219 (0.430)	0.803	0.240 (0.003)	1.271	0.096 (0.134)	1.101
Developed	−0.599 (0.0000)	0.5493	1.924 (0.0000)	6.847	−0.424 (0.0000)	0.654	−0.504 (0.0000)	0.603
Developing	0.476 (0.0003)	1.6097	1.772 (0.0000)	5.885	0.360 (0.0000)	1.433	0.711 (0.0000)	2.036
Obs. No.	8735		4033		8520		8668	
R^2	0.093		0.105		0.081		0.043	
cCor. pred.	91.4%		98%		86.4%		77.7%	
LR test	172.597 (0.0000)		82.178 (0.0000)		147.613 (0.0000)		400.9 (0.0000)	

* Constant included but not reported. *p*-values are given in parentheses. ** Dropped Prob(ExportD = 1 | LNB = 1) = 1. Variable service and CFD were not included in the model due to the collinearity. Source: Authors' investigation based on the World Bank's Enterprise Surveys—COVID-19 Survey Produced based on data taken from [43], World Bank, 2021. The World Bank approved the access to the World Bank Enterprise Survey Portal.

Another of the estimated models concerned the decline in demand. The number of observations for this model was similar to the number of observations for the sales (SalesD) and supply (SupplyD) model. Among the factors limiting the decline in demand, there was only one. It was a geographical factor, i.e., running a business in a developed country. The remaining five diagnostic variables indicate factors that increase the odds of reduced demand, including operating in a developing country, receiving any form of government support, having the basic form of aid as equity finance (EF), delaying payments (DP) and grants from the government (GG).

The last estimated model (SupplyD) was the one with the lowest number of significant factors. It is also the model with the poorest properties. Many variables coincide with those indicated in previous cases, so the factor that increased the risk of a decrease in supply was operating in a developing country. On the other hand, the odds of such a decrease were reduced by an increased share of temporary workers, running a business in a developed country and an increased share of remote work (RW).

In order to make the analysis more detailed, the more detailed models were estimated. They show the extent to which the individual types of financial support and the activities undertaken by enterprises impacted the decreases observed in particular areas of business operations. Table 5 shows the impact of various factors on the decline in sales. The three presented models relate to manufacturing, services and retail, respectively. It turns out that in the case of manufacturing companies, obtaining a loan from a commercial bank, equity finance or delaying payments increased the likelihood of a decrease in sales. The mitigating factor was the introduction of temporary work. As in the case of the models presented in Table 4, in these more detailed models, business residence turned out to be of crucial importance. Thus, operating in a developed country reduced the chance of seeing a drop in sales, while operating in a developing or "in transition" country increased the likelihood of seeing a decline in sales. Similar trends are also observed in the case of services and trade. In the latter case, the intensification of online deliveries also turned out to reduce the decline in sales.

Table 5. Logit binary model's estimation results *—sales decrease.

Variable	Manufacturing		Services		Retail	
	Coef.	**Odds Ratio**	**Coef.**	**Odds Ratio**	**Coef.**	**Odds Ratio**
LCB	0.303 (0.063)	1.354	0.061 (0.776)	1.063	−0.248 (0.365)	0.780
LNB	−0.348 (0.745)	0.705	**		**	
EF	0.429 (0.025)	1.535	0.645 (0.002)	1.906	0.198 (0.454)	1.219
DP	0.539 (0.005)	1.715	0.321 (0.218)	1.379	0.408 (0.204)	1.504
GG	0.156 (0.462)	1.168	0.218 (0.491)	1.244	0.468 (0.265)	1.597
OBA	0.101 (0.496)	1.106	−0.214 (0.268)	0.807	0.012 (0.961)	1.012
DA	0.228 (0.142)	1.256	−0.158 (0.412)	0.854	−0.597 (0.011)	0.550
RW	−0.0413 (0.723)	0.959	−0.177 (0.287)	0.838	0.233 (0.303)	1.262
TW	−0.836 (0.003)	0.433	−1.655 (0.000)	0.191	−1.400 (0.001)	0.246
Support	0.086 (0.493)	1.090	0.637 (0.001)	1.891	0.099 (0.663)	1.104
Developed	−0.403 (0.007)	0.667	−1.068 (0.000)	0.344	−0.425 (0.111)	0.653
Developing	0.454 (0.005)	1.575	0.476 (0.032)	1.610	0.517 (0.050)	1.677
Obs. No.	4295		2820		1620	
R^2	0.024		0.062		0.041	
Cor. pred.	90.2%		92.8%		92.1%	
LR test	66.535 (0.0000)		91.55 (0.0000)		36.948 (0.0001)	

* Constant included but not reported. *p*-values are given in parentheses. ** Dropped Prob(Y = 1 | X = 1) = 1. Variable CFD was not included in the model due to the collinearity. Source: Authors' investigation based on the World Bank's Enterprise Surveys—COVID-19 Survey. Produced based on data taken from [43], World Bank, 2021. The World Bank approved the access to the World Bank Enterprise Survey Portal.

Table 6 shows the factors influencing the chances of reducing exports. The residence of business was again of key importance; regardless of whether we are talking about manufacturing, trading or service enterprises, operating in "in transition" countries was a factor reducing export losses, while doing business in developed or developing countries increased these odds significantly. In the context of exports, the introduction of temporary work helped to reduce the chances of a decline only in the case of industry; in other

sectors, this factor turned out to be statistically insignificant. The deferral of payments in manufacturing companies was also a factor in reducing the odds of export losses, while in the case of services, the intensification of online activity turned out to be a protective umbrella.

Table 6. Logit binary model's estimation results *—export decrease.

Variable	Manufacturing		Services		Retail	
	Coef.	Odds Ratio	Coef.	Odds Ratio	Coef.	Odds Ratio
LCB	−0.847 (0.0371)	0.428	0.088 (0.923)	1.0925	−1.568 (0.248)	0.208
LNB	**		**		**	
EF	−0.090 (0.834)	0.913	−0.272 (0.721)	0.762	0.183 (0.896)	1.201
DP	−0.782 (0.087)	0.457	0.308 (0.790)	1.360	0.240 (0.882)	1.272
GG	−0.717 (0.203)	0.488	**		−0.380 (0.824)	0.683
OBA	0.303 (0.407)	1.354	−1.507 (0.036)	0.222	−0.491 (0.620)	0.611
DA	0.784 (0.078)	2.191	1.064 (0.219)	2.899	−0.378 (0.677)	0.684
RW	−0.300 (0.2831)	0.740	−0.183 (0.791)	0.832	−1.154 (0.236)	0.315
TW	−1.690 (0.0009)	0.184	−1.602 (0.157)	0.201	−1.337 (0.298)	0.262
Support	−0.011 (0.973)	0.988	−0.149 (0.843)	0.861	−1.908 (0.064)	0.148
Developed	1.713 (0.0000)	5.548	2.815 (0.002)	16.702	3.965 (0.001)	52.756
Developing	1.595 (0.0000)	4.930	2.132 (0.004)	8.440	3.045 (0.015)	21.022
Obs. No.	2340		1078		615	
R^2	0.081		0.173		0.317	
Cor. pred.	97.4%		99.0%		98.7%	
LR test	45.528 (0.0000)		21.178 (0.0199)		27.061 (0.0045)	

* Constant included but not reported. *p*-values are given in parentheses. ** Dropped Prob(Y = 1 | X = 1) = 1. Variable CFD was not included in the model due to the collinearity. Source: Authors' investigation based on the World Bank's Enterprise Surveys—COVID-19 Survey. Produced based on data taken from [43], World Bank, 2021. The World Bank approved the access to the World Bank Enterprise Survey Portal.

As Figure 3 shows, the decline in demand was one of the two most typical adverse effects of the COVID-19 pandemic. Table 7 presents which factors contributed to the decrease in the probability of a reduction in demand in various types of enterprises. Not surprisingly, running a business was important again, but this time running a business in a developed country was a factor reducing the chances of recording a drop in demand. The same was observed in the case of the intensification of temporary work and in production companies' case, also of remote work. As in the case of Table 4, here we can see that receiving support was associated with a greater chance of recording a decline in demand. This should be explained in the same way, i.e., directing aid to units suffering losses due to the pandemic; however, other factors proved to be statically significant in different sectors. In the case of services, it was equity finance, and in the case of manufacturing, EF and additionally a payment delay. In the case of service companies, the factors reducing losses in demand turned out to be the intensification of online activities and online delivery, and obtaining support from commercial banks.

Table 7. Logit binary model's estimation results *—demand decrease.

Variable	Manufacturing		Services		Retail	
	Coef.	Odds Ratio	Coef.	Odds Ratio	Coef.	Odds Ratio
LCB	0.017 (0.229)	1.185	0.086 (0.621)	1.09	−0.450 (0.051)	0.6376
LNB	−0.522 (0.564)	0.5931	−0.370 (0.734)	0.691		**
EF	0.341 (0.005)	1.4069	0.425 (0.008)	1.530	0.023 (0.915)	1.023
DP	0.523 (0.001)	1.688	0.008 (0.967)	1.008	0.408 (0.139)	1.504
GG	0.110 (0.553)	1.1164	0.422 (0.116)	1.525	0.246 (0.484)	1.279
OBA	0.220 (0.079)	1.2465	−0.111 (0.465)	0.894	0.359 (0.092)	1.432
DA	0.043 (0.730)	1.0444	−0.171 (0.257)	0.842	−0.621 (0.002)	0.537
RW	−0.170 (0.081)	0.8434	−0.115 (0.384)	0.891	0.144 (0.441)	1.155
TW	−1.229 (0.0000)	0.2925	−0.744 (0.028)	0.475	−1.094 (0.009)	0.334
Support	0.192 (0.079)	1.2117	0.278 (0.059)	1.320	0.304 (0.122)	1.355
Developed	−0.292 (0.020)	0.7465	−0.623 (0.0003)	0.536	−0.426 (0.061)	0.652
Developing	0.336 (0.0113)	1.3969	0.388 (0.017)	1.474	0.358 (0.103)	1.430
Obs. No.	4223		2716		1581	
R^2	0.029		0.026		0.038	
Cor. pred.	85.3%		87.3%		87.8%	
LR test	77.395 (0.0000)		54.195 (0.0000)		41.887 (0.0000)	

* Constant included but not reported. *p*-values are given in parentheses. ** Dropped Prob(Y = 1 | X = 1) = 1. Variable CFD were not included in the model due to the collinearity. Source: Authors' investigation based on the World Bank's Enterprise Surveys—COVID-19 Survey. Produced based on data taken from [43], World Bank, 2021. The World Bank approved the access to the World Bank Enterprise Survey Portal.

The data on the decline in supply are presented last (Table 8). This element turned out to be relatively insensitive to financial support and organisational changes in companies from the retail sector. However, many factors were statistically significant in the case of services. The severity of the supply drops was diversified by the intensification of temporary work apart from the aforementioned element—the level of development of the country's economy. Additionally, in the case of service companies, the chances of reducing the decline in supply were caused by the introduction of remote work and deferred payments.

Table 8. Logit binary model's estimation results *—supply decrease.

Variable	Manufacturing		Services		Retail	
	Coef.	Odds Ratio	Coef.	Odds Ratio	Coef.	Odds Ratio
LCB	0.083 (0.483)	1.087	−0.067 (0.651)	0.935	−0.217 (0.278)	0.804
LNB	−0.475 (0.560)	0.621	−0.234 (0.829)	0.790	−0.419 (0.705)	0.657
EF	0.089 (0.385)	1.093	0.079 (0.545)	1.082	−0.071 (0.691)	0.930

Table 8. *Cont.*

Variable	Manufacturing		Services		Retail	
	Coef.	Odds Ratio	Coef.	Odds Ratio	Coef.	Odds Ratio
DP	0.312 (0.021)	1.366	−0.326 (0.0387)	0.721	−0.148 (0.459)	0.861
GG	0.070 (0.654)	1.072	0.239 (0.273)	1.269	0.397 (0.160)	1.488
OBA	0.281 (0.009)	1.325	−0.134 (0.294)	0.874	0.045 (0.787)	1.046
DA	0.020 (0.848)	1.020	0.261 (0.047)	1.299	−0.194 (0.245)	0.823
RW	−0.099 (0.230)	0.905	−0.198 (0.067)	0.820	−0.076 (0.607)	0.926
TW	−0.871 (0.0001)	0.418	−0.748 (0.012)	0.473	−0.967 (0.012)	0.380
Support	0.062 (0.479)	1.064	0.138 (0.242)	1.148	0.150 (0.335)	1.162
Developed	−0.570 (0.0000)	0.565	−0.379 (0.005)	0.684	−0.509 (0.005)	0.600
Developing	0.525 (0.0000)	1.691	0.957 (0.0000)	2.606	0.734 (0.0000)	2.085
Obs. No.	4279		2772		1617	
R^2	0.041		0.056		0.046	
Cor. pred.	76.5%		78.4%		79.4%	
LR test	194.54 (0.0000)		164.83 (0.0000)		76.561 (0.0000)	

* Constant included but not reported. *p*-values are given in parentheses. Variable CFD was not included in the model due to the collinearity. Source: Authors' investigation based on the World Bank's Enterprise Surveys—COVID-19 Survey. Produced based on data taken from [43], World Bank, 2021. The World Bank approved the access to the World Bank Enterprise Survey Portal.

4. Conclusions

Our paper aims to examine the impact of COVID-19 on private sector firms in terms of sales, production, finance and employment. We determined whether the country and industry in which firms operate, government financial support and access to credit impact its behaviour and performance during the pandemic. It is crucial to keep in mind that the World Bank survey was conducted immediately after the first lockdown. Many companies did not react immediately to the pandemic and considered it a short-term phenomenon, which had a more significant impact on their behaviour. It is necessary for the authors to compare the results from this survey with the future survey conducted by the World Bank in 2021 (these data are inaccessible at the present moment).

Our results show that a country's development stage strongly influences the probability of changes in trading activities such as sales, exports, demand and supply. Our research confirms that the global COVID-19 pandemic negatively impacts firms in developing economies to a greater extent than those in developed countries (confirming the fourth hypothesis). Firms in developing countries are hit hardest because they have "fewer resources or channels" to protect themselves against this economic crisis, i.e., lower labour productivity, lower capital intensity and a lower degree of digitisation in production processes [47]. Our research indicates the need for organisations such as the World Bank or IMF to provide financial support to developing countries to respond to the health and economic impacts of COVID-19.

The analysis also provides evidence on the role of the sector in which a firm operates in the decline of economic activity due to the COVID-19 pandemic. It is less probable that firms in the manufacturing sector will be affected by decreased sales and exports than those in the services sector. It is probably related to the higher level of automation in many manufacturing processes than services. On the other hand, companies providing

services are more dependent on human contact and interaction and thus may suffer more significant losses from a crisis of this nature. Moreover, more detailed analyses (Tables 5–8) showed that different forms of aid and changes in enterprises' operating activities affect differently depending on the sector and measure of performance. Among the various discussed forms of coping with the lack of liquidity, the most statistically significant was deferment of payments. However, it occurred in both a positive and negative context. Therefore, one should be aware that this tactic works like a double-edged sword. On the one hand, it allowed entrepreneurs to postpone selected payments but thus contributed to the deterioration of liquidity in other companies, hence, for example, different directions of impact in production and service companies. Therefore, hypothesis 1, assuming that commercial banks' support will be of key importance for reducing the harmful effects of the pandemic, has not been confirmed.

The second hypothesis assumed that the intensification of online activities would significantly affect the reduction of performance drops and certainly better than remote work. This turned out to be valid only in the case of service companies. Remote work was irrelevant to retail. The intensification of online activity increased the chances of a decline in demand (most likely, the sales level was maintained throughout the entire network, but certain sales points were experiencing declines). Based on the results of our analysis, we point to an essential factor that significantly reduces the probability of the decline of sales, exports or supply—the increase in the number of temporary workers. During the COVID-19 pandemic, market conditions change almost daily, and companies struggle to keep up. Thus, while the short-term use of temporary workers helped many companies during the pandemic, it will probably be an effective tool for work management in post-COVID-19 reality, as well. Our results indirectly support the thesis with a greater emphasis on the flexibility of labour markets in countries affected by the pandemic as an economic policy tool supporting recovery from the crisis.

Our research also shows that financial aid from commercial banks and/or the government does not reduce the probability of declining sales or supply (confirming the third hypothesis). The positive impact of this support was visible only in terms of exports. These undetectable effects of financial aid could be related to too little time elapsed since the first lockdown or low interest rates (excess liquidity of the banking system), observed in many developed countries.

Our results contribute to the rapidly emerging literature examining the direct impact of the pandemic on firms' ability to operate and allow us to formulate some policy implications. We believe that the success of the recovery pace depends critically on the policy actions taken during the crisis. If policies ensure that workers do not become unemployed, firms do not go bankrupt and trade networks are preserved, the recovery will be faster and smoother. Our results underscore the fragility of businesses in sales and liquidity areas, especially in the short time after the pandemic began. Our results suggest that many of these firms had little cash on hand at the onset of the pandemic, meaning that they either had to drastically cut spending, take on additional debt or file for bankruptcy. It highlights how the immediacy of new financial resources can affect medium-term performance. This is a major recommendation for developed economies to ensure quick access to financial support, especially for small and medium firms.

Governments in developed countries can easily finance an extraordinary increase in spending even as their revenues fall. Countries with limited or no fiscal space face difficult choices and need the support of the international community. This is a case of many low-income and emerging economies facing capital flight—the challenge is even greater. This is why we recommend international institutions (e.g., the International Monetary Fund) to create a new financial support programme and help low-income countries create the right economic conditions for recovery at home.

We are aware that our research has some limitations. Some of them are related to the data. The surveys are mainly conducted in the World Bank client countries, and therefore, most of the high-income countries are not covered by the surveys (USA, Canada, Western

European countries or Japan). This is why the comparison of the COVID-19 impact on private firms' activities in developed and developing countries does not give a complete picture. Additionally, our research does not allow us to assess the impact of the COVID-19 pandemic on firms in more specific sectors. According to [48], the analysed impact depends strongly on the sector, particularly on the sectoral share of jobs that can still be performed under closure. However, the most significant limitation of our research is the inability to show the change in companies' activities over time. Many things happened in the course of the year. In late spring 2020, many countries began to lift some restrictions after the first signs of recovery. However, in late autumn 2020, the second COVID-19 wave began, and restrictive measures were again introduced. In addition, some countries were affected by the third wave of the coronavirus, which came in the spring of 2021. Therefore, in future research, when the second survey will be accessible, we plan to examine what difference a year made in the impact of the pandemic COVID-19 on firms' activities.

Further analysis is needed. The authors intend to extend research on the factors that determine the pandemic's impact on various aspects of business activities. We plan to develop a predictive model using an innovative methodology, i.e., the fuzzy logic theory. It is a tool widely used in mechanical, robotic and industrial engineering for modelling imprecise, uncertain and ambiguous phenomena. The situation of many companies in the COVID-19 pandemic is influenced by many factors that often cannot be defined precisely. Hence, the fuzzy logic approach will increase the predictive power of planned analysis.

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The Financialization of Crude Oil Markets and Its Impact on Market Efficiency: Evidence from the Predictive Ability and Performance of Technical Trading Strategies

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Abstract: Oil price forecasts are of crucial importance for many policy institutions, including the European Central Bank and the Federal Reserve Board, but projecting oil market evolutions remains a complicated task, further exacerbated by the financialization process that characterizes the crude oil markets. The efficiency (in Fama's sense) of crude oil markets is revisited in this research through the investigation of the predictive ability of technical trading rules (TTRs). The predictive ability and trading performance of a plethora of TTRs are explored on the crude oil markets, as well as on the energy sector ETF XLE, while taking a special focus on the turbulent COVID-19 pandemic period. We are interested in whether technical trading strategies, by signaling the right timing of market entry and exits, can predict oil market movements. Research findings help to confidently conclude on the weak-form efficiency of the WTI crude oil and the XLE fund markets throughout the 1999–2021 period relative to the universe of TTRs. Moreover, results attest that TTRs do not add value to the Brent market beyond what may be expected by chance over the pre-pandemic 1999–2019 period, confirming the efficiency of the market before 2020. Nonetheless, research findings also suggest some temporal inefficiency of the Brent market during the 1 and $\frac{1}{4}$ years of pandemic period, with important consequences for energy markets' practitioners and issuers of policy. Research findings further imply that there is evidence of a more intense financialization of the WTI crude oil market, which requires tighter measures from regulators during distressed markets. The Brent oil market is affected mainly by variations in oil demand and supply at the world level and to a lesser degree by financialization and the activity of market practitioners. As such, we conclude that different policies are needed for the two oil markets and also that policy issuers should employ distinct techniques for oil price forecasting.

Keywords: crude oil; energy markets; technical trading rules; predictability; data snooping; market efficiency; COVID-19 pandemic

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1. Introduction

Over the last decades, the oil market registered significant growth, becoming the world's biggest commodity market and transforming from a purely physical to a highly sophisticated and complex financial market [1]. Its rhythm of growth remains high: the global oil and gas market is expected to grow from $4677.45 billion in 2020 to $5870.13 billion in 2021 at a compound annual growth rate (CAGR) of 25.5%, and the market is expected to reach $7425.02 billion in 2025 at a CAGR of 6% [2]. In addition, crude oil also tops the commodities markets in terms of liquidity, being the most actively traded commodity around the globe, while the price of oil reflects the overall health of the energy sector worldwide.

Oil price forecasts are of crucial importance for macroeconomic projections, which is especially explained by the impact that oil prices have on inflation and output and,

consequently, on the issuance of monetary policy. However, recent movement of crude oil markets has highlighted the difficulty in forecasting oil prices and attested that oil market dynamics tend to vary substantially over time. Moreover, crude oil markets are characterized by increased volatility, which might be explained both by variations in the price elasticity of oil demand and supply, and also by the process of "financialization" of the oil market with the increasing use of oil as a financial asset [3–6]. Consequently, oil derivatives markets have expanded over the last decades, with the presence of purely financial practitioners (institutional investors such as hedge funds, pension funds, insurance companies, and also individual traders) with no interest in the physical commodity becoming more prominent. Concurrently, a variety of instruments that permit speculation in oil have become available for trading, from passive investment vehicles such as energy indexes and ETFs to derivative instruments such as futures, options, or CDFs. All these developments in oil markets have a direct impact on the oil market movements, its efficiency and subsequent predictability.

Financial institutions and regulators around the globe (i.e., The Federal Reserve Board, the World Bank, the International Energy Agency, the European Central Bank etc.) regularly issue oil price forecasts, which is further a paramount factor for policy formulation within the European Central Bank (ECB), the IMF and the Federal Reserve Board [7]. However, predicting oil price movements remains a challenging endeavor [3], which is further complicated by its increasing financialization and the intense speculative activity within the market that improved its efficiency (in Fama's EMH sense) and hence contributed to its unpredictability. Moreover, none of the techniques previously employed for oil price forecasting has proved particularly successful and thus presently there is no "optimal" or commonly accepted forecasting technique for oil price [8].

As such, the analysis of the efficiency of the crude oil markets is a timely research topic, with important implications for policy issuers and for financial markets practitioners. Nonetheless, and somewhat surprisingly given the practitioners' interest in this commodity as reflected in its market liquidity, the academic literature on the profitability of technical trading rules applied to crude oil markets remains rather scarce. Our study contributes to extending this literature. This paper thus revisits the Fama efficiency [9] of the crude oil markets though exploring the predictive ability and trading performance of a plethora of technical trading rules (TTRs) applied to relevant energy series (i.e., WTI crude, Brent crude and XTE). Moreover, our focus on energy/oil markets is even more motivated by the fact the COVID-19 pandemic has severely impacted the oil markets, due to travel restrictions, disrupted supply chains and imposed government lockdowns. Previous studies have found that the efficiency of crude oil markets is lost during crisis periods, investigating the 2008 global financial crisis [10,11]. As the impact of the ongoing pandemic crisis on the oil market efficiency has not been yet assessed, this constitutes a secondary research goal of the current study and a further contribution to the extant literature.

