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Editorial introduction

Since the early beginnings of the economic sciences, investments have been considered as one of the key drivers of economic growth. In turn, the effectiveness and resilience of investments depend on a variety of factors and circumstances, including the stance of financial and labour markets, and access to energy sources. These considerations form the main theme of the current issue of *Economics and Business Review*. It consists of seven articles written by eleven economists from four countries (Poland, Slovakia, Turkey and the United Kingdom). The authors delve into macroeconomic and microeconomic issues, and use both theoretical and empirical methods to address the research questions. It is hoped that the research findings will have resonance beyond the academic community.

The issue opens with a paper by Emil Panek (**"Very strong" turnpike effect in a non-stationary Gale economy with investments, multilane turnpike and limit technology**) that extends the existing literature on the Gale-type models of the economy in two dimensions. Firstly, it presents the non-stationary Gale-type model with investments and technology convergent to a certain limit. Secondly, it offers proof of the "very strong" turnpike theorem in such a model.

In their paper entitled **Analyst herding—whether, why, and when? Two new tests for herding detection in target forecast prices**, Callum Reveley, Savva Shanaev, Yu Bin, Humnath Panta and Binam Ghimire develop two novel tests to detect analyst herding that make use of binomial correlation and forecast error volatility scaling. These tests are then employed to explore the patterns of herding in analysts' target prices on the UK market in the years 2008–2020. Along with robust evidence of analysts' herding, it is also identified that its strength depends on *inter alia* volatility and uncertainty perceptions.

Wiktor Błoch's paper **What drives the savings rate in middle-income countries?** provides new empirical evidence for a subset of countries overlooked in earlier studies. A wide range of potential demographic and socio-economic determinants are considered. A significant positive effect is identified for the share of industry in GDP, while the unemployment rate, the share of labour compensation in GDP, military expenditure, inflation and the youth dependency ratio are found to exert a negative impact on the savings rate.

In the next paper, entitled **Russian aggression against Ukraine and the changes in European Union countries' macroeconomic situation: Do energy**

intensity and energy dependence matter?, its authors, Michał Wielechowski and Katarzyna Czech add empirically to the literature by exploring the variation in macroeconomic implications of Russian invasion of Ukraine among EU member states. They document that this variation is attributable to the country's energy vulnerability. This result could be of interest for policy makers.

The fifth paper in this issue, **Assessment of immigrants' impact on the Slovak economy**, by Raman Herasimau, contributes to the literature by applying a new analytical approach (the adjusted UN National Transfer Accounts (NTA) methodology) to a set of data collected from various sources. The results indicate that immigrants differ significantly from Slovak citizens in their labour and consumption patterns. The influx of migrants is found to have a positive impact on the Slovak's economy performance.

In his paper **Is value investing based on scoring models effective? The verification of *F*-Score-based strategy in the Polish stock market**, Bartłomiej Pilch extends the existing literature on financial market investment strategies. The testing ground for verifying the validity of *F*-Score, *FS*-Score and PiotroskiTrfm is the Polish stock market. The empirical evidence supports the claim that the measures under investigation are useful for investors.

The issue closes with an article entitled **A causal and nonlinear relationship between trade credit policy and firm value: Evidence from an emerging market** by Cengizhan Karaca. Its originality lies in the adoption of bidirectional analysis. The hypothesis of a nonlinear relationship between trade credit policy and firm value finds robust empirical support for the sample of manufacturing firms listed on the Borsa Istanbul.

Monika Banaszewska
Editor-in-Chief

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"Very strong" turnpike effect in a non-stationary Gale economy with investments, multilane turnpike and limit technology

Emil Panek[1]

Abstract

This article presents a multiproduct model of a non-stationary Gale-type economy with technology convergent to a certain limit technology, in which changes in the production technology (the dynamics of Gale production spaces) are governed by the size of investments. Thus, this model differs from the vast majority of Gale-type models considered in mathematical economy. With this assumption, the so-called "very strong" version of the multilane production turnpike theorem in the Gale economy with investments is proved. According to the theorem, if the optimal growth process in such an economy reaches the multilane turnpike, it remains on it from then on, with the possible exception of the last period of the economic horizon being analysed.

Keywords

- Gale economy with investments
- von Neumann equilibrium
- limit production space
- technological and economic efficiency of production
- multilane production turnpike
- turnpike effect