The Efficient Market Hypothesis (EMH) and the related concept of market efficiency remain paramount in modern finance, with a plethora of empirical studies dedicated to confirm it on different markets, assets and time periods, with divergent results. EMH has its roots in the works of Eugene Fama [12,13] and Paul Samuelson [14]. Furthermore, Fama's seminal work defines an efficient market as "a market with a large number of rational, profit "maximisers" actively competing, each attempting to predict future market values of individual securities, and where current important information is almost freely available to all participants" [15] and it also distinguishes between three forms (or 'strengths') of market efficiency—weak, semi-strong and strong. In its weak-form, EMH states that current prices reflect all existing historical information, and thus prices will exhibit random walk.

Alternatively, technical analysis (or Chartism) specifically involves making investment decisions based on past price movements. As Alexander [16] has said it, "the technician studies price movements of the immediate past for telltale indications of the movements of the immediate future." However, in relation to EMH, this would imply that technical trading rules (TTRs) based on historical price data would offer no predictive power, and

hence technical analysis would be inexpedient. Nonetheless, as Menkhoff [17] shows, technical analysis remains very popular among practitioners, with the vast majority of 692 surveyed fund managers from five countries acknowledging relying on technical analysis for market timing and decision-making, and to favor it relative to fundamental analysis. This is an indication that Chartism must hold some value to traders that is unaccounted by the EMH.

Consequently, in this study, we choose to employ instruments pertaining to technical analysis (i.e., TTRs) to investigate the overall efficiency of the oil markets, to assess the potential differing financialization process of the two most important crude oil markets (WTI and Brent) and to analyze the impact of the COVID-19 induced crisis on oil markets' efficiency.

The remainder of the paper is organized as follows. The next section gives a review of the literature concerned with technical trading rules applied to commodity markets and most specifically their predictive ability and performance on oil/energy markets. Section 3 discusses the data and method. Empirical results and discussions are contained in Section 4, followed by some concluding comments in the final section.

2. Literature Review

Although the predictive ability and profitability of technical trading rules applied to various international stock markets during different time periods have been thoroughly examined, the literature on technical trading rules applied to commodities markets in general and energy/oil markets in particular remains rather scarce.

One of the first studies in this narrow literature is that of Marshall et al. [18], which test over 7000 rules on 15 commodity futures markets, including WTI crude oil, heating oil and soybean oil for a period spanning 1 January 1984–31 December 2005. They analyze the entire series and two equal sub-periods and cannot report that technical rules achieve superior performance after accounting for data snooping, except the oats market. The oil markets are thus found to be efficient over the 1984–2005 period.

Further, Szakmary et al. [19] examine the profitability (net of transactions costs) arising from the implementation of 12 trading rules (six DMAC and six channel specifications) on a monthly dataset for 28 commodities, having a different start date for each series and with all series ending on 31 December 2007. The dataset includes the same three oil markets again, i.e., WTI crude oil, heating oil and soybean oil, and results confirm that technical rules do perform well, although mean returns are lower and less significant toward the end of the analyzed period (i.e., during the 1996–2007 sub-period), especially when testing is restricted to high-volume markets, a category to which WTI crude oil belongs. Nonetheless, the authors refrain to claim that their study confirms the weak-form inefficiency of commodity futures markets included in the analysis.

Narayan et al. [20] use daily data on four commodities, including again WTI crude oil, spanning the period 16 May 1983–22 November 2011, to which they apply a narrow universe of six standard moving average (SMA) trading rules and report that investors can earn abnormal return (net of commissions) from technical trading rules in three of the four markets, including in the WTI crude oil market, where trading rules achieve the highest return. However, their results do not seem to account for data snooping, which is a bias proven to have a significant impact on results and thus are not sufficiently strong to prove the inefficiency of the WTI crude oil market. Subsequently, Narayan et al. [21] also conclude that commodity futures markets can indeed offer investors statistically significant profits.

Further, Wang et al. [22] employ daily prices of WTI crude oil futures contracts over 1983–2014 and develop dynamic MA trading strategies through genetic algorithms, whose trading performance is further compared to the buy-and-hold strategy and to some static MA rules. The study confirms the superiority of dynamic moving averages on the WTI crude oil futures market during downward trending markets. However, it also lacks a check of results robustness.

More recently, Psaradellis et al. [23] offer probably the most updated study on technical trading rules applied to the crude oil market. The study thus investigates the success of the 7846 trading rules proposed by Sullivan et al. [24] applied on the daily prices of WTI crude oil futures and on the United States Oil (USO) fund, from 2006 to 2019. Results confirm that there is no persistent nature in rules' performance for the two oil markets after adjusting for data snooping, thus supporting WTI market efficiency for the 2006–2019 period, although some interim market inefficiencies might be encountered.

Overall, previous studies thus generally agree on the efficiency of the WTI crude oil market for different periods, all spanning before the ongoing COVID-19 pandemic, after adjustment for data snooping-bias is made. To the best of our knowledge, the efficiency of the Brent crude oil market in relation to the performance of technical trading strategies has not been tested, nor has the efficiency of the XLE fund market. This study intends to fill this void, providing relevant results for policy makers, academics and investment practitioners.

Thus, we add to the literature first by extending the energy markets under scrutiny by including the most traded crude oil contract at world level, i.e., Brent crude oil along with a relevant energy-traded ETF, namely XLE and, secondly and most importantly, by an updated investigation on the performance of a large universe of TTRs during an historically turbulent period for crude oil markets and energy portfolios (i.e., the COVID-19 pandemic).

Additionally, a non-trivial issue about TTRs and their performance that needs further discussion is testing the statistical significance of results.

In this respect, bootstrapping firstly emerged as a convenient way of testing TTRs on data generated using some algorithm. Brock, Lakonishok and LeBaron [25] proposed the bootstrapping methodology for testing the predictability of some of the simplest trading rules and found that technical rules—in particular SMA—were able to achieve excess returns that could not be explained by a random walk model, an AR (1) process, nor a GARCH (M or Exponential) model. Another method, the stationary bootstrap that resamples from blocks of data with random lengths, was developed by Politis and Romano [26]. However, the bootstrapping methodology developed by Brock et al. [25] is the one that has been extensively applied in the literature concerned with the profitability and predictability of TTRs on speculative markets.

Nonetheless, this method is vulnerable to the so-called data-snooping bias. Data snooping reflects the process of testing and retesting filters, rules and combinations on a high number of randomly generated series until some (apparently) significant specifications emerge. In other words, the data snooping bias reflects the danger that the best forecasting model encountered in a specification search is just the result of chance instead of superior forecasting abilities and thus has no predictive superiority over a given benchmark model. Among others, Fang et al. [27] demonstrate that the predictive ability of the technical trading rules employed by Brock et al. [25] disappears when the sample selection bias, data mining, hindsight bias, and other usual biases are accounted for. Park and Irwin [28] also confirm that most studies that do encounter superior profitability of TTRs are subject to various problems in their testing procedures, including biases, which should be addressed in order to provide conclusive evidence. In addition, Harvey and Lu [29] draw attention that seemingly successful trading strategies can be encountered by chance, and the "no–biases" assumption of traditional tools of statistical analysis no longer hold.

The first strong solution for the data-snooping danger, still seen as the standard method for adjustment, was proposed by White [30], and was based on results from Sullivan, Timmermann, and White [24]. The procedure, entitled White's Reality Check (RC) for data snooping, tests the null hypothesis that the best model does not have predictive superiority over a benchmark versus the alternative that the best model is over performing.

Afterwards, there have been some attempts in the literature to improve this methodology. Mainly, Hansen [31] maintains that the RC procedure can be affected by testing a large plethora of irrelevant rules, an issue that can be corrected by the "Superior Predictive Ability" (SPA) test. Further Bajgrowicz and Scaillet [32] introduce the false discovery rate

(FDR) as a new approach to data snooping and show that the economic value of TTRs that has been previously reported in the literature is no longer significant.

In this paper, we proceed to check the robustness of our results first by applying the popular Brock et al. [25] bootstrapping methodology (on a higher number of randomly generated series than employed by the original study and most others thereafter) and further, we correct for the data-snooping bias by following the most commonly used technique, namely, the RC procedure. This approach has the advantage of allowing easy comparison of results with previous related studies, and thus contributes to a higher relevancy of results.

3. Data and Method

3.1. Data

In the empirical modeling, we use daily spot prices of the two main grades of crude oil (Brent and WTI), as well as daily prices of a representative energy-traded fund, the Energy Select Sector SPDR® Fund or XLE. As XLE has the smallest trading history, to ensure comparability across markets, we set the same data window for the three time series, and hence data will span 1 January 1999 through 29 March 2021, or a total of 5686 daily observations for each energy market.

Brent North Sea Crude (also known as Brent crude oil) and West Texas Intermediate (known as WTI crude oil) are the most widely traded oil grades. Brent Crude is produced in the North Sea between Shetland Islands and Norway, while West Texas Intermediate is produced in the United States fields. According to the US Energy Information Administration, "sweet crude" refers to crude oil that has sulfur content of less than 1%, a category that Brent and WTI both fall under. Furthermore, both are less thick (or "lighter") than other types of crude oils, making them quicker to process and thus more appealing to manufacturers of petroleum products. Brent crude is the reference price for crude oil in Africa, Europe, and the Middle East, and it is assumed that Brent determines the value of around two-thirds of global crude oil production. Alternatively, West Texas Intermediate stands as the major oil benchmark for North America. As far as trading crude oil is concerned, Brent crude oil is listed on the New York Mercantile Exchange (NYMEX), a division of the Chicago Mercantile Exchange (CME), whereas Brent is listed on the electronic Intercontinental Exchange (ICE). As a result of their respective host markets, delivery locations vary by country in the case of Brent crude, which is traded internationally, while the main delivery location for physical exchange and price settlement for WTI is Cushing, Oklahoma. The price differential between Brent and WTI (which is a consequence, among others, of different transportation costs, of the supply and demand balance in different parts of the world, of geopolitical events, etc.) is called a spread.

The Energy Select Sector SPDR® Fund (XLE) mirrors the S&P 500's market-cap-weighted index of US energy companies. The Select Sector SPDR Exchange Traded Funds divide the S&P500 into nine industry categories, with XLE representing the energy sector. As a result, XLE is an investment vehicle that provides traders with a desired exposure to firms in the oil, gas, and consumable fuel industries, and related services.

Crude oil prices are obtained from the Federal Reserve Bank of St. Louis's (FRED) database, which collects data from the U.S. Energy Information Administration, while data for XLE are collected from Yahoo! Finance.

We argue that a separate investigation for a recent and relevant time period (the 2020–2021 COVID-19 pandemic) is not only more appropriate, but also more relevant to academics and investment practitioners. We base our hypothesis on previous empirical findings on the performance of TTRs on energy markets that show that the returns to technical strategies are not consistently strong for periods up to 2005 [18] or up to 2019 [23]. Thus, in order to take a closer look at the turbulent ongoing pandemic period, we will subset the so-called "COVID-19 window," which is spanning 1 January 2020 through 29 March 2021.

Figure 1 reflects the evolution of the BRENT and WTI crude oil price from January 2020 to March 2021, showing historical lows and significant volatility during the pandemic period. On 20 April 2020, the WTI crude oil price was disconnected from its typical relationship with the price of Brent crude oil, collapsing by more than $50/barrel.

Figure 1. Spot Prices (Crude Oil in Dollars per Barrel) during the pandemic period (January 2020–March 2021). Source of data: U.S. Energy Information Administration, Crude Oil Prices: West Texas Intermediate (WTI)—Cushing, Oklahoma and Europe Brent, retrieved from FRED, Federal Reserve Bank of St. Louis; Author's representation.

Overall, the price of both WTI and Brent crude oil during the pandemic period registered a dramatic fall in the early stages of COVID-19 up until April 2020 and a subsequent recovery to pre-pandemic levels by March 2021, attesting the efficiency of interventions by oil-producing countries that have imposed supply caps, and also reflecting the optimism about post-pandemic economic recovery resulting from the progress of COVID-19 vaccine distribution worldwide.

The three daily energy series are turned into daily returns indexed from R to T, so that T = R + n − 1. We follow White [27] and compute daily returns as:

$$y_{i,t+1} = \frac{Index_{i,t+1}}{Index_{i,t}} - 1 \quad (1)$$

where $y_{i,t+1}$ is the return of the Index i on trading day $t + 1$.

Figure 2 provides an overview of the three energy markets average return volatility over the 1999–2021 period, attesting the particularly dramatic month of April 2020, especially in the case of the WTI crude oil market.

The summary of descriptive statistics for one-day buy-and-hold returns for all three energy series employed in the empirical estimations, for the pre-pandemic period and also for the COVID-19 window, are presented in Table 1, panel A and panel B, respectively.

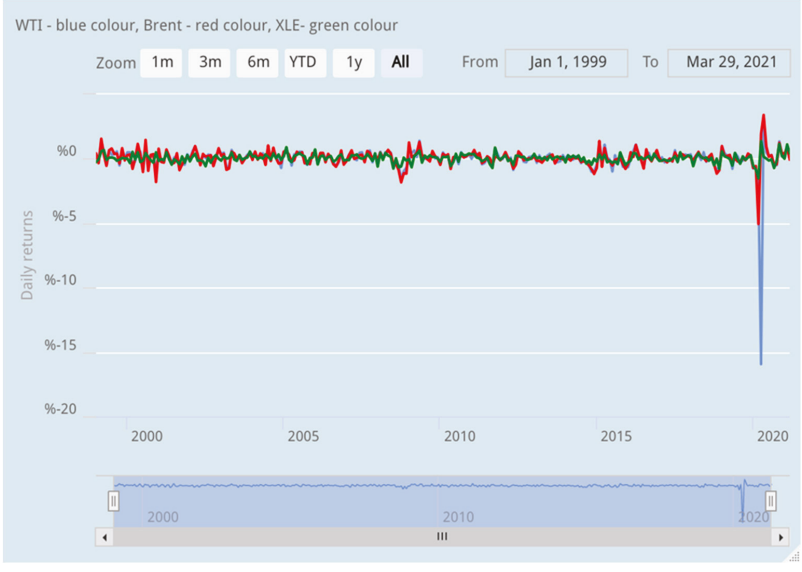

Figure 2. WTI, Brent, and XLE Average Monthly Returns (January 1999–March 2021). Source of data: Author's representation with crude oils daily price data sourced from the U.S. Energy Information Administration, retrieved from FRED, Federal Reserve Bank of St. Louis and XLE daily price data sourced from Yahoo! Finance.

Table 1. Descriptive statistics for one-day returns for WTI, Brent, and XLE.

	Panel A: 1 January 1999–31 December 2020			**Panel B: 1 January 2020–29 March 2021**		
	WTI Crude	**Brent Crude**	**XLE**	**WTI Crude**	**Brent Crude**	**XLE**
No of obs	5367	5367	5367	319	319	319
Min	−0.1571	−0.1804	−0.1444	−3.0197	−0.4747	−0.2014
Max	0.1784	0.1988	0.1647	0.5309	0.5099	0.1604
Range	0.3355	0.3791	0.3092	3.5505	0.9845	0.3618
Sum	3.7387	3.3175	2.3881	−2.8715	0.4065	0.0742
Median	0.0011	0.0006	0.0007	0.0021	0.0027	−0.0009
Mean	0.0007	0.0006	0.0004	−0.0090	0.0013	0.0002
SE mean	0.0003	0.0003	0.0002	0.0109	0.0036	0.0020
CI. mean. 0.95	0.0006	0.0006	0.0004	0.0214	0.0070	0.0039
Variance	0.0006	0.0005	0.0003	0.0378	0.0041	0.0012
SD	0.0241	0.0224	0.0168	0.1944	0.0639	0.0353
Coef. var	34.5940	36.2955	37.6722	−21.5959	50.1049	151.9894

The mean daily returns for the energy series largely confirm common perceptions of these markets. The XLE fund shows returns that compare rather well with the crude oil series during the whole 22-year period, and it also presents the lowest volatility of price returns both before and during the COVID-19 pandemic. On the other hand, during the pandemic period, WTI is the least rewarding in terms of return and also the riskier in terms of volatility among the three series. The Brent crude oil market has the highest mean returns for the pre-pandemic period (of about 0.07% per day) and also for the COVID-19 window (0.13% per day), while WTI is the only market that lost in terms of daily returns over the 2020–2021 period, whilst also being the most risky market. WTI statistics are surely strongly influenced by the historical plummet that the WTI price has suffered in April 2020. We notice from data presented in Panel B of Table 1 the dramatic aforementioned daily

drop of over 300% for WTI crude oil prices in April 2020, the largest one-day decrease in history.

This is further also more clearly reflected in Figure 3, showing returns volatility for the three energy markets during the pandemic period.

Figure 3. WTI, Brent Crude Oil and XLE Daily Returns during the COVID-19 pandemic (January 2020–March 2021). Source of data: Author's representation with crude oils daily price data sourced from the U.S. Energy Information Administration, retrieved from FRED, Federal Reserve Bank of St. Louis and XLE daily price data sourced from Yahoo! Finance.

3.2. Method

3.2.1. Signals and Excess Return of Simple Moving Average Strategies

The simple moving average (SMA) crossover is, by far, the most widely used among technical trading rules or TTRs [33]. The traditional simple moving average (SMA) rule issues buy (sell) signals that generate trades. When the short-period moving average rises above (or falls under) the long-period moving average by a pre-specified level or percentage (which is often set to zero in investment practice), buying (or selling) trades are initiated. As such, when the short-period moving average (S) exceeds the long-period moving average (L), a purchase signal is issued as follows:

$$\left[\sum_{\lambda=1}^{S} P_{t-(\lambda-1)}/S\right] > \left[\sum_{\lambda=1}^{L} P_{t-(\lambda-1)}/L\right] \Rightarrow \textit{Buy at time } t \tag{2}$$

where P_t is the price at time t, and the band equals zero.

Sell signals are generated when the short-period moving average (S) is below the long-period moving average (L):

$$\left[\sum_{\lambda=1}^{S} P_{t-(\lambda-1)}/S\right] < \left[\sum_{\lambda=1}^{L} P_{t-(\lambda-1)}/L\right] \Rightarrow \textit{Sell at time } t \tag{3}$$

Further, excess returns over a given benchmark produced by a SMA TTR is estimated as:

$$\hat{f}_{t+1} = (1 + y_{t+1} S_1(X_{1,t}, \beta_1^*)/(1 + y_{t+1} S_0(X_{0,t}, \beta_0^*) - 1 \tag{4}$$

where S_1 and S_0 are "signal functions" that take two permissible values, 1 for long trading positions and -1 for short trading positions. The signal value represents the total percentage of capital allocated at moment t in a trading position, which further implies a 100% allocation of capital at any moment in this trading system.

The signal function converts indicators $X_{1,t+1}$ or $X_{0,t+1}$ and parameters β_1^* or β_0^* in Equation (4) into trading positions. The nominator in the above equation represents the SMA technical rule to be tested, while the denominator represents the benchmark. Here, the buy-and-hold (BH) strategy, a traditional benchmark strategy in portfolio management, is the benchmark of choice.

Average excess return for a particular TTR is then estimated as:

$$\overline{f} = n^{-1} \sum_{t=R}^{T} \hat{f}_{t+1} \tag{5}$$

The parameters in Equation (4) are the lengths of the two MA averages (n_1 for the short MA and n_2 for the long MA). See Anghel and Tudor [34] for more detailed information of signals and excess returns of SMAs.

Although some pairs of parameters are popular in the literature and in practice, we avoid pre-setting them and instead we run all rules using parameters ranging from 1–30 for S and 31–500 for L for the first subperiod, and parameters ranging from 1–15 for S and 16–120 for L for subsequent pandemic subperiod. We decide to restrict the parameter n_2 to a maximum value of 120 (representing approximately 6 months of trading) in the second subsample, which is consistent with practitioners' trading strategies based on TTRs (i.e., Menkhoff [17] showed that technical analysis is generally employed for trading decisions that do not exceed a horizon of 6 months). In the first subperiod, we permit a wider investigation and allow the second parameter to vary up to a maximum value of 500, which represents more than two years of trading.

Thus, for the larger pre-pandemic window:

$$n_1 \in \{1{:}30\}$$

and

$$n_2 \in \{31{:}500\}$$

and therefore we have a total number of SMA TTRs tested on 21 years of data corresponding to the pre-pandemic timeframe equal to: length (n_1) $\times$ length (n_2) = 30 $\times$ 470 = 14,100 for the parameter β_i^* in Equation (4).

Subsequently, for the smaller pandemic interval:

$$n_1 \in \{1{:}15\}$$

and

$$n_2 \in \{16{:}120\}$$

corresponding to a total number of SMA TTRs tested during the 1 and $\frac{1}{4}$ years of pandemic timeframe equal to: length (n_1) x length (n_2) = 15 $\times$ 105 = 1575 for the parameter β_i^* in Equation (4).

Hence, first, we test 14,100, and subsequently 1575 technical trading crossover rules based on Simple Moving Averages, computed as:

$$short\ SMA_t = 1/n_1 \sum_{t-n_1}^{t} X_t \tag{6}$$

$$long\ SMA_t = 1/n_2 \sum_{t-n_2}^{t} X_t \tag{7}$$

The function S_1 in Equation (4) will then dynamically convert into trading positions (long or short) according to the specified 14,100/1575 SMA TTRs.

R software was used to implement the method and perform estimations.

3.2.2. Robustness Checks

The first step in our estimations consists in computing average excess returns over the benchmark buy-and-hold trading strategy, as in Equation (5) produced by the 14,100/1575 SMA TTRs for each of the three energy markets (WTI, Brent and XLE) in the two sample periods (pre-pandemic and pandemic).

Secondly, the significance of excess returns produced by the 14,100/1575 SMA rules is tested.

In order to accurately accomplish this task, we should consider the high non-normality of the three energy markets. For non-normal distributions, the null hypothesis of normality could lead to serious inference errors when estimating classis statistical significance diagnostics. All three energy series are highly non-normal, presenting highly leptokurtic distributions (see Table 2). Although this is expected from daily returns, especially in the case of crude oil markets, results are nonetheless surprising and show a huge amount of excess kurtosis for all three markets, both pre and during the COVID-19 pandemic, but especially higher during the pandemic period. Leptokurtosis signifies that negative returns occur more often than positive returns, and estimations confirm this is indeed the case for the crude oil market (both WTI and Brent) and also for the energy fund XLE. Further, the Anderson–Darling (A–D) test is estimated to test the normality assumption for the three energy markets in the two sample periods. Results presented in Table 2 allow us to reject the null hypothesis of normality for all markets and all time periods.

Table 2. Distribution characteristics.

	Panel A: Pre-COVID-19 Period (1 January 1999–31 December 2019)			**COVID-19 Window (1 January 2020–29 March 2021)**		
	WTI Crude	**Brent Crude**	**XLE**	**WTI Crude**	**Brent Crude**	**XLE**
Skewness	0.080747	0.101254	−0.134112	−12.38	0.50	−0.37
Kurtosis	7.3788	7.5677	11.8093	186.9	28.7	9.3
A–D Test	5362 *	5379 *	5352 *	214 *	289 *	273 *

* significant at 1%.

Thus, to deal with non-normality in our data when testing for significance, we implement the popular bootstrapping methodology proposed by Brock et al. [25] in estimating *p*-values, under a random walk assumption for the distribution of returns [35] for all three energy series. As such, the null model is first fit to empirical data and its parameters are further estimated. The residuals are subsequently 1000 times randomly re-sampled (i.e., Brock et al. [25] generated 500 random series in their original study) and combined with the model parameters to generate random price series that will present the same characteristics as the original series. According to Brock et al. [25], the results do not differ significantly irrespective of which null model is employed (random walk, AR (1), GARCH-M, or EGARCH). Thus, for the null hypothesis, we continue with the random walk assumption in this study.

Hence, firstly we test whether the 14,100 SMA TTRs can generate excess returns for traders in the three energy markets during the pre-pandemic period. Further, after first estimating excess returns produced by the 14,100 trading rules for the three energy series in the 1999–2019 period, the bootstrapping methodology allows to compare the excess returns produced by a particular TTR applied to the real time series to excess returns that resulted from the empirical distribution, where the empirical distribution has been constructed by applying the same 14,100 trading rules to 1000 simulated time series with replacement under the null of a random walk. Thus, we sample with replacement from the original return series 1000 times for each of our original energy markets (WTI, Brent and XLE), obtaining 1000 simulated series or markets for each of the three real energy

markets, each simulated series having the same length as the original series (i.e., 5367 for the pre-pandemic period). We therefore produce three data frames each with dimensions (5367 × 1000) on which the significance of each of the 14,100 TTRs is tested. This implies that for each of the three energy markets, for the pre-pandemic timeframe, the 14,100 TTRs are first applied on the real time series of returns and subsequently on 1000 simulated return series for the respective energy market. Finally, the returns for each trading rule and the mean return across trading rules are estimated.

The procedure will then be replicated for the smaller COVID-19 window so that three simulated data frames with dimensions (319 × 1000) will be produced (where 319 is the number of observations of the original series and 1000 the number of simulated time series).

The average return $\overline{f}_b^*$ is thus obtained by applying the TTRs on the simulated series, where $b = 1, \ldots, B$ is the number of the simulation from the total of B simulations performed. Here, $B = 1000$.

Next, for the pre-pandemic period, results' significance is tested by comparing excess returns obtained on each of the three real energy markets to excess returns produced on the 3 × 1000 total simulated series of returns, each of length 5367. The main idea underlying this bootstrap methodology is that for a trading rule to be statistically significant at the α level, it must generate more revenue on fewer than 1% of the bootstrapped series than on the original series. The bootstrap p-value is then the percentage of times the buy-sell profit for the rule is greater on the 1000 random series than on the original series.

The same method is applied during the COVID-19 interval, where 3 × 1000 simulated series, each of length 319 have been produced.

Therefore, the estimated bootstrap p-value results from comparing the average real return $\overline{f}$ with the quantiles of average simulated returns $\overline{f}^* = \overline{f}_b^*$, $b = 1, \ldots, B$. Hence:

$$B\ random\ bootstrap\ p\text{-}value = \frac{\sum_{b=1}^{B} 1_{\{\overline{f} < \overline{f}_b^*\}}}{B} \tag{8}$$

Finally, we account for the inherent data-snooping bias by following the standard Reality Check (RC) procedure for data snooping proposed by White [30].

White [30] develops the Reality Check Test applied to the best model (here, the best performing TTR) selected from a large sample of previously tested models. His algorithm consists in firstly computing the performance of the benchmark, which is expressed here as average excess return over the BH return. Thus, the first step consists in computing $\overline{f}_1$—the average excess performance of rule 1, followed by computing $\overline{f}_1^* = \overline{f}_{1,b}^*$, $b = 1, \ldots, B$, which is a vector of length B (the number of simulations or bootstrapped samples, here, set again to 1000) containing the average excess performances on simulated (bootstrapped) time series, all for rule 1. Basically, up to this point, the procedure is identical to the earlier random bootstrap p-value estimation.

Next, White [30] sets $\overline{V}_1 = \overline{f}_1$ and $\overline{V}_{1,b}^* = \overline{f}_{1,b}^* - \overline{f}_1$, $b = 1, \ldots, B$, so that the performance of rule 1 relative to the benchmark is tested by comparing $\overline{V}_1$ with the quintiles of $\overline{V}_{1,b}^*$. Similarly, for rule 2:

$$\overline{V}_2 = max\left\{\overline{f}_2, \overline{V}_1\right\} \tag{9}$$

and

$$\overline{V}_{2,b}^* = max\left\{(\overline{f}_{2,b}^* - \overline{f}_2),\ \overline{V}_{1,b}^*\right\} \tag{10}$$

where, as before, $b = 1, \ldots,$ B. In order to test whether the best of rule 1 and 2 is better than the benchmark, $\overline{V}_2$ is compared with the quintiles of $\overline{V}_{2,b}^*$.

Thus, there is a recursive process of testing whether the best model for the kth rule is superior to the benchmark, where $k = 3, \ldots,$ l and l is the number of rules to be tested (here, l equals first 14,100 and subsequently, 1575 corresponding to the two sub-periods). The method thus implies comparing:

$$\overline{V}_k = max\left\{\overline{f}_k, \overline{V}_{k-1}\right\} \tag{11}$$

with the quintiles of:

$$\overline{V}^*_{k,b} = max\left\{\overline{f}^*_{k,b} - \overline{f}_k,\ \overline{V}^*_{k-1,b}\right\} \quad (12)$$

where $b = 1, \ldots, B$ for each of the l rules until a conclusion can be reached about the best performing trading rule.

Formally, Reality Check p-value could be expressed as:

$$RC\ p\text{-}value = \frac{\sum_{b=1}^{B} 1_{\{\overline{V}_l < \overline{V}^*_{l,b}\}}}{B} \quad (13)$$

4. Results and Discussion

In Table 3, we present the parameters and performance (excess returns over the benchmark BH returns) for the best performing TTRs encountered on the three energy markets across the two subperiods (results for the pre-pandemic period are presented in Panel A, while results for the pandemic period are reported in Panel B). Random bootstrapping p-values resulting from 1000 iterations, together with the number of signals generated by the optimal TTR are also presented. Note that transaction costs are not included in the first estimations.

Table 3. The best TTRs' parameters and performance with no transaction costs and BH returns as benchmark.

	Panel A: Pre-COVID-19 Period: 1 January 1999–31 December 2019 Total No. of SMA TTRs Tested: 14,100			**COVID-19 Window: 1 January 2020–29 March 2021 Total No. of SMA TTRs Tested: 1575**		
	WTI Crude	**Brent Crude**	**XLE**	**WTI Crude**	**Brent Crude**	**XLE**
Best Rule: SMA (n_1, n_2)		SMA (5, 33)	SMA (27, 281)	SMA (3, 28)	SMA (12, 17)	SMA (5, 16)
Excess Return (%/day)	−0.1324	0.00782 **	−0.0024	0.08244	0.5357 ***	0.2762
Excess Return (%, annualized [1])	−28.38	1.99 **	−0.52	20.00	284.32 ***	83.45
1000 Random bootstrap p-value [2]		0.037	0.118	0.182(0.854 Rpc)	0.064(0.38 Rpc)	0.148
No of Signals		201	22	8	16	18

** denotes significance at the 5% level, *** denotes significance at the 10% level. [1] To be more suggestive, daily returns have been annualized such that for every market: annual excess return = $[(1 + \text{daily excess return})^{\wedge 252-1}]$. The benchmark return is the buy-and-hold return. [2] This represents the random bootstrapping p-values resulting from 1000 iterations across the three energy markets and the two subperiods. Even without adjusting for data-snooping bias, this approach is nonetheless relevant not only for comparative purposes with previous studies, but also as it helps in identifying the total number of TTRs that are profitable prior to data-snooping bias adjustment. A tested TTR is statistically significant at the 5% level if excess returns on the 1000 random bootstrapped series exceed excess returns on the original series less than 5% of the time.

Results in Table 3 indicate that technical analysis appears to be significantly more profitable over the pandemic period than over the pre-pandemic period. Excess returns achieved by all 14,100 SMA crossover TTRs are negative in the pre-pandemic period for the WTI and XLE markets, indicating some small profits only for the Brent crude oil market (annualized excess return of the optimal TTR over the buy-and-hold benchmark return of about 2%, which is statistically strong, with a 1000 random bootstrap p-value of 0.037). Figure 4 reflects excess return for all 14,100 tested TTRs for the Brent market over the 21-years of pre-pandemic period. We chose to show only the Brent market as it is the only one for which some over-performing rules exist. It is obvious by looking at the chart below that only a small number of strategies are able to gain excess return over the benchmark BH strategy for the Brent market in the pre-pandemic period. Indeed, estimations confirm that only 7 rules out of the universe of 14,100 (or approximately 0.04%) are over-performing during 1999–2019.

We thus far conclude that none of the 14,100 moving average crossover TTRs can generate excess returns on the WTI and XLE markets, suggesting that the two energy markets are weak-form efficient over the 1999–2019 period with respect to these technical indicators. However, it seems that the same 14,100 rules were able to achieve statistically significant excess return, albeit rather small in magnitude, for the Brent market over the 1999–2019 pre-COVID-19 period, indicating this market might present weak-form inefficiency.

Figure 4. Annualized excess returns achieved by all 14,100 SMA crossover rules for the Brent market over the 1999–2019 period.

In turn, the pandemic period presents consistent excess returns achieved by the 1575 tested SMA trading strategies for all energy markets, and especially for the Brent market where an annualized excess return of over 284% has been achieved by the best performing TTR, which is SMA (12,17). However, for the WTI and XLE markets, this over-performance (annualized excess return of 20% for WTI and 83.45% for XLE) does not hold strong when its significance is tested via the standard bootstrapping methodology (1000 random *p*-values of 0.182 and 0.148, respectively). For the Brent market, TTRs are again able to achieve superior and statistically significant predictability (1000 random *p*-value equals 0.037).

Thus, we show in Figure 5 the excess return for all 1575 tested strategies for the Brent market over the 1 and $\frac{1}{4}$ year of pandemic period. Again, only the Brent market has been chosen, as it is the only one where signs of inefficiency are present. Therefore, while the best rule's performance indicates that over-performing trading strategies in terms of excess returns over the BH strategy exist for all markets in the second subperiod, the number of out-performing strategies is nonetheless very high for the Brent market. More precisely, 1528 out of the total number of 1575 TTRs (more than 97%) managed to achieve positive excess returns (which is also confirmed by Figure 5, where it can be easily seen that most of the strategies gain abnormal returns during the COVID-19 pandemic, whilst we remember that only 7 TTRs were found to be over-performing over the pre-pandemic period).

Moreover, as mentioned earlier, these excess returns are statistically significant for the Brent market during the pre-pandemic and also during the COVID-19 period (with 1000 random bootstrap *p*-values of 0.037 and 0.064, respectively). Moreover, we notice that during the pandemic period, the most successful SMA TTRs are the ones with shorter time horizons in the long-run moving average, while the time horizon for short-run moving average varies across the three markets. For example, n_2 equals 16 (XLE), 17 (Brent), and 28 (WTI) when it is allowed to vary in the interval (16:120) during the pandemic period.

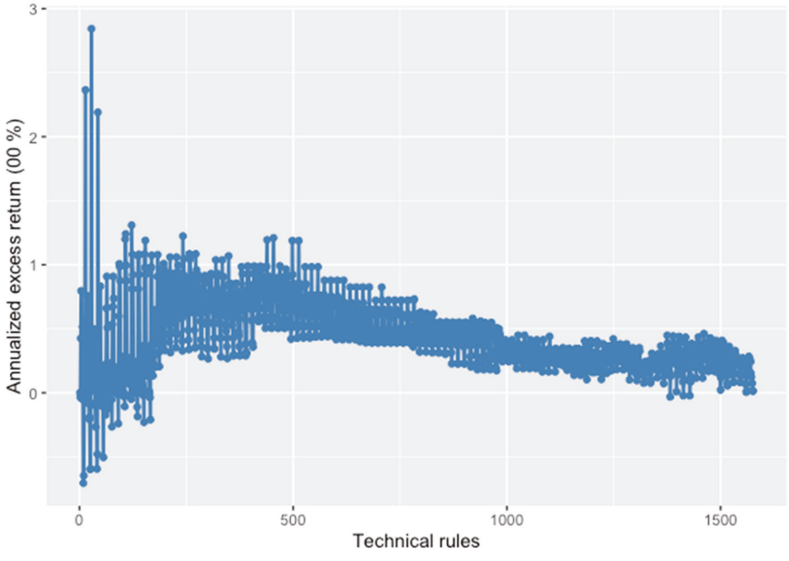

Figure 5. Annualized excess returns * for all 1575 SMA crossover rules for the Brent market over the January 2020–March 2021 COVID-19 pandemic period.

There is also some variation in the trading frequency of the best performing trading rule across the three energy markets over the two subperiods. For example, during the pandemic window in the WTI market, the most profitable TTR only signals a total of 8 trades over the 1 and $\frac{1}{4}$ year period, whilst for Brent and XLE 16 and, respectively, 18 trades are generated. Surprisingly, the best performing TTRs over the 1999–2019 period do not signal significantly more trades than over the much shorter pandemic period for WTI and XLE. On the contrary, for the Brent market, the optimal TTR is the short-term moving average rule SMA (5, 33), which generates a total of 220 trading signals over the pre-pandemic 21-year period, whilst the optimal TTR generates only 16 trading signals over the COVID-19 period, as seen above.

Despite the fact that the analysis is performed ex-post and also that transaction costs have not been included at this point, the above results still indicate some predictability of technical indicators in the case of Brent market, and especially during the pandemic period, that needs further investigation.

So, we test next for the economic significance of results and find that excess returns during the pandemic period remain abnormal for Brent when we include transaction costs in estimations. For the pre-pandemic window, excess returns disappear with the inclusion of trading costs.

Table 4 presents excess return net of transaction costs over the benchmark buy-and-hold strategy for the best performing TTR on the Brent market during the pandemic period, along with its corresponding 1000 bootstrapped *p*-value and the data snooping adjusted RC *p*-value. Meanwhile, Figure 6 reflects annualized excess returns net of transaction costs for all 1575 technical rules applied to the Brent market over the same period. The graph confirms that an overwhelming 96.20% of TTRs are still over-performing (1515 out of 1575 tested TTRs) after trading costs of 5 basis points (bps) are considered. This implies that only 13 rules' performance has been affected by the inclusion of transaction costs. Moreover, the over-performance is high in terms of magnitude of excess returns, with more than 92% of rules (1452 TTRs) achieving annualized excess returns of over 10%, and more than 31% of TTRs (493 rules) achieving annualized excess returns higher than 50%, while the best performing rule gains 270% annualized excess return net of transaction costs over the BH strategy. On the other hand, the under-performance is far less severe: only

60 TTRs out of the total universe of 1575 tested over the COVID-19 period (or 3.8%) have no economic value relative to the benchmark BH trading strategy, the majority of which (34 TTRs or 56.67%) under-performing by less than 10% in annualized terms.

Table 4. Excess returns of the best performing trading rule on the Brent market during the COVID-19 pandemic (January 2020–March 2021) net of transaction costs *.

Optimal Trading Rule	No Signals	Daily Excess Return **	Annualized Excess Return	1000 Random Bootstrap *p*-Value	Reality-Check (RC) *p*-Value
SMA (12,17)	16	0.5213%	270.69%	0.064	0.406

* Includes trading costs of 5 bps. ** The buy-and-hold strategy is the benchmark.

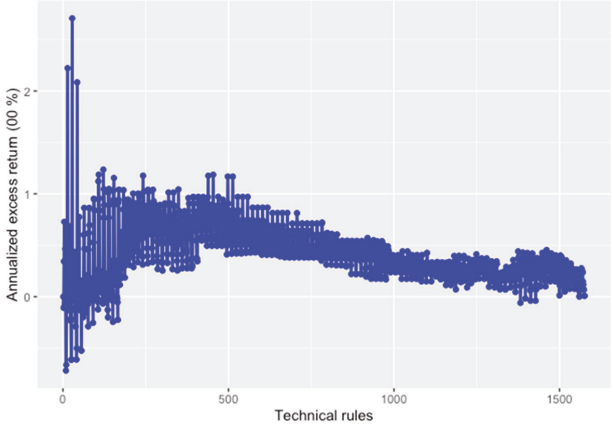

Figure 6. Excess returns* net of transaction costs of 5 bps for all 1575 SMA cross-over rules for the Brent market over the January 2020–March 2021 COVID-19 pandemic period.

When it comes to the statistical significance of the best TTR's performance, results hold strong when the bootstrapping methodology is applied (the 1000 random bootstrapping *p*-value of 0.064 is not affected by the inclusion of transaction costs in the estimation), but in turn the *p*-value resulting from the Reality Check test is no longer significant (RC *p*-value = 0.406). This indicates that the adjustment for data-snooping bias still has an important impact on the significance of results.

Overall, excess returns gained by the optimal TTR on the Brent market during COVID-19 do not hold strong after accounting for data-snooping bias by employing White's Reality Check test, but we feel the adjustment of the *p*-value via the RC procedure might be too severe and the procedure too conservative in this particular situation. We argue that the vast number of over-performing rules encountered on the Brent crude oil market over the COVID-19 pandemic period together with the magnitude of this over-performance, compared with the small number of underperforming rules (60 TTR out of 1575) and the "mild" relative underperformance (only 7 rules, or 0.04% of all TTRs achieve relative losses higher than 50%, while the majority encounter losses of less than 10% relative to the benchmark) already mitigates the data-snooping bias.

Consequently, in light of the aforementioned arguments, one cannot completely exclude the possibility that this adjustment via the RC procedure might be too severe and thus we should not be too quick to eliminate the possibility that over-performing TTRs might exist on the Brent market during the COVID-19 pandemic.

5. Conclusions

As a means of extending previous literature, this paper has analyzed the profitability of a significant number of SMA TTRs on a wider range of energy markets and a period that includes the ongoing COVID-19 pandemic.

Using daily data for Brent and WTI spot crude oil prices and for the energy fund XLE and splitting the data into a pre-pandemic window (1999–2019) and a "pandemic period" (January–March 2021), we employ 14,100 SMA crossover TTRs for the longer pre-pandemic period and 1575 SMA crossover TTRs for the shorter pandemic interval.

To the best of our knowledge, this is the first research attempt to investigate the effectiveness of technical indicators on both main crude oil markets, as well as on a relevant energy exchange traded fund, in comparative perspective between the pre-COVID-19 pandemic and the pandemic period.

Overall, we find that technical trading rules can achieve high abnormal returns for all three energy markets over the COVID-19 pandemic period (annualized excess returns over the BH strategy of approximately 20% for WTI, 284% for Brent, and 83% for XLE, without including transaction costs), and only for the Brent market, some small abnormal annualized excess returns (of about 2%) over the 21-years of pre-pandemic period.

However, these excess returns encountered over the pandemic period are not strong on the WTI and XLE markets when their significance is tested by the standard Brock et al. [25] bootstrapping methodology with 1000 iterations, while for Brent market, excess returns gained by TTRs hold strong in all subperiods against the standard bootstrapping methodology. Over the pandemic period, excess returns achieved by TTRs on the Brent market are still high in magnitude and remain statistically significant after transaction costs are included in estimations. Over the pre-pandemic period, the small excess returns achieved by some technical rules on the Brent market are eroded by transaction costs and thus have no economic value. Similar to Taylor [36], our findings could thus reflect a relationship between technical rules' performance and market conditions.

Nonetheless, the abnormal return achieved by the best-performing TTR on the Brent market over the 1 and $\frac{1}{4}$ years of pandemic period no longer holds strong against White's [30] Reality Check test. Thus, we find that SMA TTRs are not consistently profitable in the three energy markets once the data-snooping bias is accounted for.

However, while our results allow us to confidently conclude on the weak form efficiency of the WTI crude oil and the XLE fund markets throughout the 1999–2021 period relative to the universe of TTRs that we apply, and also to sustain the conclusion that TTRs do not add value on the Brent market beyond what may be expected by chance over the pre-pandemic 1999–2019 period, we refrain to also attest the weak-form efficiency of the Brent market over the COVID-19 pandemic. We feel that the performance of TTRs on the Brent market during the pandemic period needs further investigation, as most technical trading strategies achieve high excess returns over the benchmark buy-and-hold strategy, these excess returns hold when their significance is checked by the standard bootstrapping method and are also unaffected by transaction costs. The excess return gained by the optimal TTR only disappears after adjustment for data snooping is accomplished via the employment of White's Reality Check procedure. In this particular situation, the RC test might be too conservative and thus prone to type II errors. By presenting the results of all 1575 tested TTRs on the Brent market over the pandemic interval (both with and without transaction costs), and by showing that an overwhelming number of these strategies have been able to achieve abnormal returns of high magnitude on the Brent market during the COVID-19 pandemic (96.20% of strategies are still substantially over-performing even after adjustment for trading costs is made and thus have economic value), we sustain that survivorship bias is already mitigated. The adjustment made on the bootstrap *p*-values via the RC procedure could thus be too severe.

Consequently, while similar to Psaradellis et al. [23], we did not encounter enough evidence to be able to reject the weak-form efficiency of the three energy markets (Brent crude, WTI and XLE) for the whole 1999–2021 period, it would be hazardous to completely

dismiss the above argument in the case of the Brent crude oil market over the COVID-19 pandemic period, when TTRs seem to have benefited from the extreme evolutions that characterized the market. As such, future studies on the Brent market efficiency during crisis are needed to sustain the right policy formulation process.

This paper makes several contributions to the existing literature. The first contribution is to revisit the predictive ability and performance of technical trading rules (TTRs) on some oscillated energy markets. This is the first paper to include both main grades of crude oil (WTI and Brent crude) and a relevant energy fund, XLE, and to assess the trading rules' performance over two different subperiods: pre-COVID-19 (January 1999–December 2019) and COVID-19 (January 2020–March 2021). The second contribution thus consists in presenting proof of TTRs' performance during the historically turbulent COVID-19 pandemic period for crude oil markets. Previous studies mostly refer to the WTI crude oil and cover periods no more recent than year 2019. Other contributions consist in the large universe of tested TTRs (14,100 over the pre-pandemic period, and 1575 over the pandemic period, respectively) and also in estimating the relevancy of results by evaluating the performance of the universe of TTRs while considering both naïve [25] (Brock et al. random bootstrapping method—with 1000 iterations) and more severe methods of accounting for data snooping effects (White's Reality Check procedure—also based on 1000 iterations). In addition, this strategy allows easy comparison with previous findings that have employed one of the two (or both) techniques. A fifth contribution consists in also estimating the economic value of results by allowing for transaction costs, while a final contribution stems for the identification of distinct financialization process between the two main crude oil markets, WTI and Brent. As such, research findings further imply that there is evidence to the existence of a more intense financialization process within the WTI crude oil market, whereas the market for Brent seems to be more impacted by shifts in global supply and demand. This has important implications for both the right choice of oil price forecasting methods by policy issuers and also for identifying the accurate policy measures.

Policy makers must thus consider these market characteristics that the study encounters for effective oil price forecasts and for efficient policy issuance. Moreover, as the financialization of the WTI market and the approaching expiration date for WTI contracts for delivery in May 2020 [37], coupled with insufficient storage capacity have determined its historical and unforeseen plummet on April 2020 into uncharted negative territory [38] regulators of WTI commodity market (i.e., The U.S. Commodities Futures Trading Commission), should also consider tighter measures (i.e., mandatory reporting of high volume trades, short selling restrictions, etc.) to prevent the recurrence of such events.

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Hold-Up Problems in International Gas Trade: A Case Study

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Abstract: The infrastructure required for international natural gas trade is considerable, which often leads to hold-up problems and supply disruptions. This study discusses disruptions of gas supply from Algeria, Indonesia, Russia, and Turkmenistan since the early 1980s. The novelty of this study is its focus on the issues related to transit countries, which are rarely considered in the literature. The results of the study classify supply disruptions into six types, show the evolution of supply disruptions over time, and discuss mitigation strategies. The six types of disruptions include political change, price demands, debts, technical issues, transit fees, theft of gas. The evolution of the disruptions shows that the issues related to transit countries have become more frequent in the last two decades. Mitigation strategies tailored to transit countries include using an international organisation, designing contracts with price mechanisms that might reduce the possibility of disputes and reducing the number of parties involved in the trade.

Keywords: hold-up problem; natural gas; transit country; gas wars

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1. Introduction

Since the break-down of the Soviet Union and until the hot war between Russia and Ukraine, these countries were involved in a mutually dependant gas trade, where Russia was an exporter and Ukraine was an importer as well as a transit country. During the 2000s Russia and Ukraine engaged in multiple severe gas wars in which Russia shut off the gas supply to Ukraine due to non-payment of debts, and as a bargaining tool for a price increase. Ukraine demanded a higher transit fee and diverted Russian gas exports to Europe for its own consumption, leading to supply disruptions in Europe. These gas wars led to a heightened interest in the hold-up problem and European gas supply security [1–4].

International natural gas trade is especially susceptible to hold-up problems because gas pipelines are expensive and asset-specific investments. Though natural gas can also be transported by specialised tanker ships as LNG (liquefied natural gas), liquefaction and re-gasification also require costly investments [5]. The hold-up problem is thus crucial for landlocked countries, as pipelined natural gas exports have to go through transit countries. The problem is exacerbated when more expensive alternative routes imply inertia in building such routes, overinvestment, and overdependence on transit countries [6,7]. Hence, the novelty of this study is its focus on the supply issues related to gas transit countries, which are rarely discussed in the existing literature.

As gas trade contracts are necessarily incomplete, changing market conditions might enable one party to take advantage of the other. For example, the higher oil price has led to Russia's demands for higher gas price; and higher gas price in Europe has led to Ukraine's demands for higher transit fee. As the value of asset-specific investments—gas pipeline—is zero in other trades, once the investments are made (often by the exporter), the counterparty (often a transit country) might attempt to appropriate quasi-rents from the investor [8]. The quasi-rents might be substantial, ranging from 5% to 22% of the value of the gas trade [7]. The appropriation of quasi-rents is easier with repeated bargaining and changing market conditions.

Participants in natural gas trade often try to solve the problem by vertical integration or incomplete long-term contracts, as specifying all contingencies might be prohibitively costly [8,9]. Long-term contracts help avoid repeated bargaining in the presence of asset-specific investment. Trades involving more substantial asset-specific investments are associated with longer-term contracts [10]. Changes in contract terms, which might reflect poor design, reduce the average contract duration [11]. However, these changes might also take place due to significant market changes, for example, decreased gas demand in Europe after the global financial crisis forced Gazprom to soften some terms of its long-term gas export contracts [12,13]. As contracts might be too rigid for some market changes, complex provisions, such as take-or-pay obligations, price adjustment provisions, and the use of the most favoured nation clause provide incentives for contractual performance [14,15].

The issues of supply security and hold-up became topical after Russia disrupted its gas supply to Europe. These gas wars lead to new measures of dependence on suppliers and transit countries in the literature, such as the Transit Risk Index [16]. Some authors suggest that Europe can improve its gas supply security by arranging supplies from Central Asia or the Middle East, by relying more on LNG, or by creating a unified energy market in the EU—Energy Union [3,17]. Others state that Russian gas will continue to dominate European gas supplies over the next decade [18].

Such gas supply disruptions in recent years show that long-term contracts often cannot prevent contractual breakdown. As discussed below, in the last few decades, many contracts have failed due to higher price demands, political changes, and other reasons, which often involve opportunistic behaviour. Hence, a broader view of such contractual breakdowns is necessary to generalize the causes and develop mitigation strategies. Hence, the contributions of this study include (1) summarising the major occurrences of gas supply disruptions since the 1980s; (2) classification of supply disruptions based on their causes; (3) illustration of the evolution of hold-up types over time; (4) suggesting hold-up mitigation strategies. This study expands understanding of the transit-related hold-up problem beyond the Transit Risk Index [16] by looking at different forms of risk. This study benefits energy policymakers in their endeavours to minimise the probability of gas wars and to secure energy supplies.

2. Case Studies

In presence of hold-up potential, there is a trade-off between an immediate opportunistic gain and a long-term cooperation gain. Below are several case studies where hold-up took place, involving some of the largest exporters of natural gas over the last few decades. The supply disruptions discussed below were often mainly initiated by the exporter, and sometimes by a transit country.

The exporters discussed below include Algeria, Indonesia, Russia and Turkmenistan. The selection criteria for the case study countries is the combination of the volume of natural gas exports and the availability of public information on their contractual performance. This study omits some large natural gas exporters, such as Qatar, due to a lack of publicly available information on opportunistic behaviour. Future research into Qatar's experience might illustrate strategies that promote cooperation between trade partners, for example, amicable nationalisation of the world's largest gas field in the late 1970s, and repeated forgiveness of take-or-pay penalty [19,20].

2.1. Algeria

Algeria has the 11th largest natural gas reserves in the world, at 4.5 Tcm (trillion cubic meters) (EIA, 2019). Over 70% of its gas exports go to Italy, Spain, France, and Turkey [21]. Algeria has acted opportunistically several times, involving contractual breakdowns, interrupted supplies, and unexpected price changes. This opportunistic behaviour was often associated with significant changes in market prices. The following paragraphs present the details of some instances of opportunistic behaviour.

2.1.1. Price Demands and Discontinued Supplies in 1980

In the early 1980s, with growing oil prices, Algeria's contractual base gas price of \$1.30/MBtu was unattractive. In comparison, the UAE increased its LNG price from \$2.36/MBtu to \$4/MBtu [22]. In January 1980, Sonatrach (the Algerian state-owned exporter) informed El Paso (USA) and Gaz de France (France) that its LNG price was increasing to \$6.11/MBtu [23]. That doubled the price for France and tripled it for the USA. After three months of unsuccessful negotiations, on 1st April 1980, Algeria stopped sales to both buyers.

In the spring of 1981, the contract with El Paso (USA) was written off. Algeria claimed that deliveries to France in April 1980 were cut due to technical problems at the Skikda liquefaction plant. French technical advisers, however, found no problems at Skikda. Algeria also had spare liquefaction capacity at its Arzew plant once it cut deliveries to the USA [23]. Hence, these price demands resemble a hold-up rather than a result of market price change. Additionally, Algeria was flexible with export agreements of short duration and low volumes. A contract with Distrigas (USA) for less than 1.5 bcm (billion cubic meters) per year continued uninterrupted at the original price. In autumn 1980, Algeria agreed to extend an LNG contract with British Gas (UK) by nine months at \$4.60/MBtu and \$4.80/MBtu in the first and second halves of 1981. Beyond 1981, the parties agreed on fixed annual increases of 12%.

Non-opportunistic relations with France were restored in May of 1981, as the new Algerian government attempted to improve the relations. Gas deliveries to France were resumed with prices to be negotiated later. Later that year, Algeria and France agreed on the price of \$5.118/MBtu. The parties applied the price retroactively to January 1980 [23].

2.1.2. Price Demands and Discontinued Supplies in 1981

In the autumn of 1981, Algeria unilaterally cancelled its LNG contracts with the Netherlands and West Germany. Distrigaz (Belgium) agreed to pay a higher price of \$4.80/MBtu. In mid-1981, when the pipeline Algeria-Tunisia-Italy was more than half completed, Algeria informed SNAM (Italy) that the price demand increased from \$3.50/MBtu to \$5.50/MBtu. Consequently, the pipeline stayed idle for one year.

Non-opportunistic relations were restored in mid-1982, SNAM agreed to pay the higher price with the Italian government's 12% subsidy. Algeria's demands of higher prices from Belgium and Italy came at the cost of reduced export volumes.

2.1.3. Price Demands in 1986

The oil price collapse in 1986 led Sonatrach to alter its gas pricing policy again. After some difficult negotiations in Europe, Sonatrach arranged a new base price of \$2.30/MBtu to reflect low oil prices and reintroduced a minimum price of \$1.30/MBtu [22]. Algeria also modified its contractual principles (including switching from indexation formula to market-based pricing) to resume exports of LNG to the deregulated US market.

Algerian push for higher gas prices resulted in lost market share in the USA in the 1970s and in Europe in the 1980s. Sonatrach's low gas exports led to reduced investments [22] and resulted in reduced production capacity. Consequently, when world energy consumption began to rise, Algeria could not increase its exports accordingly. This, together with the oil price collapse in 1986, brought a considerable financial strain on the country.

Non-opportunistic relations were restored in the early 1990s, as investment requirements prompted the government to attract foreign investments in the gas industry by relaxing some legislation. In the first half of the 1990s, Sonatrach offered more flexible take-or-pay provisions and pricing. New contracts signed in the early 1990s for the sale of gas to southern European countries indexed the price to gas oil and heavy fuel oil, to reflect the final consumers' willingness to pay. Capital inflow from the new contracts allowed doubling of the capacity of the Trans-Mediterranean pipeline (Transmed) in 1994, and completion of the MEG (Maghreb-Europe Gas) pipeline in 1996.

In the 2000s, Algeria's economy was booming given the high prices for oil and natural gas. By 2004, Algerian gas production became the eighth-largest in the world. By 2007, Algeria's proven gas reserves became the eighth-largest in the world [24]. Algeria has increasingly allowed greater foreign investment, and foreign gas producers have entered into numerous partnership agreements with Sonatrach. In 2006, however, Algeria created a windfall tax on profits of foreign oil companies when oil price exceeds $30/bbl. In addition, Sonatrach's option for new projects was increased from 30% to 51% [24,25].

2.2. Indonesia

Indonesia has about 3 Tcm (trillion cubic metres) of gas reserves [26], the largest in the Asia Pacific region. More than 70% of its reserves are located offshore. Since 1971, foreign oil companies can operate in Indonesia as contractors to state-owned Pertamina. Sales to Japan, South Korea, Taiwan and Singapore account for most of the Indonesian gas exports. Liquefied natural gas (LNG) is supplied under long-term contracts [5]. The gas is liquefied in two plants: Bontang and Tangguh; before 2015, a third plant—Arun—was operational, but it currently lacks feed gas for liquefaction [5,27–30].

Gas prices within the country are regulated, and the difference between the local price and the higher export price has caused friction between gas producers and the state in the 2000s [27]. For example, Indonesia has diverted gas exports to serve growing domestic demand. Indonesia has also disrupted exports due to a lack of gas reserves, which resulted from the failure to attract investments upstream. Changing market conditions have also led Indonesia to increase gas prices for new long-term contracts. The following paragraphs present the details of each instance of opportunistic behaviour.

2.2.1. Political Change and Price Demands in 2004–2005

In 2004, due to declining gas extraction and growing domestic demand, the new Indonesian government requested to divert some of the LNG-destined gas to local customers. This can be viewed as a hold-up of the firms producing gas in Indonesia, as the regulated domestic price was below the export price. The diversion resulted in LNG supply shortages, uncertainty about contract renewals, and possibly reduced upstream investments.

Due to the diversion, in 2005, Pertamina decreased LNG supplies to Japan, Korea and Taiwan by 51 cargoes, a significant reduction compared to the contracted volumes for that year [31]. Indonesia also increased its exported LNG price from $2.40/MBtu to $3.35/MBtu to Chinese, South Korean, Mexican and Japanese buyers [27]. This price increase was partly due to the diversions, and partly due to higher crude oil prices.

2.2.2. Political Changes and Discontinued Supplies in 2006

In 2006, due to growing domestic demand and lack of upstream investments, Indonesia restructured the gas industry to attract foreign investments. Foreign oil companies operating under PSA (production sharing agreement), however, had to sell at least 25% of oil and gas production locally at regulated low prices [31]. This requirement resulted in low upstream profitability and low investments. Despite restructuring the gas industry, due to lack of investments and consequent lack of gas reserves, Indonesia could not export the promised volumes of LNG under long-term contracts to the East Asian buyers in 2006 [27].

2.2.3. Discontinued Supplies in 2007–2009

While prioritisation of growing domestic gas consumption continued, it was not the main reason for falling LNG exports. During 2000–2006, gas consumption increased by 1% per year, and LNG exports declined by 3.2% per year [5]. Since 2006, the main reason for falling LNG exports was declining gas production, which was due to failure to attract investments. As a result, in 2007, Pertamina did not renew a contract for 3.1 bcm with South Korea. In March 2008, Pertamina reduced LNG supplies to Japan for the post-2010 period, from 16.3 bcm to 4.1 bcm for the first five years and 2.7 bcm afterwards. This reduction

was crucial for Japan, as 16.3 bcm represented about 20% of Japan's annual LNG imports. In 2009, Pertamina did not renew a contract for 2 bcm with Taiwan [5,32].

2.3. Russia

Russia is the largest natural gas producer and has the largest reserves in the world. Gazprom is the main producer of natural gas in the country with monopoly rights over gas exports. In 2017, Russia accounted for 35% of total European imports [33]. Russian gas will continue to dominate European gas supplies over the next decade [18]. Most of the Russian gas supplies to Europe passed through Ukraine, Belarus and Moldova. These transit countries are also heavily dependent on deliveries of Russian gas.

During the 1990s and 2000s, there were numerous gas disputes between Russia and these transit countries, emphasising the need to study the mutual dependence of suppliers and transit countries. The disputes arose due to accumulated debts, Russia's price demands, theft of gas in transit to Europe, and Russian pressure to exchange debts for a share in gas transit networks [2].

2.3.1. Supply Interruptions in the 1990s

In February of 1993, Gazprom cut off the gas supply to Ukraine for the unpaid debt of over 238 million USD [34]. This interruption lasted for one day because Ukraine threatened to close the transit pipeline to Europe. This threat illustrated the mutual dependence between Russia and Ukraine, where Ukraine depended on imports of Russian gas and held negotiating power as a transit country. This interruption was one of several that happened for the reason of unpaid debts by the newly established states after the collapse of the Soviet Union.

Perhaps the newly established independent states were still learning how to deal with the disputes in the 1990s, as during 1998–1999, there was a continuous diversion of gas in transit to Europe by Ukraine. In November of 1999, Russia interrupted oil and electricity sales to Ukraine in response to a theft of nearly 4 bcm of gas in that month [35].

2.3.2. Gas Diversion and Interruption in 2003–2004

During 2002 and 2003, Gazprom tried to purchase a 50% stake in Beltransgaz, owner of the Belarusian transit network. At that time, Belarus was importing gas at Russia's domestic prices. Russia and Belarus did not agree on the price of Beltransgaz, so the attempted purchase failed, and Gazprom warned of a price increase in 2004 from \$30/1000 m^3 to \$50/1000 m^3. Belarus refused, and Gazprom stopped the supplies to Belarus on 1 January 2004. Belarus started to divert Russian gas destined for Europe to domestic consumption. On 18 February 2004, Gazprom completely cut off the supplies to Belarus. In June 2004, Belarus agreed to the price of \$46.68/1000 m^3 [34].

This was one of the earliest examples of the bargaining power held by transit countries: the diversion of supplies. It illustrates the importance of setting up an international framework to ensure uninterrupted supplies to the final importer during a dispute between an exporter and a transit country.

2.3.3. Gas Diversion and Interruption in 2004–2005

In the summer of 2004, Russia and Ukraine agreed on the delivery of Central Asian gas to Ukraine and settlement of Ukraine's debts for Russian gas delivered during 1997–2000. The transit fee in Ukraine was set at \$1.094/1000 m^3/100 kilometres, 2.5 times lower than in Poland [36]. Russia would pay the transit fee with gas at the price of \$50/1000 m^3, hence Russia would provide Ukraine with 21–25 bcm per year during 2005–2009 [1,35].

In March of 2005, the new Ukrainian government suggested that the transit tariffs be set at European levels and paid in cash. Gazprom, in return, suggested that Ukraine pays the European gas price. At that time the price paid by Ukraine was 25–30% of the gas price at the German border [1,35]. The disagreement escalated by May of 2005 when Gazprom could not retrieve 7.8 bcm of gas that it had pumped into Ukraine's storage facilities.

Gazprom suggested that the stolen volume would be subtracted from transit payments to Ukraine, valued at the European export price. Ukraine threatened to appropriate the corresponding volume from the gas in transit to Europe. Eventually, this problem was resolved by the agreement that part of the gas would be considered as payment for transit by Gazprom, and the rest would be returned during 2005–2006 [1].

2.3.4. Gas War in 2005–2006

In the summer of 2005, Ukraine objected to the debt settlement of 2004 as being excessive. In late 2005, Gazprom demanded an increase in gas prices to European levels ($160–$230/1000 m^3) starting from 2006, unless Ukraine allowed the company to buy a stake in Ukraine's transit pipelines. Ukraine rejected the acquisition but suggested a gradual increase in prices, starting from $80/1000 m^3 in 2006 [1,34]. Ukraine also threatened to steal gas in transit to Europe or increase the transit fee if Gazprom insisted on the earlier price hike. On 1 January 2006 Gazprom cut off gas supplies to Ukraine. It appears that the root of this disruption was in Ukraine's unwillingness or inability to settle its debt.

On 1 January 2006, Ukraine stole some of the Russian gas in transit to Europe. By 2 January European countries lost 14% to 40% of Russian gas supplies. On 2 January, Gazprom stated that it would pump an additional 95 million cubic metres of gas per day to compensate for Ukraine's withdrawals. By 4 January, Russian gas supplies to Europe were back to normal. On 4 January, Gazprom and Naftogaz also announced the end of the dispute. They signed a contract for five years, stipulating a transit fee of $1.6/1000 m^3/100 kilometres for 2006, and an average price for the mix of gas, mostly from Central Asia, of $95/1000 m^3, including gas from Gazprom for $230/1000 m^3 [1,34].

During these events, many European commentators suggested that Russia used its economic power in political relations with Ukraine. However, similar increases in Russian export prices occurred in other CIS countries. In 2006, for example, the Caucasus countries were required to pay $110/1000 m^3. Similarly, Moldova was required to pay $160/1000 m^3, double the price paid in 2005. When Moldova refused, Russia stopped deliveries to Moldova for 12 days in January 2006 [1]. Russia and Moldova agreed on the price of $110/1000 m^3 [37]. In December of 2006, after a short dispute and a threat to cut gas supplies, Gazprom increased the price to Belarus to $100/1000 m^3 (more than doubling of price) and purchased Beltransgaz for the minimum price requested by Belarus in the earlier dispute [38].

2.3.5. Threats and New Contract in 2007–2008

In late 2007, Russia increased the gas price to Ukraine to $179.50/1000 m^3, and Ukraine increased the transit tariff to $1.7/1000 m^3/100 kilometres [2,34]. In early 2008, Ukraine put these arrangements in doubt. By February Gazprom complained that Ukraine was taking gas in transit to Europe [2,34]. When the negotiation ran into some difficulties, Gazprom briefly reduced the supply of gas to Ukraine on 3 March 2008. Naftogaz replied that it could not guarantee the transit of gas to Europe if Gazprom decreased the supplies to Ukraine.

In October of 2008, Russia and Ukraine annulled the January 2006 contract and agreed on the following: (1) the price and tariff would increase gradually over three years; (2) Ukraine guarantees a reliable transit of gas; (3) Gazprom and Naftogaz would jointly export some gas to Europe [2]. Gazprom shared its lucrative European market with Naftogaz by allowing Ukraine to re-sell some of the gas to incentivise Ukraine for a peaceful implementation of the contracts.

2.3.6. Gas Wars and Debts Problems in 2009

On 2 December 2008, Naftogaz acknowledged that it faced difficulty repaying around $1 billion owed for Russian gas. In mid-December, Gazprom stated that the debt grew to $2.195 billion, and in response, Naftogaz paid $800 million [2]. On 19 December, Gazprom said that if Naftogaz does not pay the balance by the end of 2008, no supply contract would

be signed for 2009. Previously Gazprom stated that if no agreement was reached by the end of 2008, the gas price could rise to \$400/1000 m^3.

On 30 December, Naftogaz paid \$1.52 billion but disagreed with penalties of \$614 million. On 1 January 2009, Gazprom cut gas supply to Ukraine, while supplies to Europe continued. On 4 January, Gazprom claimed that Ukraine had stolen 50 million m^3 of gas, the next day the claim increased to 65.3 million m^3. Gazprom requested that Ukraine supplied this volume to Europe from its own resources. Naftogaz stated that it took 52.2 million m^3 as technical gas (Technical or fuel gas is required to run the compressor stations along a pipeline. The general practice is that technical gas is provided by the transit country and included in the transit tariff) [2].

On 6 January, Ukraine stated that Gazprom sharply reduced the gas flowing into the transit pipeline. Gazprom said that it provided only 64.7 million m^3 out of 130 million m^3 required on that day expecting Ukraine to add the missing 65.3 million m^3. On 7 January, Gazprom stated that it had stopped all deliveries into the transit pipeline because Ukraine had closed it; Naftogaz said that it had closed the pipeline because Gazprom had stopped the supplies [2].

In the following days, the European Union prepared the terms of reference for a monitoring mission with representatives from both sides of the conflict and major European gas companies. Deployment of the monitoring mission did not result in the resumption of the supply of gas. Russia claimed that the gas could not flow because the transit pipeline was blocked; Ukraine said that no gas was supplied. Naftogaz requested that Gazprom should provide both the technical gas and linepack (Linepack gas is the gas that is maintained within the pipeline to keep the pressure and ensure uninterrupted flow) gas of 140 million m^3 [2].

On 19 January, Russia and Ukraine finally signed an agreement to end the dispute. Gas flow to Europe restarted on 20 January and was back to normal after two days. The contract stated that 40 bcm would be delivered to Ukraine in 2009 and 52 bcm per year afterwards. The take or pay provision was 80%. The gas price would be 80% of the European price (netback from the German border) in 2009 and 100% beginning in 2010. The annual transit volume would be at least 110 bcm per year. The transit tariff was set at \$1.7/1000 m^3/100 kilometres for 2009 and \$2.04/1000 m^3/100 kilometres, plus an element of the 2009 gas price, for 2010. From 2011 the transit tariff would be indexed to EU inflation [2].

During the 2009 gas dispute, both sides clearly added to the creation and escalation of the dispute. The final payment for the debts by Ukraine was probably too late, there was no time left to make the 2009 agreement before the start of the year.

2.4. Turkmenistan

Turkmenistan has the 6th largest natural gas reserves in the world, at 7.5 Tcm [39]. During the Soviet era, Turkmenistan sent gas to the republics and received transit permission through Russian territory to sell gas to European customers. Deliveries of Turkmen gas were often disrupted due to the inability to pay (repay debts) for the imported gas, Turkmenistan's demands for a higher price, hold-up by a transit country, and technical issues.

Turkmenistan's dependence on transit countries was the highest until the late 1990s, when only one gas export pipeline was available, which connected Turkmenistan to Russia via Uzbekistan and Kazakhstan (Central Asia—Centre). Since 1993, Russia has stopped exports of Turkmen gas to Europe.

In 1997, Turkmenistan and Iran built a connecting pipeline with an initial capacity of 4 bcm per year, which was doubled by 2006 [34,40]. Iran financed much (80%) of the pipeline construction costs (\$190 million), and 35% of annual deliveries of Turkmen gas were considered as reimbursement for Iran's contribution [41].

In August of 2007, Turkmenistan and China started the construction of a connecting gas pipeline via Uzbekistan and Kazakhstan; Turkmenistan granted Chinese CNPC local exploration and production licences [34]. On 14 December 2009, gas started flowing from

Turkmenistan to China [42,43]. Initially, the gas flow was around five bcm per year, with the full capacity of 40 bcm per year expected to be achieved by 2012.

Although these relatively newer pipelines to Iran and China improved Turkmenistan's export options, a substantial share of the exports still had to transit through Uzbekistan and Kazakhstan.

2.4.1. Price Demands and Discontinued Supplies in 1992

In 1992, Turkmenistan demanded payment for its gas from all former republics in hard currency. Numerous non-payment disputes followed. In the spring of 1992, a price dispute between Turkmenistan and Ukraine led to the disruption of gas supplies to Ukraine. Turkmenistan wanted a price of \$80/1000 m^3 (comparable to the Norwegian export price of \$92/1000 m^3 [44]. Ukraine refused to pay more than \$4.7/1000 m^3. Turkmenistan cut the supplies on 1 March. After negotiations, Turkmenistan resumed gas supply in the autumn with the price set at \$7.2/1000 m^3 until the end of 1992 [45].

2.4.2. Transit Fee Demands in 1993

In January of 1993, Armenia, Azerbaijan, Georgia, Kazakhstan, Ukraine, and Uzbekistan increased the transit tariff for deliveries of Turkmen gas from \$0.07/1000 m^3/100 km to \$0.43/1000 m^3/100 km. In October 1993, Turkmenistan again tried to raise its gas price but did not succeed because the importers could not afford the higher price. Kazakhstan and Uzbekistan, which were among the importers as well as transit countries, retaliated by demanding higher transit fees for deliveries of Turkmen gas [45].

2.4.3. Debt Problems and Discontinued Supplies in 1994

In February of 1994, Turkmenistan cut gas deliveries to Ukraine due to the accumulated debt of \$850 million. Later, Turkmenistan allowed Ukraine to pay partly in barter [34]. In early 1994, Turkmenistan also cut gas supplies to countries in Central Asia and the Caucasus because of non-payments [45]. Supplies to Georgia and Azerbaijan were interrupted because of the debt of \$140 million and \$35 million respectively. After negotiations, both countries agreed to the price of \$80/1000 m^3, with Georgia paying in barter and Azerbaijan paying partly in barter.

2.4.4. Debt Problems and Discontinued Supplies in 1997

In 1997, despite the gas sales to Iran, Turkmenistan's exports fell to 6 bcm [32], as gas exports to Ukraine were stopped due to unpaid debts in March 1997 [34,35]. Between August 1997 and January 1998, the parties could not agree on a new price for the resumption of gas deliveries. During 1998 Russia encouraged the sales of Turkmen gas to Ukraine, which would free up some of the Russian gas for sales to Europe. In January of 1999, deliveries of Turkmen gas to Ukraine resumed under the agreement for 20 bcm per year at the price of \$36/1000 m^3, paid 60% in barter.

2.4.5. Debt Problems and Discontinued Supplies in 1999

In April 1999, Turkmenistan stopped gas deliveries to Ukraine again as Ukraine was already \$100 million in debt and was unable to pay for any more gas [34,35]. In the summer of 2000, Turkmenistan and Ukraine signed a preliminary 10-year agreement with the price of \$42/1000 m^3 to be paid 50% in barter. Later, the Ukrainian president criticised the agreement because the price was too high. In October of 2000, Turkmenistan and Ukraine agreed for 5 bcm to be delivered in the rest of the year and 30 bcm in 2001 for a price of \$40/1000 m^3 [34,35]. Due to past non-payment problems, the agreement involved a \$7 million insurance fund and weekly advance payments.

2.4.6. Price Demands and Discontinued Supply in 2001

In August 2000, Turkmenistan and Russia agreed on the purchase of 10 bcm from Turkmenistan at the price of \$38/1000 m^3, paying 60% in barter [35]. In January of 2001,

Turkmenistan stopped deliveries to Russia after only 6 bcm had been delivered. Turkmenistan demanded that Russia match the payment terms of its contract with Ukraine; Russia agreed to the new terms in February.

2.4.7. Debt Problems and Discontinued Supply in 2005

In May of 2001, Turkmenistan and Ukraine signed a contract for 2002–2006 for the delivery of 40 bcm in 2002, 50 bcm in 2003, and total expected delivery of 250 bcm until 2010 [34,35]. The agreed price was \$42/1000 m^3, with 50% in barter. In October of 2002, the parties settled on a price of \$44/1000 m^3 for 2003 (50% barter) with 36 bcm to be delivered that year.

During 2003–2004, Ukraine failed to make timely payments to Turkmenistan, adding new debts to old ones. After several warnings, Turkmenistan cut the supply of gas to Ukraine (and to Russia) on 31 December 2004, and requested a higher price of \$60/1000 m^3 for supplies in 2005. Turkmenistan resumed exports to Ukraine on 3 January 2005 at \$58/1000 m^3, paid 50% in barter [34,35].

2.4.8. Price Demands and Discontinued Supply in 2005

In April of 2003, Russia and Turkmenistan signed a long-term agreement for 2003–2028 [35,46,47]. Gazprom would purchase 4–6 bcm in 2004, –7 bcm in 2005 and 10 bcm in 2006 at \$44/1000 m^3, with 50% in barter. The volumes would increase to 60–70 bcm in 2007, 63–73 bcm in 2008, and 70–80 bcm for 2009–2028. No prices were set for the post-2006 period. The significant increase in the volumes after 2006 would require most of the gas left after local consumption to be exported to Russia. This implies that Russia was taking over the supply of Turkmen gas to Ukraine once the contract between Turkmenistan and Ukraine was due to expire. Possibly, this was Gazprom's way of ending direct gas deliveries from Turkmenistan to Ukraine, due to increased European gas prices.

On 31 December 2004, Turkmenistan cut the supply of gas to Russia (and to Ukraine) and requested a higher price of \$60/1000 m^3. Exports to Russia were resumed in May of 2005. Turkmenistan and Gazprom agreed that the price would stay at \$44/1000 m^3 in 2005–2006 but that the payment would be 100% cash. Turkmenistan justified the higher price demand and the supply interruptions on (1) a weaker US dollar, (2) higher prices of steel products received in barter in exchange for gas, (3) higher European gas prices.

2.4.9. Price Demands and Discontinued Supply in 2007

In December of 2007, Turkmenistan cut off gas supplies to Iran, attributing it to a technical fault. Extremely cold weather and a dispute over volumes and prices are suggested to be among the reasons for the supply disruption. Iran had been buying Turkmen gas for \$95/1000 m^3, significantly lower than its export price of about \$300/1000 m^3 to Turkey [5,34]. After four months of negotiations, Turkmenistan and Iran agreed on a price of \$130/1000 m^3 for the first half of 2008 and \$150/1000 m^3 for the second half of 2008.

2.4.10. Lower Price Demands by Importer and Technical Issues in 2009

In April of 2009, another dispute occurred between Turkmenistan and Russia. On 9 April, there was an explosion on the Central Asia—Centre gas pipeline because Russia significantly decreased the offtake from the pipeline. With the decreased gas demand and prices in Europe, Russia cut the imports from Turkmenistan, maintaining its own exports to Europe. Turkmenistan blamed Russia for the accident, while Russia answered that Turkmenistan was informed about the decrease in offtake and could have reduced the flow of gas into the pipeline. The price of Turkmen exports was around \$200/1000 m^3. In May, Gazprom suggested a decrease in the contracted sales volume for the second quarter of the year by 80% or a decrease in the current price of around \$200/1000 m^3, to which Turkmenistan did not agree. Gas supplies were resumed only in January 2010 at the annual volume of 11 bcm [48–51], considerably lower than the 70–80 bcm contracted in 2003.

3. Summary on Hold-Up Occurrences

3.1. Classification of Hold-Up Occurrences

In this section, we categorise the supply disruptions described above. The following categories emerge. (1) Non-payment of debts by the importers. This often led to the interruption of gas supplies and was most common in the 1990s after the break-up of the USSR. (2) Technical faults leading to supply disruptions. This might have been used to cover opportunistic behaviour. (3) Political changes (most notably, a change in the government or domestic orientation of a resource policy) that led to the non-fulfilment of existing agreements. (4) Demands for higher gas export prices, often based on significant changes in market conditions. In some cases, the exporters resort to supply disruptions. (5) Demands for a higher transit fee. This can also lead to supply disruption. (6) Theft of gas in transit. This can lead to supply disruption.

The first two categories listed above (debts and technical faults) are different from the rest in that they often are not due to opportunistic behaviour or hold-up. The latter two categories (transit fee and theft of gas) are special in that they are done by a transit country. The Table 1 below allocates the supply disruptions hold-ups into six categories.

Table 1. Summary of disruptions.

Initiator	Date	Opportunistic Behaviour	Classification
Algeria	1980	Disrupted supply from Algeria to France and the USA.	Price demands
Algeria	1981	Disrupted supply from Algeria to Germany and Netherlands. Price hike for Belgium and Italy.	Price demand
Algeria	1986	Price hike for European importers.	Price demand
Indonesia	2004–2005	Reduced supply from Indonesia to Japan, Korea, Taiwan. Price hike for China, Japan, Korea, Mexico.	Price demand, Political change
Indonesia	2006	Disrupted supply from Indonesia to East Asian importers.	Political change
Indonesia	2007–2009	Disrupted supply from Indonesia to Korea and Taiwan. Reduced supply to Japan.	Political change
Ukraine	1993	Disrupted supply from Russia to Ukraine.	Unpaid debts
Ukraine	1999	Disrupted crude oil and electricity supply from Russia to Ukraine.	Theft of gas
Russia	2003–2004	Disrupted supply from Russia to Belarus.	Price demand, Theft of gas
Ukraine	2004–2005	Disrupted supply from Russia to Ukraine.	Political change, Transit fee demand, Theft of gas
Ukraine	2005–2006	Disrupted supply from Russia to Ukraine, higher transit fee.	Political change, Transit fee demand, Theft of gas
Russia	2006	Price hike for Belarus.	Price demand
Russia	2006	Price hike and disrupted supplies to Moldova.	Price demand
Ukraine	2007–2008	Reduced supply from Russia to Ukraine, price hike, higher transit fee.	Price demand, Transit fee demand
Ukraine	2009	Disrupted supply from Russia to Ukraine. Ukraine stole some of the Russian gas.	Political change, Unpaid debts, Theft of gas
Turkmenistan	1992	Disrupted supplies to Ukraine, price hike.	Price demand
Multiple transit countries	1993	Higher transit fee for gas from Turkmenistan.	Transit fee demand
Turkmenistan	1994	Disrupted supplies to Ukraine due to debts.	Unpaid debts

Table 1. *Cont.*

Initiator	Date	Opportunistic Behaviour	Classification
Turkmenistan	1994	Disrupted supplies to countries of Central Asia and the Caucasus due to debts.	Unpaid debts
Turkmenistan	1997	Disrupted supplies to Ukraine due to debts.	Unpaid debts
Turkmenistan	1999	Disrupted supply to Ukraine due to debts, price hike.	Unpaid debts, Price demand
Turkmenistan	2001	Disrupted supply to Russia, price hike.	Price demand
Turkmenistan	2005	Disrupted supply to Ukraine due to debts, price hike.	Price demand, Unpaid debts
Turkmenistan	2005	Disrupted supply to Russia, price hike.	Price demand
Turkmenistan	2007	Disrupted supply to Iran due to a technical fault, price hike.	Price demand, Technical issues
Russia	2009	Disrupted supply from Turkmenistan to Russia due to pipeline explosion, reduced imports.	Technical issues

Figure 1 below shows the evolution of hold-up types, indicating greater diversity of reasons for supply disruptions, which attracted more attention to supply security indicators [52]. Before 2000, supply disruptions occurred mostly due to price demands and non-payment of debt. Most of the price demands were made by Algeria in the 1980s and by Turkmenistan in the 1990s. Most of the debt-related disruptions took place in the early 1990s, soon after the collapse of the Soviet Union. Many of the newly-emerged economies were too weak to pay for energy imports with hard currency. Supply disruptions related to transit countries—transit fee demands and theft of gas—occurred infrequently before 2000.

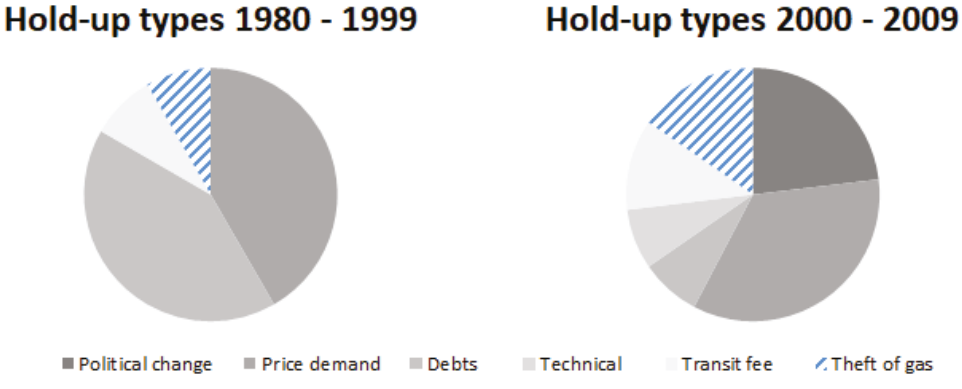

Figure 1. Classification of hold-up occurrences.

Since 2000, all six types of hold-ups took place. The most common cause for supply disruptions were price demands. The second most common cause for supply disruptions was political change. Price demands were made by Indonesia in the early 2000s and by Russia and Turkmenistan throughout the 2000s. Political changes led to supply disruptions in Indonesia and Russia as well as Ukraine throughout the 2000s. Hence, designing supply contracts that minimise the likelihood of a price dispute, even in case of some political changes, is crucial.

The importance of studying this evolution is emphasised by growing international integration, growing global demand for natural gas to reduce emissions, and growing costs of natural gas investments that increases hold-up potential. Since 2000, supply disruptions related to transit countries—transit fee demands and theft of gas—became

more frequent and often complicated the situations around the hold-up. Disruptions related to transit countries are jointly the second most common after price demands since 2000. Hence, arrangements that minimise the likelihood of a dispute with transit countries are also crucial.

The hold-up problem is especially important in the multi-lateral framework, where transit countries are involved. Theoretically, the involvement of a transit country complicates the natural gas trade and increase hold-up potential. Empirical data seems to align with this theoretical notion: the evolution of supply disruptions emphasises the recent importance of transit countries, as disruptions related to transit countries have become more frequent since the year 2000. However, the literature does not contain a considerable discussion of hold-up problems due to a third party. This paper is an early step towards exploring supply disruptions related to transit countries.

3.2. Hold-Up Mitigation

Gas supply disruptions negatively impact households and businesses. Any future disruptions of the supply of Russian gas to Europe would have a significant impact on the economies of Eastern Europe, and a moderate effect on Western Europe [4,53]. This is because Eastern Europe depends more heavily on the supplies of Russian gas. Hence, mitigation of future hold-up is crucial. Three strategies may effectively mitigate the hold-up problem when three parties—exporter, transit country, importer—are involved in trade dependent on asset-specific investments coupled with volatile markets.

The three strategies discussed below are (1) resolving disputes through an international organisation; (2) designing contracts with price mechanisms that might reduce the possibility of disputes; (3) reducing the number of parties involved in the trade. Political issues have often led to gas supply disruptions multiple times. One strategy to mitigate the hold-up problem is to set up an international organisation that can help avoid or resolve the disputes. The Energy Charter Treaty (ECT) was created to facilitate energy flows from east to west in Europe. The ECT covers four main dispute areas: trade, investment, transit and settlement [54].

The Treaty promotes the principles of freedom of transit and non-discrimination, includes an obligation to provide national treatment for energy in transit, and prohibits interruption of flows and the placing of obstacles to the construction of new energy transportation facilities. It also contains a specific conciliation procedure for disputes over energy transit. The ECT requires that, in case of a dispute, the transit country shall not interrupt or reduce the existing flow of energy materials and products prior to the conclusion of the conciliation mechanism. The flow can only be stopped if it was allowed by the original contract or by the conciliator.

The ECT experience so far shows that the hold-up potential has not been eliminated, as parties can simply renege on the agreements. The ability of an international organisation to resolve disputes thus needs further improvement. Before the 2009 gas dispute between Russia and Ukraine, the Energy Charter Secretariat warned that Ukraine had to ensure non-interruption of transit [2]. However, the ECT could not prevent or effectively alleviate the dispute. The ECT (which had been signed and ratified by Ukraine) did not stop Ukraine from interrupting the transit. However, Russia has not ratified the Treaty, stating that it is biased towards consumers. Hence, for the ECT or any future similar organisation to effectively prevent and resolve disputes, it must have some enforcement mechanism.

One such enforcement mechanism is reputation, which has been used relatively successfully by the WTO (World Trade Organisation). The DSB (Dispute Settlement Body) of the WTO has at times been successful at resolving political hold-up problems by providing transparency and reputation damages for violators [55]. Another example of an enforcement mechanism derives from Klein's [9] self-enforcing range: the parties could post substantial collateral forfeitable upon non-compliance.

Price disputes have also led to gas supply disruptions multiple times. Hence, a second strategy to mitigate the hold-up problem is to design contracts with price mechanisms that

might reduce the possibility of disputes as a result of market changes. Current pricing in long-term gas contracts indexes the gas price to trailing averages of fuel oil derivatives prices in Europe [56] and of crude oil prices in Asia [52]. Temporarily large deviations of current price from longer-term averages might lead to disputes. Additionally, eliminating seasonality by indexing contract prices to longer-term average prices might lead to sub-optimal gas consumption or require additional costly gas storage. Although designing a better pricing mechanism than indexing gas prices to average fuel prices is difficult, perhaps accounting for seasonal changes in demand is beneficial.

The gas wars between Russia and Ukraine show that eliminating the need for a transit country can reduce hold-up potential significantly. Hence, a third strategy to mitigate the hold-up problem is to reduce the number of parties involved. This is what Russia is trying to achieve with its new gas pipeline projects, such as Nord Stream and Blue Stream. These pipelines connect Russia with its European customers while avoiding the territories of former Soviet republics (Belarus, Estonia, Latvia, Lithuania, Moldova, Ukraine). The drawback of this strategy is its cost; and delaying investment into expensive alternative routes might also serve as a deterrent [6].

Nord Stream is an offshore pipeline connecting Russia directly with Germany via the Baltic Sea. This pipeline has two lines, opening in 2011 and 2012, with a total capacity of 55 million m^3. The capacity is being expanded with Nord Stream 2; which is expected to be completed in the third quarter of 2021 [57]. The cost of the pipeline is over $15 billion (onshore and offshore sections). Russian and German officials stated that this pipeline reduces costs due to the elimination of transit fees and increased pipeline pressure (eliminating the need for midway compressors) [58].

Blue Stream is an offshore pipeline connecting Russia with Turkey via the Black Sea. This pipeline started commercial gas supplies in 2003, with a capacity of 16 billion m^3 per year. The cost of the pipeline is over $3.2 billion (onshore and offshore sections). Russian Gazprom stated that the significance of this pipeline is in bypassing transit countries (Bulgaria, Moldova, Romania, Ukraine) [59–62].

Russian investments in new multi-billion-dollar pipelines to avoid hold-up risks recognise the importance of hold-ups related to transit countries. Game-theoretic models show that potential investment in alternative transit routes shifts the bargaining power [7]. A broader understanding of transit-related hold-up problems and the development of mitigating strategies benefit from a clear account of historic cases of opportunistic behaviour. Hence, this study might be useful for academics in energy economics, for practitioners involved in international energy trade, and for policymakers at the highest state levels.

4. Conclusions

The potential for a hold-up problem is an important challenge in the international natural gas trade. As discussed above, multiple significantly large supply disruptions in the last two decades illustrate this importance. The reasons for this importance are because (1) gas pipelines are expensive and asset-specific investments; (2) international gas trade might include more than two parties to a transaction due to the presence of transit countries. The hold-up problem is thus crucial for landlocked countries. As discussed above, gas supply disruptions due to issues related to transit countries happened quite frequently in the last two decades.

The contribution of this paper is filling the gap in the literature, which rarely discusses the issues related to transit countries, despite their relative importance. Additionally, this paper also suggests three ways to ameliorate the issues related to transit countries: (1) use of an international organisation; (2) designing contracts with price mechanisms that might reduce the possibility of disputes; (3) reducing the number of parties involved in the trade.

Future research on the hold-up problem in natural gas might go along two routes. First, theoretical studies of the cost of a hold-up as a function of relevant factors. Second, empirical studies to test these theoretical studies. A better understanding of the factors affecting hold-ups might be enormously beneficial to avoiding them.

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Socioemotional Wealth (SEW) of Family Firms and CEO Behavioral Biases in the Implementation of Sustainable Development Goals (SDGs)

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Abstract: Agreed upon by the UN member states, Agenda 2030 assumes joint action for long-term sustainable development. These actions are focused on the implementation of 17 Sustainable Development Goals (SDGs), where actions are assumed to lead to the suppression of negative externalities of human activity. It is stressed that the objectives of sustainable development can only be achieved through deep institutional changes in most dimensions of the economy, including the entrepreneurship dimension. Entrepreneurship plays a pivotal role in the sustainable transformation of the community, as the related activities of companies are the source of the desired structural changes. Entrepreneurial projects make the biggest contribution to the objectives of sustainable development through research and development, investment in new technologies, and innovation. The biggest threat to sustainable entrepreneurship is firms' aggressive corporate financial strategy, which most often results from CEO overconfidence and aggressive financial behavior. The aim of the article is to indicate differences in corporate financial strategies regarding the status of the company (family or non-family) and CEO characteristics (overconfident or non-overconfident). The fulfilment of this aim by analyzing a selected EU member country (Poland) found more aggressive behavior of overconfident CEOs in non-family firms. It was also found that family firms are a fairly coherent group of companies that implement a more conservative corporate financial strategy regardless of CEO characteristics. We can state that family power can curb CEO overconfidence and its impact on aggressive financial strategy. This means that family firms are much more able to create sustainable entrepreneurship and contribute to Sustainable Development Goals (SDGs) within a market framework.

Keywords: Sustainable Development Goals (SDGs); sustainable entrepreneurship; family firm; managerial overconfidence; financial strategy

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1. Introduction

Today, in most world economies, we observe intense processes of globalization, rapid economic growth, and significant institutional and social changes [1–6]. An increase in production, competitiveness, investments, and innovations in these countries, as well as changes in the labor market and consumer patterns [7–11], leads to a systematic increase in energy consumption [12,13]. The continuous increase in the demand for energy causes the resources of energy from non-renewable sources to be no longer sufficient, and its production becomes more expensive and harmful to the environment [14,15]. This situation forces an intensive energy transformation in most countries, including the countries of the European Union [16,17]. Energy transformation is understood as a transition from the

current energy system using non-renewable sources to an energy system based mainly on renewable and low-emission sources. In the European Union, a transition to a sustainable and green economy has become a strategic goal in the fight against climate change, leading to improved energy security, competitiveness, and attractiveness of the economies of Member States [18–20]. The institutional actions of the European Union are in line with the voice of 193 member states of the UN, who in September 2015 put forth the 2030 Agenda for Sustainable Development [Agenda 2030] which assumes joint actions to "combine economic prosperity, social inclusion, and environmental sustainability" [21,22].

Agenda 2030 is focused on the implementation of 17 Sustainable Development Goals (SDGs) that aim to mitigate negative externalities of human activity [21]. In the EU, these agreements have become the basis for achieving improvements against climate change (SDG 13), sustainable consumption and production (SDG 12), protection and conservation of biodiversity (SDGs 14 and 15), and sustainable agriculture and food systems (SDG 2) (Institute for European Environmental Policy, 2019). The EU defined three priority areas to support the achievement of SDGs: (1) Internal priorities for the EU and member states; (2) European diplomacy and development cooperation; and (3) Tackling negative international spillovers [21]. In terms of internal priorities, the focus on sustainable energy production, sustainable land use and food production, and sustainable internal closed-loop systems is intended to lead to the achievement of sustainable development goals [21]. According to the EU strategy, the actions are meant to lead to a situation in which, in 2050, Europe will be the first continent that is neutral in terms of climate and the environment. In the EU, a systematic process of sustainable transformation of the economies of its member states is underway [23]. It is stressed that the objectives of sustainable development can only be achieved through deep institutional changes in most dimensions of the economy [24].

In this transformation, entrepreneurship plays an essential role, which can best translate into the implementation of sustainable development goals by selected countries or the entire EU. In recent years, the concept of sustainable entrepreneurship has been at the forefront of interest in both academic research and global social discourse. As noted by Kraus [25], sustainable entrepreneurship requires an entrepreneurial reorientation towards 'a more ecological, social and economic equilibrium', while 'discovery and exploiting economic opportunities', conversely, is the fundamental aspect of conventional entrepreneurial theories. In the case of sustainable entrepreneurship, investments, innovations, business angels, and family businesses are exchanged among those responsible for its positive development [26–29]. This article focuses on the potential impact on the development of sustainable entrepreneurship on the part of family businesses, which, due to the multitude of these type of business entities in the entire economy, seems to be an important research problem.

During the last decade, a great deal of research has emerged on environmental, sustainable, and green (ESG) entrepreneurship [30–32]. Entrepreneurial ESG projects that contribute to the SDGs are based on radical innovation and very often originate in emerging and young firms (start-ups), implying their strong contribution to the transition to a sustainable economy [33]. Prior research has demonstrated that family firms also contribute significantly to the achievement of SDGs. However, their ability to create new technologies, jobs, and wealth, and thus to conduct decisions in order to become and stay competitive in the long term, might be negatively affected by the risk aversion [27]. Innovations are costly, and one strand of research suggests that family firms avoid uncertain activities more than their nonfamily counterparts, resulting in a general lower level of R&D spending and innovations [34–36]. Following this argument, family firms should initially lag behind non-family firms in terms of reflecting and achieving the SDGs. On the other hand, there is increasing empirical evidence that SDG-related activities have very often been successful, and therefore a catch-up process should also be started in family firms with respect to their innovation efforts. Furthermore, notable theoretical work points to the strong focus on longevity in family firms, that is, accumulation and conservation of wealth

for future generations, and thus less volatile behavior in terms of consistent implementation of activities that support the SDGs, innovations, and performance [26,27,37].

In analyzing sustainable family-owned entrepreneurship and its drivers, the academic literature also aims to understand the relationship between sustainability and entrepreneurial financial strategies. A basic tenet of classical financial theory is that family businesses, in contrast to their non-family counterparts, operate largely within the framework of sustainable entrepreneurship and thus contribute to the achievement of the Sustainable Development Goals (SDGs) due to their conservative values and lower propensity to take risks, resulting in preferring less risky financial options [38]. Non-family businesses, in pursuit of risk and as a result of consciously bearing higher risk, will pursue an aggressive financial strategy, which in most cases precludes sustainable entrepreneurship. Therefore, family firms have been argued to be much more capable of creating sustainable entrepreneurship and contributing to SDGs compared to their non-family peers, which could be more threatened by agency conflicts between different stakeholders and CEO opportunism, overconfidence, and aggressive financial strategies [38–40].

The dominant role of the CEO in creating entrepreneurship and company survival has been widely discussed in the academic literature [41–43]. This is especially true for small- and medium-family companies that rely on personal relationships. These family ties are essential. Recently, the development of the behavioral attitude in investigation towards CEO decision-making opens new opportunities in terms of further research. One of these behavioral characteristics is overconfidence, which has been the subject of increasing research interest [43]. Overconfident CEOs are most often the subject of aggressive financial strategies focused on achieving above-average profits while exposing companies to higher risks. In such a constellation, it is difficult to establish sustainable entrepreneurship and follow SDGs. This is due to the fact that SDG-compliant projects require higher investments, longer payback times, and lower margins. This led us to explore the factors affecting financial strategies in family firms and thus their contribution towards more sustainable development.

The main aim of the article is to investigate whether differences in corporate financial strategies can be detected in a sample of Polish firms with regards to both the status of the company (family or non-family) and the characteristics of the CEOs (overconfident or non-overconfident). To the best of our knowledge, we contribute to the literature two-fold. First, there is a paucity of empirical studies analyzing the relationship between ownership structure and financial strategies with regards to the characteristics of CEOs. Second, our contribution is also of a methodological nature, as we study the aspect of sustainability in a novel way. We do so by interlinking two areas of academic literature: one on family firms and one on sustainable financial strategy. Our results suggest that in non-family firms more aggressive attitudes to financing are being pursued by overconfident CEOs. Additionally, family firms are a coherent group that implements more conservative corporate financial strategies regardless of the characteristics of the CEO. We imply that family power can curb CEO overconfidence and its impact on financial strategy.

We believe that our findings have important implications for firm owners, investors, and policy decision makers as these findings prove that managerial overconfidence and the family status of the firm have an impact on financial strategies. Another implication is that the family status of the company might mitigate managerial overconfidence and thus contribute to more sustainable development.

The remainder of this paper is structured as follows: We begin with a theoretical background that describes the role of CEOs in family firms, allowing us to raise research questions and justify research hypotheses. In the next section, we outline the methodology. The section after that presents the research findings. The last sections contain the discussion and main conclusions.

2. Literature Review

In the transformation towards sustainable development covering the SDGs, entrepreneurship represents the main source and catalyst of the desired structural changes. Academic theory and empirical evidence suggest that sustainable entrepreneurial projects are more rooted in radical innovation than incremental innovation [33]. Patzelt and Shepherd [44] emphasize that sustainable entrepreneurship that contributes to SDGs can be defined as 'the discovery, creation and exploitation of opportunities to create future goods and services that sustain the natural and/or communal environment and provide a development benefit for others'. There are several aspects that distinguish these sustainable enterprises from each other and from more 'conventional' firms [33]. Previous research has also shown a variety of typologies of sustainable entrepreneurship, which are helpful when motivation, social impact, level of profitability, and financial challenges are evaluated [45–47]. For instance, Bergset and Fichter [47] developed an innovative concept on how to classify green firms based on three aspects. These involve product-related characteristics (product quality, long-term focus, and need orientation), entrepreneur-related characteristics (sustainability-related motivation, use of guiding sustainability principles, and level of business qualification), and strategy-related characteristics (level of market orientation, level of growth, control, and decision-making rights). A growing body of academic literature has documented that 'radical innovation originates disproportionally in smaller and more entrepreneurial new firms' [48], making them more likely to support a sustainable and green transition of the economy. Horne et al. [49] propose an original approach to documenting SDG-linked activities of new companies and provide a detailed analysis of the entrepreneurship landscape of Germany along the 17 SDGs. The main findings are twofold. Firstly, 'very heterogeneous entrepreneurial activities along the SDGs could be identified, while there are also significant correlations between multiple goals that are often addressed jointly'. Second, the authors showed that there are multiple SDGs that most entrepreneurs do not address at all, although there are strong needs for improvement.

The implementation of entrepreneurial projects that support SDGs requires the adoption of innovative financial strategies that represent a central issue of entrepreneurial success [47]. A broad discussion has emerged about established financing concepts that support sustainability [50,51]. There is a general agreement that conventional finance is not sufficient to support the achievement of SDGs and that there are specific financing challenges and opportunities that distinguish sustainable entrepreneurs from their conventional peers. Financial theory has delivered a range of theoretical explanations. Bergset [33] summarizes the bulk of them and emphasizes the role of informational asymmetries, the adverse selection problem, the principal agent problem, and the moral hazard problem. A general conclusion stemming from research on the matter is that conventional financial models do not consider an all-dimensional perspective of sustainable development (i.e., environmental and social issues are neglected) [50]. For new and (mostly) small entrepreneurial firms, it might be more difficult to access external funding, particularly in the early stages of entrepreneurial development. The lack of resources, the lack of history, and the high level of risk can cause financial constraints that ultimately result in the loss of business ideas [52].

Therefore, a paradigm shift in financial theories towards sustainable finance addressing non-financial factors, that is, environmental, social, and governance (ESG factors) is needed [50,53]. Research efforts have been focused on topics such as how to analyze sustainable financing concepts and investments [54] or how to design sustainable finance models [53]. Moreover, Bergset [33] calls for a new kind of 'socially responsible investors' or 'impact investors, who invest in a 'value-oriented manner', are motivated to 'strengthen' the ability of enterprises to have a social impact, or fund entrepreneurs 'with a sustainability-related' field of activity and are also focused on non-profit objectives. Therefore, finance is identified as the main source of sustainability, in particular through sustainable investments. There is a general agreement that both companies and investors should integrate environmental, social, and corporate governance factors (ESG factors) into

the decision-making process to mitigate the risk of ESG [50]. Vandekerckhove and Leys [54] focused on covering the gap between sustainable development and finance and call for better indicators to assess sustainable development goals (SDGs) and recommendations for sustainable financing strategies and investments [50].

In the vast majority of countries, family companies constitute a large share of economic performance [55,56]. Therefore, family firms play an important role in economic activity around the world [57–59]. As outlined in the Introduction, family firms differ from their non-family counterparts due to the 'family-centered goals' [27]. From this point of view, family firms focus on the accumulation and conversion of socio-emotional wealth (SEW) that should be passed on to the next generation [27,38]. In this context, Antheaume et al. [26] argue that family businesses prefer longevity, which is reflected in the prioritization of long-term, rather than short-term financial goals, and which corresponds to the concept of sustainable development.

SEW refers to the non-financial aspects of the firm that meet the affective needs of the family, such as identity, the ability to exercise family influence, and the perpetuation of the family dynasty [60] and can drive the behavior of family business to a large extent. Given that family firms are often loss averse when it comes to their SEW, they will behave to preserve these nonfinancial benefits, which may have a significant effect on the decision-making process [61]. SEW concerns can lead to favorable outcomes (e.g., employee commitment, emotional attachment, and better environmental performance) in family firms [62].

Existing research indicates that family companies implement conservative financial strategies, both in investment and financing [63,64]. Furthermore, owners of family firms are found to be averse to external financial sources and prefer internal financing [65]. In addition, they often give up growth opportunities that need external equity, as they endanger family control [66,67]. These research results allowed us to assume the following first research hypothesis (H1) stating that family firms are characterized by a significantly safer financial strategy (both investment and financing) in comparison to non-family firms. The verification of the assumed research hypothesis means that family companies are much more likely to create sustainable entrepreneurship and to achieve the Sustainable Development Goals (SDGs) in comparison to non-family companies. There are already some research studies supporting the thesis that family firms are sustainability oriented. Le Breton-Miller and Miller [68] underline the sustainable approach in the management of family firms due to a long-term orientation and a desire to pass on a healthy business to later generations. Arregle et al. [69] pointed out that families with businesses are anchored in their communities and their long-term presence and values. They build their business on social and relational capital. To achieve recognition, reputation, and longevity, family firms are more likely to invest in economically and socially responsible projects that generate sustainable profits [70,71]. The orientation towards the welfare of current and future family members makes family firms more willing to participate in environmental action [72]. Family firms are perceived as stewards with long-term orientation devoted to social and environmental goals [73].

The most powerful position in the running of every company is held by the CEO [41]. The CEO is responsible for setting and implementing the financial entrepreneurial strategy of each company and creating entrepreneurship. Adams et al. [74] show, in their study of CEOs of 336 Fortune 500 companies, that CEOs and executive managers can indeed affect corporate decisions. Since then, many studies [75–77] have extensively investigated the characteristics of CEOs, finding support for the assumption that their personal characteristics, such as age, gender, and professional background, influence organizational outcomes.

The recently developed behavioral attitude in the investigation of decision making leaves some room for further research on CEO behavioral characteristics. This attitude assumes that CEOs' biases and fallacies of cognitive processes have an impact on corporate finance. Cognitive psychology stems from the work of Kahneman and Tversky [78].

One of the cognitive biases and fallacies is overconfidence. Kahneman [79] calls overconfidence the most significant of cognitive biases. Bazerman and Moore [80] find that overconfidence is the mother of all biases by 'giving the other decision-making biases teeth'. Research in cognitive psychology establishes that people are usually overconfident. 'No problem in judgment and decision making is more prevalent and more potentially catastrophic than overconfidence' ([81], p. 217). 'Perhaps the most robust finding in the psychology of judgment is that people are overconfident' ([82], p. 389). Overconfidence was identified as a complex phenomenon [83] consisting of over-estimation, over-optimism, and over-placement. Overconfidence has been subjected to much inquiry, with a confirmed significant impact on the decision-making process.

Overconfidence in corporate finance has drawn a great deal of attention and has been thoroughly investigated (e.g., [43,84,85]). It was shown that overconfidence also affects financial decisions and financial performance. Overconfident managers have many specific characteristics making them more aggressive in their financial behavior [86,87]. There is some research demonstrating overinvestment [88] as a result of overconfidence. There is also research showing an excessive use of debt by overconfident managers [89,90]. This paper will consider the problem of CEO overconfidence broken down into family and non-family businesses.

In non-family firms, where there are no mechanisms limiting CEO characteristics (and these are even encouraged), overconfident CEOs will manage in a risky manner in order to obtain an above-average level of profit. Family firms, on the other hand, present a more coherent group of companies, especially in terms of conservative values. This means that the mechanisms operating in family firms may weaken the CEO's characteristics (overconfidence) and influence on the firm's financial strategy. These findings led the authors of the article to propose two additional research hypotheses. In hypothesis two (H2) we expect to find a more aggressive financial (investment and financing) strategy conducted by overconfident managers in non-family firms compared to family firms. On the other hand, in hypothesis three (H3) we assume that the management style of non-overconfident CEOs in terms of aggressive financial strategy is similar in both family and non-family firms.

Additionally, the problem of the influence of CEO characteristics on corporate financial strategies is worth considering. Again, this problem will be broken down into family and non-family businesses. So far, the role of the CEO in family firms has drawn attention in many research studies. Villalonga and Amit (2006) find that family firms create value only when the founder serves as CEO or when the founder is chairman with a hired CEO. Since this research there has been quite abundant research on the role of the CEO in family firms; CEOs coming from the family and (non-family CEOs) coming from outside [91,92]. Another stream of research on the role of the CEO in family firms refers to the theory of the upper echelon and the individual characteristics of the CEO [93].

Based on the existing research findings on the impact of CEO overconfidence and family status on corporate financial strategy and firm performance, we think that there exists an interesting avenue of research. The corporate financial strategy of family firms was shown to be both conservative and aggressive while the overconfident CEO was proved to implement an aggressive corporate financial strategy.

With regard to family firms and CEO overconfidence, to the best our knowledge, there are only two studies: one by Hung et al. [94] and the other by Orlando et al. [95]. On the one hand, Hung et al. (2013) examined the effect of managerial overconfidence and family business characteristics on financial distress. Their empirical results show that overconfident CEOs in non-family businesses and non-overconfident CEOs in family businesses are significantly and negatively correlated with financial distress, respectively. On the other hand, Orlando et al. [95], in their theoretical paper, study how the risk propensity of family firms is influenced by the overconfidence of those family members who are participating in the board of directors. They hypothesize that the beliefs of those

family members who exert control over the firms are a relevant predictor of the risk behavior of the company.

Additionally, it can be stated that in the case of non-overconfident CEOs, there should be convergence between the CEO's financial strategy and the expectations of the owner family. However, in the case of a divergence of opinions on the company's financial strategy, the family's power may weaken the CEO's characteristics (overconfidence) and influence on the direction of this strategy. In the case of firms without family influence, the overconfident CEO may have more influence on the adoption of an aggressive financial strategy compared to the non-confident CEO. Therefore, two further research hypotheses were put forward by the authors. The fourth hypothesis (H4) states that in family firms the management style of non-overconfident CEOs and overconfident CEOs is similar in terms of financial strategy. However, in hypothesis five (H5), in non-family firms we expect to find a more aggressive financial (investment and financing) strategy conducted by overconfident managers when compared to non-overconfident managers.

It should be noted that a specific financial strategy (aggressive or conservative) also has specific results. Implementing an aggressive strategy should lead to higher profitability, while a conservative strategy (as it is more costly) generally leads to lower profitability [96].

3. Research Methodology

To achieve our main research aim and verify research hypotheses, we employ the research process that includes, e.g., a way of identifying family firms, managerial overconfidence, investment, and financing strategy.

To identify the status of the firm (family or non-family), we follow the Substantial Family Influence (SFI) index. SFI index is composed of three elements [97]: the family's share in the capital of the firm, on condition that the family holds at least some shares; the family's share of the seats on the governance board; and the family's share of the seats on the management board. According to Klein (2000), a company can be considered a family company, when the sum of the family's share in the equity, government, and management board is equal to or greater than 1 (maximum 3). If the SFI index indicates that it is a family firm (FF), then the value equals 1, otherwise (nFF) the value equals 0.

To identify and measure overconfidence, we followed the methodology of Wrońska-Bukalska [85], who assumes, after Moore & Healey [83], that overconfidence is a complex phenomenon consisting of over-estimation, over-placement, and over-optimism. She uses the survey approach to identify overconfidence and developed an original method of overconfidence measuring. This methodology allows identifying managerial overconfidence and separating overconfident managers from the non-overconfident. If the survey indicates that a manager is overconfident (OC), the variable is equal to 1, and 0 otherwise (nOC).

There are two main elements of financial strategy that managers can influence: investment and financing [42]. Herein, dividend decisions are a type of decision that belongs solely to the owners and not to the managers. Managers can only suggest, and the recommendation is not binding. Financial strategy and firm performance are identified through financial ratios. These variables (financial ratios) are commonly used in research on CEO power, family firms, and the impact of overconfident managers on corporate strategy [98,99]. We use these in our research to ensure comparability of our findings with previous studies.

The sample in our study comes from non-listed (private) enterprises based in Poland. We decided on undertaking a research study of privately owned companies as, in Poland, this type of business is dominant (99.9% of active business entities); hence, private companies are representative for the average Polish business enterprise. We surveyed only those companies that meet the following requirements: established before 2010, active in business for the entirety of the 2010–2015 period, having the same president in place for the entire period, and having a complete and available financial statement. In addition, we remove insurance and banking companies. The final sample includes all companies that were willing to participate in the survey (out of those that met the above requirements).

Subsequently, we collected the financial statements of the companies from the sample, with financial data covering the whole period. Financial data was collected from the Notoria Serwis database. Our sample constitutes the panel data sample. We collect 145 surveys and were able to divide the sample (870 observations) into two subsamples:

- family firms (FF-97 companies and 582 observations) and non-family firms (nFF—48 companies and 288 observations),
- overconfident managers (OC—67 companies and 402 observations) and non-overconfident managers (nOC—78 companies and 468 observations).

In the study, two grouping variables were used to divide the companies into two groups. The first grouping variable made it possible to divide the companies into family and non-family firms. The second grouping variable allowed for the division into groups of companies managed by an overconfident CEO and a non-overconfident CEO. To assess the differences between subsamples in terms of research questions (investment and financing strategies, firm performance) on the basis of the collected data, we employ a non-parametric U Mann Whitney test. The set of variables used in the study, their formula, and their interpretation are presented in Table 1.

Table 1. Description of the variables used in research.

Variables Describing Financial Strategy			
Variables	**Proxy for**	**Formula**	**Interpretation**
Invest1	Investment strategy	Increase in Fixed Assets + Depreciation to Total Assets (in %)	higher Invest1 Ratio = more aggressive investment strategy
Invest2	Investment strategy	Increase in Fixed Assets + Depreciation to Sales Revenue (in %)	higher Invest2 Ratio = more aggressive investment strategy
Fin1	Financing strategy	Total liabilities to Total Assets (in %)	higher Fin1 Ratio = more aggressive financing strategy
Fin2	Financing strategy	The sum of Equity and Long-Term Debt to Fixed Assets (in %)	higher Fin2 Ratio = less aggressive financing strategy
Grouping variables			
Variables	**Proxy for**	**Formula**	**Interpretation**
FF/nFF	Family Firm status	Dummy variable: 0 or 1	1 if the company is a family firm; 0 otherwise
OC/nOC	CEO Overconfidence	Dummy variable: 0 or 1	1 if the CEO is overconfident; 0 otherwise

Source: author's own elaboration.

4. Results and Discussion

Tables 2–6 present the descriptive statistics reflecting investment and financing strategy for two subsamples and the results of the non-parametric U Mann Whitney test. From the data collected, we identify the differences in corporate strategies depending on the status of the company and its managerial characteristics. We applied the U Mann Whitney test for two independent samples to find statistically significant differences in the investment and financing strategy of the sample companies. We use this test because our data do not reflect the normal distribution.

Table 2. Descriptive statistics describing financing strategy in family and non-family firms.

Variables	Descriptive Statistics		UM-W Test	
	FF	nFF	Test Statistics	*p* Value
Invest1	2.1	4.6	−4.825	~0.00
Invest2	1	2.2	−4.84	~0.00
Fin1	49.1	51.4	−2.126	0.024
Fin2	191.6	144.8	−3.275	0.012

Source: author's own calculations.

Table 3. Descriptive statistics describing investment and financing strategy in subsamples for overconfident CEOs.

Variables	Descriptive Statistics for OC		UM-W Test	
	FF	nFF	Test Statistics	*p* Value
Invest1	0.2	2.9	−4.739	~0.00
Invest2	0.1	1.3	−4.504	~0.00
Fin1	46.2	54.5	−3.375	0.001
Fin2	190.2	111.6	−4.415	~0.00

Source: author's own calculations.

Table 4. Descriptive statistics describing investment and financing strategy in subsamples for non-overconfident CEOs.

Variables	Descriptive Statistics for nOC		UM-W Test	
	FF	nFF	Test Statistics	*p* Value
Invest1	0.8	0.8	−0.764	0.272
Invest2	0.4	0.4	−1.037	0.322
Fin1	49.6	47.6	−0.056	0.861
Fin2	216.6	230.3	−1.121	0.262

Source: author's own calculations.

Table 5. Descriptive statistics describing investment and financing strategy in subsamples for family firms.

Variables	Descriptive Statistics for FF		UM-W Test	
	OC	nOC	Test Statistics	*p* Value
Invest1	2.3	1.8	−0.674	0.102
Invest2	1.1	0.9	−0.192	0.133
Fin1	47.8	49.4	−0.818	0.2
Fin2	185.7	207.6	−1.461	0.488

Source: author's own calculations.

Table 6. Descriptive statistics describing investment and financing strategy and firm in subsamples for non-family firms.

Variables	Descriptive Statistics for nFF		UM-W Test	
	OC	nOC	Test Statistics	*p* Value
Invest1	6.1	2.8	−3.066	0.002
Invest2	2.8	1.8	−2.807	0.002
Fin1	53.6	45.8	−2.145	0.045
Fin2	111.2	167.9	−4.576	~0.00

Source: author's own calculations.

According to the results in Table 2, when describing family firms, we find statistically significant differences to non-family firms. These differences refer to all variables that reflect both financial strategies (both investment and financing) and firm performance.

Here, family firms invest less. Invest1 and Invest2 is lower which means that Increase in Fixed Assets in relation to Total Assets and Sales Revenue is lower than for non-family firms. This means that approximately 2% of Total Assets (compared to almost 5% in non-family firms) is invested by family firms. Non-family firms invest twice more than family firms, as Invest1 and Invest2 are twice as high for non-family firms. Higher investments are a proxy for a more aggressive strategy.

Family firms also have a lower debt ratio. Fin1 (Total Liabilities to Total Assets) for family firms is less than 50%. This means that less than 50% of Total Assets are financed by Total Liabilities. The Total Assets of non-family firms are financed by Total Liabilities to a greater extent—more than 50% of Total Assets are financed by Total Liabilities. A higher level of Total Liabilities financing Total Assets means an aggressive financing strategy. Fin2 (the sum of Equity and Long-Term Debt in relation to Fixed Assets) for family firms is at a level of almost 192%. This means that Long Term Capital is two times higher than Fixed Assets for family firms. A higher level of Fin2 is evidence for a conservative strategy. For nonfamily firms, Fin2 is much lower and means that Long-Term Capital accounts for 150% of Fixed Assets. This means that non-family firms pursue an aggressive financing strategy.

The lower level of Invest1 and Invest2 for family firms indicates a conservative investment strategy. The lower level of Fin1 and the higher level of Fin2 for family firms again indicate a conservative financing strategy. This means that family firms pursue conservative financial strategies compared to non-family firms, which allows us to state that the first hypothesis (H1: assuming that more conservative financial strategy is implemented by family firms) is positively and fully verified.

Based on the results of Table 3, it can be concluded that overconfident managers behave differently depending on the status of the company. In family firms, overconfident managers invest significantly less—Invest1 and Invest2 are much lower than for non-family firms. In addition, the financing strategy of overconfident managers differs significantly depending on the company status—for family firms overconfident managers implement more conservative financing strategies: Fin1 is lower, proving a lower level of Total Liabilities, and Fin2 is higher, proving more Long-Term Capital in Fixed Assets financing. Company status is an important factor affecting different behavior of overconfident managers—in family firms, overconfident managers behave in a more conservative way. The analysis of the obtained results allows us to verify the next two research hypotheses, hypothesis two (H2: assuming more aggressive financial—investment and financing—strategy conducted by overconfident managers in non-family firms compared to family firms).

According to the results of Table 4, the nature of the financial strategy generated by the non-overconfident CEO is similar for both types of companies: family and non-family. In the case of family and nonfamily companies managed by non-overconfident managers, there are small differences between the levels of variables, but they are statistically insignificant. Companies managed by non-overconfident managers implement similar strategies. The analysis of the obtained results allows us to verify hypothesis three (H3: assuming that the management style of non-overconfident CEOs in terms of financial strategy is similar in both family and non-family firms).

Based on the results presented in Table 5, the financial ratio that describes the investment and financing strategy for overconfident managers shows the implementation of a slightly more aggressive strategy. Both Invest1 and Invest2, however, show no statistically significant differences in family firms managed by overconfident managers or non-overconfident. The same situation holds for Fin1 and Fin2. It can also be concluded that in family firms there are no statistical differences in the levels of variables adopted to describe the nature of the financial strategy, regardless of whether the overconfident CEO or non-overconfident CEO is behind the financial strategy. This means that family firms present a more coherent group of companies due to the financial strategy pursued regardless of the CEO's overconfidence. The CEO characteristics have no impact on financial—investment and financing—strategy in family firms.

We can state that family power can curb CEO characteristics (overconfidence) and their impact on financial strategy. The family firms present a more coherent subsample no matter what the CEO characteristics are. This means that the family status of the company is a more impactful management process than is the case with non-family firms. The obtained results allow us to verify the fourth hypothesis (H4) stating that in family companies the management process by non-overconfident CEOs and overconfident CEOs is similar in terms of financial strategy.

CEO characteristics are more impactful in companies without family influence. Analyzing the results presented in Table 6, it should be stated that there are statistically significant differences in financial strategy between companies managed by overconfident and non-overconfident managers in the non-family firms subsample. Invest1 and Invest2 are higher for overconfident managers and this means that non-family companies managed by overconfident managers pursue a more aggressive investment strategy. In addition, higher Fin1 and lower Fin2 for overconfident managers mean that overconfident managers implement a more aggressive financing strategy. The obtained research results allow us to verify the last and fifth research hypothesis (H5: assuming that in non-family firms a more aggressive financial—investment and financing—strategy is conducted by overconfident managers, when compared to non-overconfident managers). When there is no family involved in the company, the CEO characteristics matter.

Summarizing all the results obtained, it should be stated that there are more differences between family and non-family firms than between companies managed by overconfident or non-overconfident managers. This means that company status (especially family) has a stronger impact on corporate financial strategies.

Our findings on family firm corporate financial strategies show that sample firms conduct conservative investment and financing strategies, in line with previous research [63–67]. They also find that family firms implement conservative financial strategies, both in investment and financing. Our findings of conservative financial strategies of family firms contradict those showing a more aggressive picture of family firms [98,99]. However, when it comes to aggressive financial strategy, we find that non-family companies managed by overconfident CEOs present more aggressive financial managers' behavior. If CEO overconfidence has an impact, this impact is explicit in non-family firms. This confirms previous findings [84,87]. Based on the research, the authors propose the following recommendations.

1. It is worth supporting the functioning of family businesses and conducting activities that encourage sustainable entrepreneurship.
2. It is worth promoting the value of family businesses in society.
3. It is worth introducing the institutional, official status of a family business, which would be taken into account in the EU economic policy and in the statistics.
4. In the case of non-family businesses, it is worth implementing solutions such as family ones, focused on sustainability and non-financial values.

5. Conclusions and Recommendations

In this article, we attempt to determine the impact the characteristics of CEOs (overconfident or non-overconfident) on corporate financial strategies. The problem is relevant to the issue of sustainable entrepreneurship and the achievement of sustainable development goals (SDGs). An overconfident CEO usually contributes to an aggressive financial strategy of the company, which usually excludes the possibility of ending up as a sustainable entrepreneur. We find a fairly coherent group of family firms that implement a more conservative corporate financial strategy regardless of the characteristics of the CEO. The behavior of an overconfident CEO in family firms is similar to that of a non-overconfident CEO in family firms (more conservative). We can state that family power can curb CEO overconfidence and its impact on financial strategy and firm performance.

This means that family businesses, as opposed to non-family businesses, have a much higher potential to implement actions related to sustainable entrepreneurship. The process of achieving sustainable development goals (SDGs) in the EU should be multidimensional,

by which the authors mean implementing these goals in many economic, social, and environmental areas, with the simultaneous involvement of society, local authorities and institutions, national authorities and institutions, and the involvement of community institutions. The market-oriented functioning of family businesses, combined with their socio-emotional wealth and conservative financial strategy, translates better into most of the mentioned areas related to the achievement of the SDGs. A high share of family businesses in the total number of small and medium-sized private enterprises should be a priority of the policy promoting sustainable development of individual Member States, as well as the entire European Union.

Our research is not free of limitations related to the nature of the survey study. The sample selection was purposive, which, however, is typical for most studies on the functioning of enterprises. We included in the sample all those who agreed to participate in the survey, and the percentage of refusals to participate in the study did not exceed 5%. The authors are aware of the limitations of such a study related to the composition of the sample and the sampling process. Our sample is not representative and limited to non-listed companies. Research limitations, however, indicate the direction of future research. It is recommendable to conduct this research on a bigger sample of representative companies, or maybe even on an international scale. Additionally, we believe that in the transformation process towards sustainable goals, some friction may appear. As friction is difficult to investigate with economic methods, we might implement econophysics methods devoted to the efficiency of dynamic process calculations [100].

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Directions and Prospects for the Development of the Electric Car Market in Selected ASEAN Countries

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Abstract: The purpose of this article is to present the current situation and evaluate the opportunities for the development of the electric car market in selected Southeast Asian countries in the context of the current situation in the rest of the world. Currently, the electric car market is at an advanced stage of development in regions such as Western Europe, the USA, and China. It should be noted, however, that the number of electric cars in a given country results not only from market demand and access to vehicle charging networks but also from nonmarket mechanisms such as subsidies and tax or administrative solutions. It turns out that these are important elements that influence the final shape of a country's market. This article analyses the current situation on the electric car market taking into account the legal, administrative, and tax conditions that affect the final number of vehicles and the infrastructure necessary for the operation and use of electric cars in selected Asian countries.

Keywords: electric cars; Asia; ASEAN; tax incentives; development forecasts

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1. Introduction

Despite the negative impact of the COVID-19 pandemic on many spheres of daily economic life, electric car sales and the construction of infrastructure for their charging and use are accelerating worldwide. Around the world, governments and representatives of vehicle manufacturers alike are recognising that the transition to electric vehicles can be an opportunity to simultaneously pursue two fundamental, often mutually exclusive, goals, namely economic growth and sustainable development that address issues related to the reduction in negative environmental impact [1].

In Southeast Asia, as in other regions, the benefits of vehicle electrification are tangible and widespread. In addition to favourable regulations, governments desire to fulfil obligations regarding the changes in climate, reduction in pollution (including air), and visible improvement of energy supply security. It should also be noted that the Asian market offers many possibilities due to the presence of well-established automotive manufacturing centres in countries such as Korea, Japan, Indonesia, and Thailand [2].

This article attempts to analyse the current market situation in selected Asian countries and presents potential directions of development. Furthermore, this article presents the benefits of transition to electric cars [3]. When exploring electric vehicles, it is important to consider how to deal with the growing global demand for vehicles and, thus, fuel consumption and air pollution, as well as emission of greenhouse gases and other harmful substances such as particulate matter (PM), nitrogen oxide (NO_x) and sulphur oxide (SO_x) in some urban areas. Gradually deployed EV technology can ultimately lead to improved energy efficiency and positively impact the environment and human health [4].

However, it should be clearly indicated that the source of electricity generation is the most important factor for electric vehicle policy, and in some cases BEV production may emit more CO_2 than conventional vehicles [5]. For example, a joint research project

between Mazda and Kogakuin University estimated the CO_2 emission of conventional and electric vehicles in Japan, China, Australia, Europe, and the USA [6]. The results of the study showed that BEVs in Australia do not emit less CO_2 than conventional vehicles due to the country's heavy reliance on fossil fuels for electricity generation. In Japan, China, Europe, and the USA, some conventional vehicles, under certain conditions, generated less CO_2 than BEVs. Thus, the implementation of electric vehicle development policy must be comprehensive, taking into account a number of economic, environmental, technological, and administrative and legal factors [7].

The article is an innovative attempt to analyse, evaluate, and present possible prospects for the development of the electric vehicle market of the ASEAN group of countries from various perspectives (regulations, consumer approach, infrastructure challenges, etc.). Although these countries are relatively rich and developed, they remain, at least in the electric car market, overshadowed by China, which has quickly become not only a local but also a global leader in this industry.

It is worth noting that China, Korea, and Japan have recently announced a number of targets for the decarbonisation and complete elimination of conventionally powered vehicles in the upcoming decades. Other countries in the region, including in particular ASEAN countries, are expected to make similar decisions. This, in turn, will mean a rapidly progressing revolution both in the overall industry and in other sectors of the economy, including an important branch—transport.

Changes, apart from the progressive decisions of individual governments, will also be forced by global decisions made at cyclical climate conferences, which define various goals. ASEAN, which is an organization of economic and political cooperation between 10 countries, can be expected to take coordinated actions, such as those undertaken in Europe by the European Union, imposing specific and ambitious climate goals on individual members within the electric car industry.

The article presents collective data from specialist studies, reports, and analyses. The study was supplemented with an analysis of the literature using the methods of deduction and inference as well as a data analysis comparison method. The article combines the use of scientific methods with quantitative data from industry reports.

Prior to analysing the situation of electric vehicles, including data on the volume of sales and the structure of the electric car market, as well as legal and administrative conditions for the operation of infrastructure related to electric vehicles, first of all, it is important to draw attention to the definition of an electric car [8]. This is because different agencies and research institutes define this concept differently [9]. With the above in mind, it should be acknowledged that among the cars that today are, in principle, considered to be electric cars, three basic types of vehicles can be distinguished. These include the following types of vehicles [10]:

- BEV (Battery Electric Vehicle)—an all-electric vehicle with an installed battery, which is the sole source of power;
- PHEV (Plug-in Hybrid Electric Vehicle)—a hybrid vehicle (i.e., with a gasoline internal combustion engine and an electric motor) with the possibility to recharge electricity from the grid;
- FCEV—Fuel Cell Electric Vehicles—cars powered by hydrogen fuel cells. Such cars, similar to BEVs, use an electric motor, but they acquire energy in a completely different way. Instead of charging a battery, the FCEV stores hydrogen gas in a tank. The fuel cell in the FCEV combines hydrogen with oxygen from the air. The energy created as a result of this reaction reaches an electric motor that powers the vehicle as is the case in BEVs; and
- HEV Hybrid Electric Vehicle)—a hybrid vehicle without the ability to recharge electricity from the grid (electricity is generated by installing a traditional internal combustion engine in the vehicle).

The HEV group does not allow the car to be recharged from an external source (the primary driving motor is the combustion engine, while the electric motor is only a

supporting unit—the energy to power it is acquired from the vehicle's braking—so-called hybrid vehicles) [11]. For the purpose of this article, the authors only considered the first three types of vehicles, i.e., BEVs, PHEVs, and FCEVs. However, it is worth noting that the production and sales of FCEVs is very small, and often the number of these vehicles is not even included in official statistics (Figure 1).

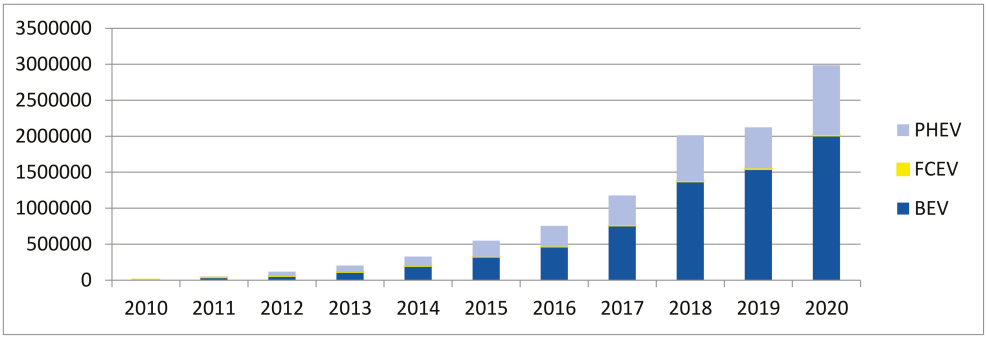

Figure 1. PHEV, BEV, and FCEV sales cars worldwide, 2010–2020. Source: https://www.iea.org/articles/global-ev-data-explorer (accessed on 10 October 2021).

2. Current Situation in Global Markets

According to data from the International Energy Agency (IEA), sales of various electric vehicles amounted to three million in 2020. Currently, China has the largest electric vehicle market, boasting 1.29 million EVs sold in 2020, which is an 8.3% year-over-year increase and constitutes as much as 40.5% of global sales in 2020 (Figure 2) [12].

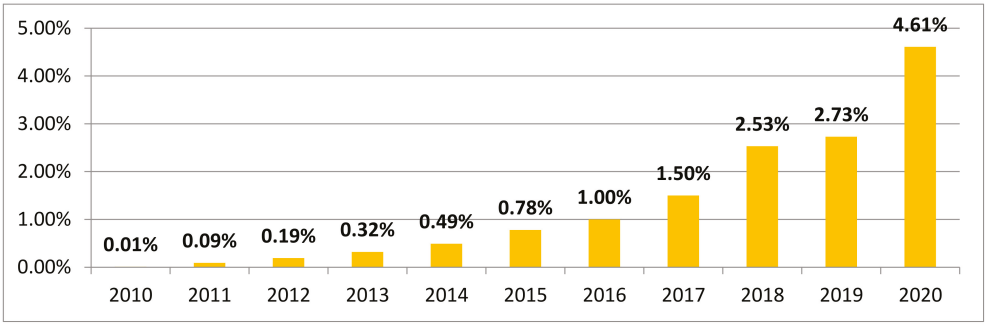

Figure 2. EV sales' share among cars worldwide, 2010–2020. Source: https://www.iea.org/articles/global-ev-data-explorer (accessed on 10 October 2021).

By the end of 2020, a total of 10 million electric cars had been registered worldwide. In 2020, electric car registrations increased by 41%, despite a pandemic-related worldwide decline in car sales, which saw global car sales drop by 16% [2].

It should be noted that in 2020 electric cars were reported to account for 4.61% of total passenger car sales globally. This was, however, mainly thanks to the European market (in Europe, the share of electric vehicles in new car sales in 2020 was 10%); in Norway the share in vehicle sales reached a record value of 75%, that is about 30% more than in 2019 [13]. High shares of electric car sales were also recorded in Iceland (50%), Sweden (30%) and the Netherlands (25%) (Figure 3) [2].

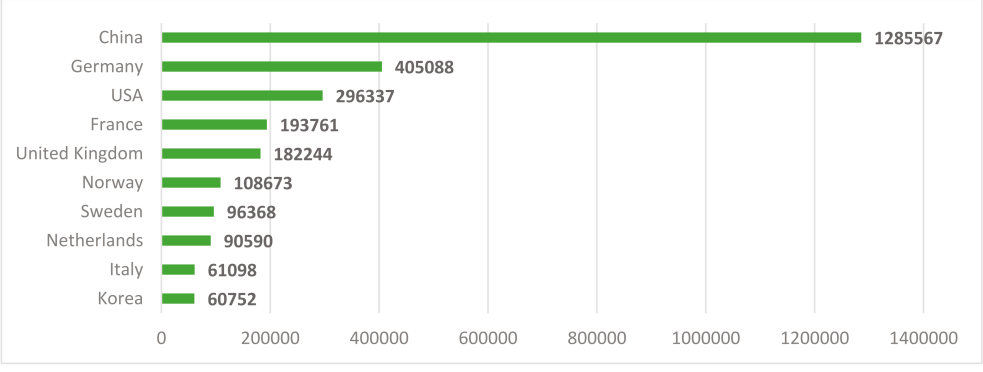

Figure 3. Top ten markets for electric vehicles by unit sales in 2020. Source: https://www.iea.org/articles/global-ev-data-explorer (accessed on 10 October 2021).

Outside China, it is Europe and the USA that account for the largest sales volume. Among the top 10 electric car consuming countries in 2020, there was only one Asian country, i.e., South Korea. Interestingly, in 2020, the European conventional vehicle market saw sales decline by 22%. Yet electric car registrations more than doubled to 1.4 million. This means that the electric car market was clearly immune to the negative effects of the COVID-19 pandemic. Currently, the highest sales volume in Europe was recorded in countries such as Germany, France, Great Britain, and Norway. For years, Norway had occupied first place; however, due to the rapid increase in the number of electric vehicles in the country in recent years, the Norwegian market has saturated and demand has decreased (Figure 4) [2,13].

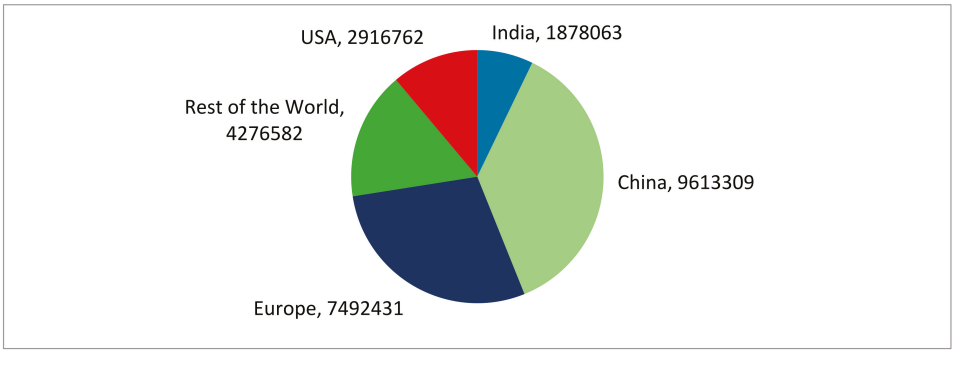

Figure 4. Global electric vehicle sales: market share in 2030 (forecast). Source: https://www.ubs.com/global/en/asset-management/insights/emerging-markets/2021/electric-vehicles-asia-investing.html (accessed on 10 October 2021).

China is projected to become the worldwide largest electric vehicle market by 2030, based on IEA forecasts of annual sales of 9.61 million of EV. It should be noted that the forecasts do not cover regions such as South America, Africa, and other Asian countries (Figure 5) [14].

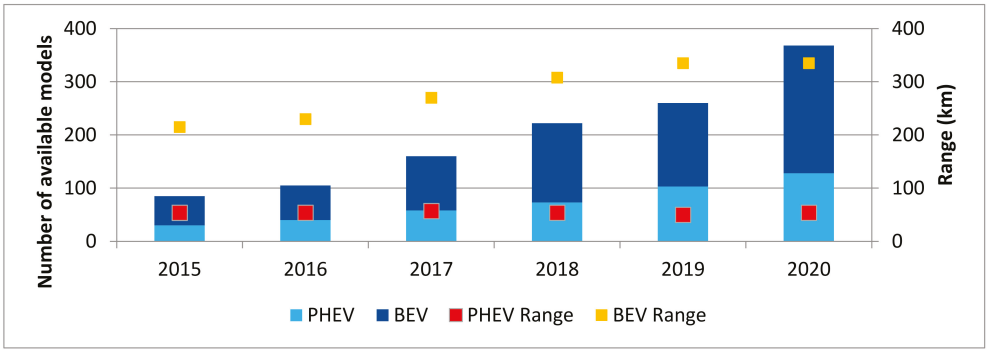

Figure 5. Electric car models available globally and average range, 2015–2020. Source: https://iea.blob.core.windows.net/assets/ed5f4484-f556-4110-8c5c-4ede8bcba637/GlobalEVOutlook2021.pdf (accessed on 10 October 2021).

It should also be emphasised that electric vehicle sales continue to grow even in the face of the pandemic due to three key factors [15–17]:

1. Support in the form of legal and administrative regulations—many countries are increasing the environmental requirements for new vehicles sold, which naturally promotes low-emission vehicles. Further, in 2020, more than 40 countries (including EU countries) announced that they would soon introduce a policy to phase out vehicles with conventional engines, up to and including a complete ban on their sale (it is forecasted that by 2035, the two key markets of China and Europe will be affected by this ban).
2. Additional tax incentives and direct subsidies to boost or maintain the levels of electric vehicle sales (some European countries have increased economic incentives; China, for example, has delayed withdrawing its subsidy programme).
3. Continuous increase in the number of EV models on offer, decrease in battery manufacturing costs (an important part of the total cost of a vehicle), increase in vehicle range, and increase in the number of publicly available chargers.

Not without significance is the last abovementioned factor, namely the growing number of available models and increasing vehicle range [18]. Until a few years ago, the range of an electric vehicle (BEV) oscillated around 200 km, which made such a car unsuitable outside a city. Now that the average range of this type of vehicle has increased significantly, it positively affects decisions on the purchase of this type of car. In addition, potential buyers also have the option to choose from a growing number of models offered [19].

For the promotion of electric vehicle deployment policy, it is also important that these cars are considered environmentally-friendly. Below is a graph showing the overall environmental benefits of introducing electric cars.

It should be noted that with each passing year the amount of conventional fuel saved increases but so too does the demand for electricity needed to charge the cars. At this point, it should be stressed that for an electric car deployment policy to be considered ecological, it is also necessary to obtain electricity from renewable or low-emission energy sources. Otherwise, electric cars cannot be considered fully zero-emission and environmentally friendly (Figure 6) [20].

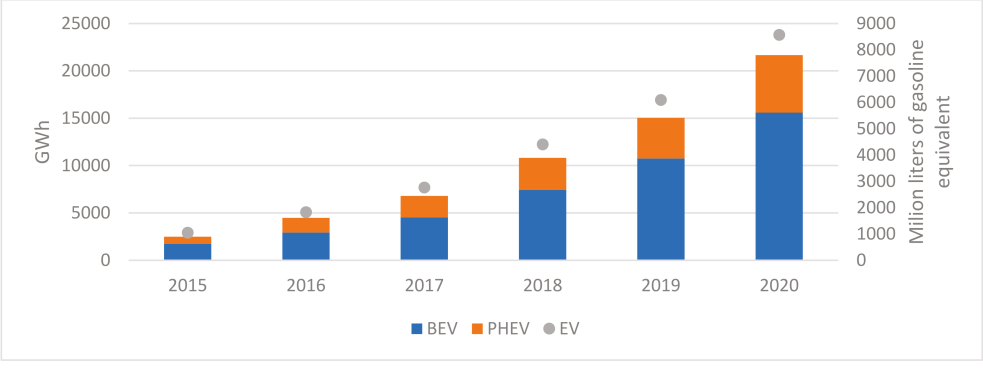

Figure 6. Electricity demand vs. oil displacement among cars, worldwide between 2015 and 2020. Source: https://www.iea.org/articles/global-ev-data-explorer (accessed on 10 October 2021).

3. Analysis of the Situation in Selected Southeast Asian Countries

As mentioned before, there are several key countries in the global electric car market at present. Some countries have achieved high sales volume through extensive policy to support vehicle purchase and maintenance (e.g., government subsidies, tax incentives, as well as participation in the construction and upkeep of a publicly accessible electric car charging infrastructure) [8]. It should be noted, however, that a number of countries are not even mentioned in multiple reports and statistics because of negligible or virtually nonexistent sales of electric vehicles (often not exceeding even a 0.1% share in total car sales) [21].

Currently and, as forecasts assume, also in the near future, China will remain the world leader in electric vehicle sales. In Asia, however, unlike in Europe, there are no strong international organizations that would firmly harmonize individual economic processes. Nevertheless, individual countries of Southeast Asia see both bottom-up and group processes for implementing policy to promote electric vehicles [22].

The largest organization of Southeast Asian countries is the Association of Southeast Asian Nations (ASEAN). Currently, the group comprises 10 countries—Philippines, Indonesia, Malaysia, Singapore, Thailand (founding members—1961), Brunei (since 8 January 1984), Vietnam (since 28 July 1995), Laos and Myanmar (since 23 July 1997), and Cambodia (since 30 April 1999) [23]. Interest in electric vehicles among the ASEAN countries is growing. However, there is a shortage of accurate statistics related to electric car sales [24]. According to the ASEAN Automotive Federation, a specialized agency that analyses the automotive market, in 2019, the total volume of electric vehicle sales in ASEAN member states was 3.4 million in 2019. However, this number includes HEVs, which are not analysed in this article. Some of the member states have attempted to define desired directions for the development of the electric car market. In the following discussion, the authors of this study present the current and planned achievements in the deployment of electric cars in selected ASEAN countries, as well as in some countries that have also prepared specific policies in this area [25].

When analysing the current situation of the electric vehicle market in selected ASEAN countries, it should be noted that, firstly, access to data is significantly limited, and secondly, market development is at a very early stage (Table 1).

Table 1. Sales volume in selected ASEAN countries and countries of the region.

Group	Country	2015	2016	2017	2018	2019	2020
PHEV	Japan	12,413	5365	31,504	19,761	14,965	11,315
EV		10,356	15,203	17,441	26,127	20,424	12,976
FCV		411	1055	849	575	644	717
PHEV	Korea	273	281	233	3434	2436	8548
EV		3025	5483	13,766	30,100	29,480	33,342
FCV		0	80	61	17	0	79
PHEV	Taiwan	0	0	0	0	0	0
EV		20	2	14	40	71	31
PHEV	Thailand	0	0	17	0	13	1
EV		0	0	0	0	126	1071
PHEV	Malaysia *	0	0	0	0	0	0
EV		11	95	0	0	0	0
PHEV	Indonesia	0	0	7	1	4	82
EV		0	0	0	0	0	5
PHEV	Philippines	0	0	12	3	19	21
EV		0	0	0	0	1	0
PHEV	Singapore						
EV		2	5	236	185	281	22
PHEV	India	0	0	0	0	0	0
EV		0	0	0	434	50	1148
PHEV	Australia	69	32	29	206	563	540
EV		286	134	120	202	675	830
PHEV	New Zealand	0	0	0	0	0	0
EV		21	24	244	254	802	593

* Limited access to data from Malaysia, which may mean that it is not accurate between 2017 and 2020. Source: https://www.marklines.com/en/vehicle_sales/search_country/search/?searchID=1701312 (accessed on 4 November 2021).

As can be seen from the presented data, the highest sales have been recorded in countries such as Japan and Korea (and Thailand from ASEAN countries), the lowest in Philippines and Indonesia [26].

Due to limitations in access to data, the authors decided to present countries not belonging to the ASEAN group, such as India, New Zealand, Australia, and Japan, since these are countries from the same region characterized by a similar level of development. Therefore, comparisons can be made to a limited extent.

It is thus worth noting that ASEAN, as an organization promoting cooperation in the region, can build common policies for supporting and promoting the purchase of electric vehicles, taking advantage of the common competitive advantage and the synergy effect.

In addition, in most of the ASEAN countries, consumers tend to choose alternative versions of vehicles such as two-, and three-wheeled units that are not listed as a typical electric car (Table 2).

ASEAN countries have different levels of wealth, calculated as nominal GDP and GDP per capita. The level of the most important economic indicator characterizing the level of wealth of a country and its citizens has a significant impact on consumer decisions, including the decision to buy an electric vehicle, which is usually more expensive than a traditional vehicle. The fact that wealth is extremely differentiated in the analysed countries will also undoubtedly affect the tendency of individual consumers to purchase an electric

vehicle. It should be assumed that in countries where GDP per capita is low (Cambodia, Myanmar, and Laos), the propensity to buy an electric vehicle will be much lower than in countries with high GDP per capita (Singapore, Brunei, and Malaysia). Such inference may be an oversimplification, and the decision to purchase an electric vehicle will be influenced by a number of other factors, which are analysed below [27].

Table 2. GDP and GDP per capita in ASEAN countries in 2020.

	Country	Population in Million	GDP Nominal (Millions of USD)	GDP Nominal (per Capita USD)
1	Indonesia	272.270	1,158,783	4256
2	Thailand	69.947	538,735	7702
3	Philippines	110.432	402,638	3646
4	Malaysia	33.358	387,093	11,604
5	Singapore	5.840	374,394	64,103
6	Vietnam	98.328	354,868	3609
7	Myanmar	53.545	76,195	1423
8	Cambodia	15.836	27,239	1720
9	Laos	7.371	2044	2773
10	Brunei	0.461	15,278	33,097
	ASEAN in total	667.393	3,355,655	4849

Source: World Economic Outlook database: April 2021, International Monetary Fund. https://www.imf.org/en/Publications/WEO/weo-database/2021/April/weo-report (accessed on 1 November 2021).

3.1. Brunei

Currently, Brunei has a small fleet of electric vehicles. The latest available data show that in 2017 only 18 BEV units were registered in the country (the total number of cars in the country was about 300,000) [21].

Therefore, when comparing this data with the total number of vehicles, the share of electric vehicles in the overall automotive market is symbolic. Brunei has made an attempt to promote electric vehicles as a part of the Land Transport Master Plan (LTMP) of 2014 [28]. This strategy includes goals to be achieved by 2035.

Currently, a new policy of The Brunei Darussalam National Council on Climate has been introduced. This is the first comprehensive climate policy of the country. The main goal is to increase the share of electric cars to 60% of the total amount of vehicles, but a specific date was not mentioned in the strategy [29].

Brunei's electric vehicle policy can only change if the government of the country changes its energy policy, including electricity generation, and pursues renewable energy sources.

3.2. Indonesia

In Indonesia, attempts have been made to implement electric vehicle policies. In 2012, then President Yudhoyono was a supporter of the idea of a national electric vehicle to be developed by the national universities. The next president, Joko Widodo, also supports the introduction of electric cars in the country [21].

Indonesia is also postulating legal and tax advantages for EV buyers, e.g., reduced VAT, luxury vehicle and goods tax, and import duties. It should also be pointed out that electric vehicles can be supported under the existing Low Carbon Energy Programme (LCEP) [30].

In 2019, President Widodo introduced a law on the promotion and support of electric vehicles. Competing with Thailand, Indonesia wants to establish an electric vehicle centre in the region by providing tax incentives and legal and administrative facilitation for potential HEV and PHEV manufacturers [31].

The Indonesian market focuses currently on the so-called electric two-wheeled units (mainly motorcycles) rather than on cars. There were nearly 16,000 such units in 2019.

It would be difficult for Indonesia to quickly increase the number of electric cars, as the charging infrastructure has only 20 charging station in the country—all of which are state-owned.

When analysing Indonesia's policy, it is important to acknowledge that the country has formulated a specific scope of action. Its potential has also been recognised by international automotive corporations such as BYD, Hyundai, JAC, and Toyota, which plan to start producing electric cars or components (batteries, motors) in the near future.

3.3. Malaysia

Compared with other countries of the region, Malaysia launched a policy to support the purchase and maintenance of electric vehicles early. Proposals to support this market were included back in 2009 as a part of the National Green Technology Policy.

The policy is based on four pillars that represent energy, environment, economy, and a social perspective. The strategy notes that the support for EVs is considered to be a part of a major transformation towards a sustainable economy and society [32]. The Malaysian government has adopted specific objectives, which covered, in particular, the construction of a charger network and the total number of electric vehicles in the country. However, the implementation of the assumed policy is at risk, as most of the goals have not been achieved so far, and the achievement of some of the goals (such as the vehicle fleet or the construction of a common charging network) has been postponed from 2020 to 2030 [33].

Currently in Malaysia there are 500 available charging points [34]. However the government has ambitious plans to install up to 25,000 public and 100,000 charging points by 2030 [35].

3.4. Philippines

In the Philippines, EVs have been supported by public policy since 2006. This could be characterized as very early in comparison to other countries of the region. The early regulations allowed duty-free import of EV components to encourage local manufacturing. While it would seem that the country would gain an early advantage in the region due to the rapid implementation of measures, this has not been the case. As the analysis shows, in 2006, the Philippines only granted benefits for suppliers, without addressing issues of demand or infrastructure. What is more, in 2014, further measures were implemented to support the production of electric vehicles. This strategy entitles investors to a six-year tax exemption, among other things.

However, this means that the country seeks foreign investment or public-private partnerships, rather than being interested in supporting domestic demand for the purchase and maintenance of electric vehicles. Indeed, it should be noted that currently the charging infrastructure is largely absent and the market itself should be described as undeveloped. Moreover, the experience so far does not give rise to optimism. For example, at the beginning of the decade, the government initiated a program to subsidize the purchase of three-wheeled EVs. The program was supported by the Asian Development Bank (ADB) and the World Bank's Clean Technology Fund, as well. It was assumed that, by the end of 2017, a fleet of 100,000 three-wheeled alternative fuel vehicles would be replaced with similar electric vehicles. However, the program was halted in 2016 after 3000 three-wheeled EVs were produced but did not attract drivers, because the initial costs and maintenance proved too expensive for operators. Another major reason for the failure was the insufficient number of charging stations in the planned deployment areas in Manila.

Moreover, there is also a narrow selection of electric vehicles in the Philippines, as the country's existing electric vehicles have been distributed mainly by the Chinese manufacturer BYD. Thus, it should be pointed out that at this stage the Philippine government is mainly interested in attracting foreign investors willing to manufacture EVs and their components in the country, rather than in supporting local individual demand.

3.5. Singapore

Singapore adopted an electric car policy relatively late, i.e., 2021, with financial incentives mainly. However, in early 2010, the national Land Transport Authority (LTA) and the Energy Market Authority (EMA) initiated a series of tests and feasibility studies for specific scenarios [36]. However, apart from the abovementioned measures, so far no detailed strategy for electric car deployment has been defined [37].

According to LTA data, all electric vehicles constituted a fraction of the 930,000 vehicles in total (2018 data). In 2020, as few as 1125 electric vehicles were registered in the country. So, despite Singapore being one of the richest countries in terms of GDP per capita, still relatively expensive electric vehicles remain only a niche product [21].

The low share of PHEVs and BEVs in the EV fleet may be due to the low availability of common charging stations. Currently, there are 1800 publicly available charging points with ambitious plans to increase the number to 60,000 by 2030 [35].

Recently, the Singaporean government has implemented several measures that support the use of electric vehicles. The country's government allowed the French Bolloré20 Group to launch a car-sharing service. The service, called blueSG, debuted in December 2017 and aims to deliver 1000 BEVs. The French investor additionally decided to install 2000 charging points (divided into 500 charging stations) across the country by 2020, 400 of which should be available not solely to the company's customers [38].

In addition, LTA has begun to shift its public transport procurement policy to electric vehicles. LTA has purchased, inter alia, 50 hybrid buses and plans to acquire 60 BEV buses [39].

Further, the Singaporean government adopted legislation that increased the cost of purchasing cars with conventional engines through additional fiscal burdens. This has resulted in an increase in hybrid vehicle sales but has not directly translated into a rise in the number of electric vehicles in the country [40].

Meanwhile, the government in Singapore imposed a law to stop issuing new registrations for diesel cars from 2025 and announced that internal combustion cars will be withdrawn from the country by 2040 [38].

3.6. Thailand

Thailand is a significant car manufacturer—across the globe (according to the International Organization of Motor Vehicle Manufacturers—OICA [41]). Therefore, when constructing a policy for the deployment of electric cars, the country must pay attention to its own automotive market whilst also offering a number of amenities for potential buyers. First, Thailand has revised taxation in a way that makes electric vehicles more attractive to consumers (excise tax is no longer based on motor size but on CO_2 emission, which led to much lower taxes on electric cars and hybrids). In addition, and somewhat against protecting its national automotive market, Thailand has decided to abolish duty on all-electric vehicles imported from overseas [42].

However, it should be noted that a number of incentives have been created to encourage vehicle manufacturers in Thailand. Special administrative and tax facilitations are provided for manufacturers (exemption from corporate income tax for eight years with the possibility of extension for additional years if production scales up), but the potential investor must ensure the production of at least 100,000 vehicles or a certain number of other components (batteries or motors for HEVs, PHEVs, BEVs, and FCEVs) [21].

In addition, the Thai government also wants to attract electric bus manufacturers by exempting companies from income tax for three years (extendable for another three years if production scales up) and reducing import duties on machinery needed to start production [43].

From the infrastructure point of view, Thailand had about 647 charging points in 2020. These were operated by 10 companies [37]. Due in part to this, Thailand has currently one of the largest fleets of EV in the analysed ASEAN countries region.

In 2020, Thailand expanded its electric vehicle development plan, which aims to produce 250,000 electric vehicles and develop an ASEAN electric vehicle hub by 2025 [44].

4. Key Considerations for the Development of the Electric Car Market in Southeast Asia

The final shape of the electric vehicle market depends on many factors, and the most important of them include:

4.1. Total Cost of Ownership (TCO)

TCO is the most important indicator influencing vehicle purchase decisions for both private and fleet customers. The indicator is affected by, among other things, taxes, electricity costs and, above all, vehicle price and its maintenance costs (repairs, servicing, and inspections). It should be noted that Southeast Asia will have to follow the example of other countries and introduce new forms of financing facilities as well as increase the price competitiveness of TCO through direct state involvement, e.g., by reducing taxes or introducing tax relief mechanisms [45].

4.2. Battery Range and Life

This is a key element that affects the ability to use the vehicle, especially outside of the city. As already mentioned, the range of electric cars is increasing, which is an optimistic indicator. It should be noted, however, that the problem for consumers may be the vehicle charging time, which, depending on the technology used, varies between 20 min and several hours [46].

4.3. Charging Networks

The availability of charging infrastructure (especially the so-called fast chargers) is the main factor affecting the development of electric vehicles. To increase interest in these vehicles in Southeast Asian countries, individual governments should consider co-funding private charging stations, and, in the early stages of the market development, fund stations in key urban locations and between cities (e.g., on motorways) [47].

4.4. Regulatory Environment and Subsidies

In European markets and the USA, which have some of the highest sales volumes, the increase in sales has often been the result of government intervention and not solely a consequence of price, functionality of the vehicles, or construction and financing of charging infrastructure. International examples show a significant acceleration of the EV market development upon the launch of direct subsidies for EV purchases. Economic priorities are usually considered to be in conflict with the environment and climate. However, for many Southeast Asian economies, the transition to automotive electrification is undoubtedly an opportunity to achieve their goals in both these dimensions simultaneously [8].

It should be noted that the first attempts to introduce and promote electric vehicles can be traced back to the 1990s. The forerunner of these measures was Norway, which is also an example of a country where stimulating the demand for electric cars through a package of national regulations yielded very good results. The country's electric car history began in 1994, when Norwegian corporation PIVCO began using 12 EVs to service the 1994 Winter Olympics in Lillehammer [48]. The first incentives from the government started appearing soon after: in 1996, the registration fee was reduced; in 1997, EVs were exempted from road tax; in 2001, a 0% VAT rate was introduced; in 2003, bus lanes were made available for electric cars; and in 2009, construction of a public charging network began. In 2011, the first fast charger was installed in Norway [49].

It is worth noting that the vast majority of countries that record the highest levels of electric car sales tend to offer, especially at the beginning, a system of incentives of an economic and administrative nature for those who decide to purchase and use electric vehicles. It can be concluded that the introduction of special advantages causes more

consumers to decide to purchase this type of car, due to the fact that it is cheaper, and its use grants, among other things, access to zones that exclude regular traffic, or to publicly available charging terminals.

The subsidies are a key tool to maintain EV policy due to the higher costs of vehicles in most countries. For example, in 2021, Japan has set aside a budget of JPY 8 billion (USD 77.1 million) in electric vehicle subsidies, which can be used for up to JPY 800,000 (USD 7710) per vehicle to fund 10,000 BEVs [50]. Meanwhile, the USA provides a maximum of USD 7500 in federal and USD 1500–5000 in state grants per vehicle [51].

5. Consumer Survey Results in Selected Southeast Asian Countries

The consumer interest in electric vehicles is also the subject of much research and analysis. Until recently, no such studies had been conducted in Asian countries (Figure 7).

For example, a study carried out by Frost & Sullivan on behalf of Nissan showed that consumers in Southeast Asia are very enthusiastic about owning an electric vehicle [26,52]:

1. of the total respondents, 64% say they are more likely to consider an electrified vehicle than they were five years ago;
2. moreover, 66% believe they will inevitably adopt electrified mobility as a part of their lives in the near future;
3. finally, 37% say they would definitely consider an electrified vehicle as their next car purchase in the next three years.

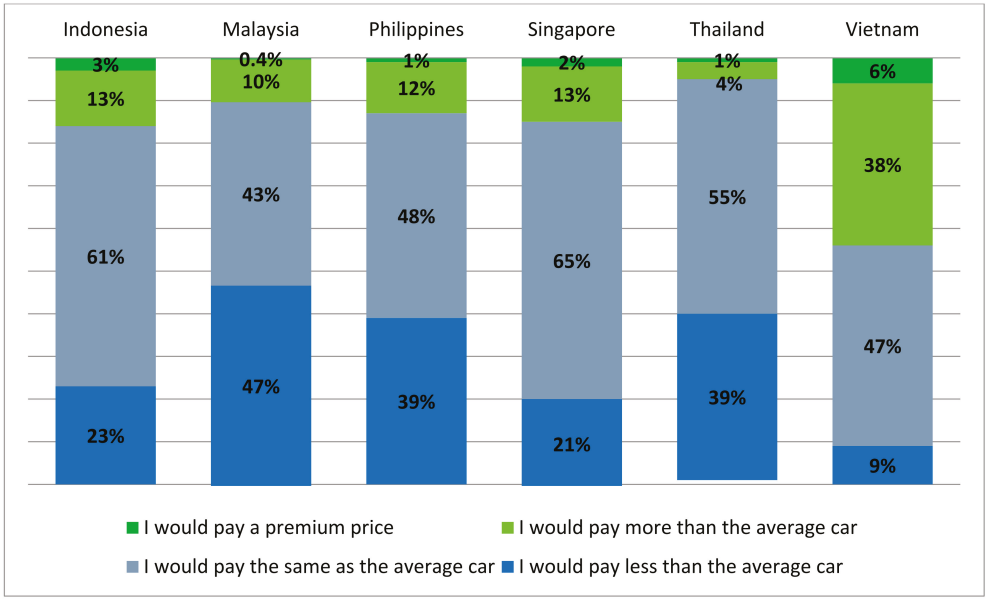

Figure 7. Consumers' expected EV price range after incentives in selected ASEAN countries. Source: https://www2.deloitte.com/content/dam/Deloitte/sg/Documents/strategy/sea-strategy-operations-full-speed-ahead-report.pdf (accessed on 4 November 2021) [53].

Other surveys, conducted by Deloitte, address issues of the main factors that influence the final purchase decision, among others [53].

It should be noted that the first and most important criterion for choosing an electric car is its price. As the results of the survey in the selected countries show, the majority of respondents believe that the price of an electric vehicle should be lower than or close to that of a standard vehicle. The vast majority of the respondents are not willing to pay a

premium price or significantly more than for a standard vehicle. The exception are the respondents in Vietnam, who are willing to pay a price higher than the price of a standard vehicle. Such survey results may indicate that a significant barrier in the development of electric vehicle market is the price, which is generally higher than that of standard vehicles (Figure 8).

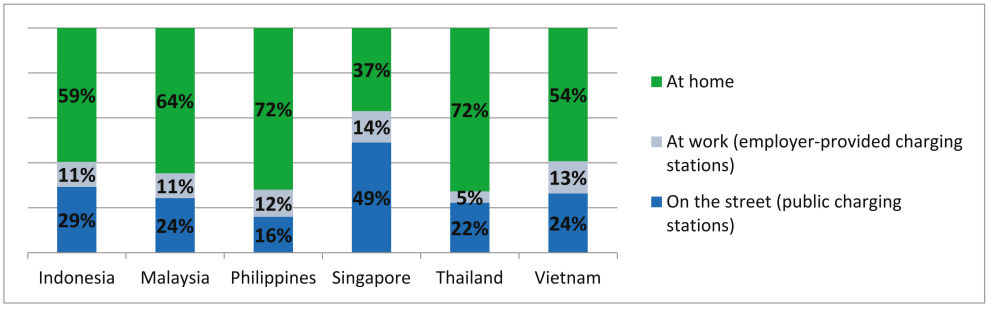

Figure 8. Consumers' expectations for the availability of EV charging facilities in selected ASEAN countries. Source: https://www2.deloitte.com/content/dam/Deloitte/sg/Documents/strategy/sea-strategy-operations-full-speed-ahead-report.pdf (accessed on 4 November 2021) [53].

A major factor inhibiting the development of electric vehicles is the charging method. As mentioned, depending on the technology used, charging takes from a dozen minutes (the so-called fast chargers—usually available in city centres) to a few hours (usually at home). As the survey results indicate, most respondents expect to be able to charge their vehicle at home. Different results were reported in Singapore, where the majority of respondents would like to be able to charge their car at public charging stations. This may be due to the specific urban structure of this city-state (Figure 9).

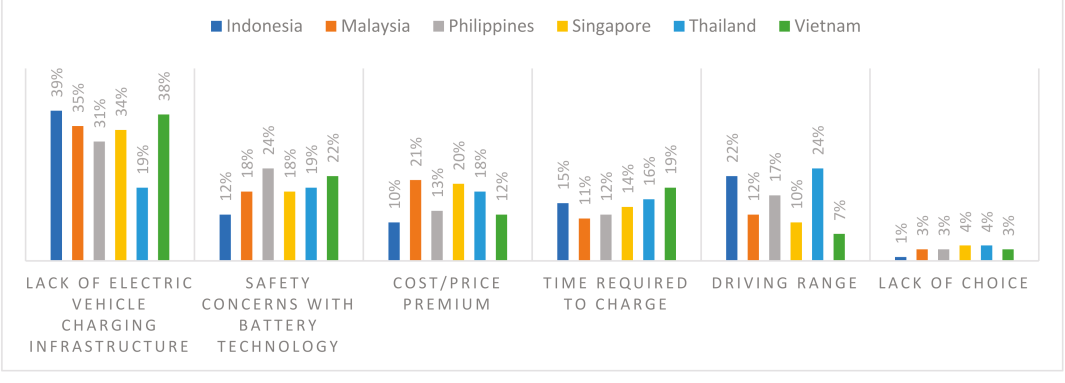

Figure 9. Consumers' top concerns for the adoption of EV in selected ASEAN countries. Source: https://www2.deloitte.com/content/dam/Deloitte/sg/Documents/strategy/sea-strategy-operations-full-speed-ahead-report.pdf (accessed on 4 November 2021) [53].

The survey also asked potential consumers about their top concerns associated with the purchase and use of electric vehicles. The most important concerns include (in order of mention):

- no charging infrastructure,
- safety issues related to battery use,

- vehicle purchase price,
- charging time,
- vehicle range, and
- small number of models available.

6. Conclusions

The development of the electric vehicle market in Southeast Asian countries, as in other regions of the world, depends on many factors. The most important ones include the cost of purchasing and maintaining a car, access to charging infrastructure, and other amenities for electric car users. Cost-effectiveness remains an important criterion for buyers when deciding to purchase a vehicle. The costs of acquiring and operating an electric car currently exceed the costs incurred in the case of combustion engine vehicles. With their experiences and highly developed industry, Southeast Asian countries have an opportunity to achieve excellent results. However, for this to happen, it is worth considering the introduction of incentives similar to those that have contributed to the rapid development of the market in some European countries. The most commonly mentioned incentives include: tax reduction, investor facilitation, user amenities, and, most importantly, government commitment to building and maintaining a widespread charging network. Due to the fact that Asia is a very dynamically developing region, it should be noted that the pace of development of the electric vehicle market may be very high.

An important issue concerning the ASEAN countries is the fact that within a united organization, these countries can impose, following the example of the European Union countries, common rules for introducing, supporting, and promoting electric vehicles. It should also be noted that ASEAN countries can imitate their neighbour, China, which has a strong and highly developed electric vehicle market.

Moreover, ASEAN countries such as Thailand and the Philippines are not only a potential demand market but also an important supply market, as they are already producing both electric vehicles and components such as motors and batteries.

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