JEL codes: C62, C67, O41, O49

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Introduction

In multiproduct models of Gale economic dynamics, which are in the focus of interest of the turnpike theory, the productive potential of an economy is embodied in what are called production spaces (technology sets; the basics of the turnpike theory are explained, e.g., in: Makarov and Rubinov (1977), McKenzie (2005), Mitra and Nishimura (2009), Nikaido (1968, chapt. 4), Takayama (1985, chapters 6, 7). In the stationary models, they are constant in time, whereas in the non-stationary ones their shape is changing, though these changes are exogenous in nature. It is assumed that changes in technology determining the dynamics of the production spaces do not require any investments, they are God's/nature's gift of sorts and humans have no impact on the direction of these changes. In contrast, the article by Panek (2022) presents a model of the Gale economy in which the dynamics of the production spaces is determined by the investments undertaken for this purpose. It has been proven that in this type of economy the optimal growth processes "almost always" (always, except for a certain limited number of periods of time, independent of the length of the economy horizon) remain in any neighbourhood of the multilane turnpike. In the classical literature, these theorems are known as the so-called "turnpike theorems" (cf. Makarov & Rubinov, 1977, chapter 4, th. 13.3; Nikaido, 1968, chapter, 4, th. 13.8; Panek, 2000, chapter 5, th. 5.8, 2016, 2017), see also e.g. (Babaei, 2020; Babaei et al., 2020; Cartigny & Venditti, 1994; Dai & Shen, 2013; Giorgi & Zuccotti, 2016; Heiland & Zuazua, 2021; Jensen, 2012; Khan & Piazza, 2011; Majumdar, 2009; McKenzie, 1976, 1998; Sakamoto et al., 2019; Zaslavski, 2015). This article makes a direct reference to the above-mentioned work by Panek (2022). It presents some evidence for the "very strong" theorem about the multilane turnpike in a non-stationary Gale economy with investments and technology convergent to a certain limit. The theorem asserts that if during its optimal growth process an economy reaches a multilane turnpike, it remains there from that time, possibly except for the last period of its analysed time horizon. Both the Gale model of a non-stationary economy with investments and the proof of the "very strong" turnpike theorem in such a model are novel.

The structure of the paper is as follows: In Section 1 a model of the Gale--type economy with investments and limit technology is presented. The multilane production turnpike and optimal stationary growth process (production trajectory) are defined in Section 2. The conditions under which the optimal von Neumann equilibrium state exists in such an economy are presented in Section 3. The main result, i.e. proof of the "very strong" turnpike theorem in the Gale-type economy with investments and limit technology is in Section 4. The paper ends with conclusions and final remarks, which indicate possible directions of further research.

1. The model

The model we use is presented in detail in Panek (2022). An economy is considered in which time is discrete, $t = 0, 1, \ldots$ Let $x(t) = (x_1(t), \ldots, x_n(t)) \geqq 0$ denote the n-dimensional vector of the goods consumed during period t, and let $y(t) = y_1(t), \ldots, y_n(t)) \geqq 0$ denote the n-dimensional vector of the goods produced in this period; if $a, b \in R^n$, then the inequality $a \geqq b$ means that $\forall i \ (a_i \geq b_i)$, whereas $a \geq b$ means that $a \geqq b$ and $a \neq b$.

Vectors $x(t)$, $y(t)$ are called the vector of inputs and the vector of outputs, respectively. If, in time period t, the $x(t)$ input allows the output $y(t)$ to be obtained, then the pair $(x(t), y(t))$ describes a technologically feasible production process (in period t). The set of all the technologically feasible processes in period t is referred to as $Z(t)$. The notation $(x, y) \in Z(t)$ (or $(x(t), y(t)) \in Z(t)$) states that in period t outputs y can be produced from inputs x with the technology available in the economy. The production spaces $Z(t)$, $t = 0, 1, \ldots$ are assumed to satisfy the following conditions:

(G1) $\forall (x^1, y^1), (x^2, y^2) \in Z(t) \ \forall \lambda_1, \lambda_2 \geq 0 \ (\lambda_1(x^1, y^1) + \lambda_2(x^2, y^2) \in Z(t))$

(inputs/outputs proportionality condition and additivity of production processes).

(G2) $\forall (x, y) \in Z(t) \ (x = 0 \Rightarrow y = 0)$

(“no cornucopia” condition).

(G3) $\forall (x, y) \in Z(t) \ \forall x' \geqq x \ \forall y' \leqq y((x', y') \in Z(t))$

(a possibility of wasting inputs and/or outputs).

(G4) Production space $Z(t)$ is a closed subset of w R^{2n}_+.

Production spaces $Z(t)$, satisfying conditions (G1)–(G4), are referred to as Gale spaces. In accordance with (G1) and (G4), every Gale production space is a convex, closed cone in R^{2n}_+ with a vertex at 0. In compliance with (G2), if $(x, y) \in Z(t)$ and $(x, y) \neq 0$, then $x \neq 0$. We consider only nonzero (nontrivial) production processes $(x, y) \in Z(t) \backslash \{0\}$.

The production technology in the economy in period $t + 1$ will depend on the production technology in period t, as well as the investments $i(t) = (i_1(t), \ldots, i_n(t)) \geqq 0$ undertaken in period t but effective in the next period, as a result of the production carried out in period t:

$$0 \leqq i(t) \leqq y(t) \tag{1}$$

(for the sake of simplicity,we assume the annual investments cycle).

Let $\sigma(R_+^{2n})$ denote the family of Gale production spaces (convex cones closed in R_+^{2n}, satisfying conditions (G1)–(G4)). The dynamics of the technology is described by the recursive equation:

$$Z(t+1) = F_{t+1}(Z(t), i(t)) \tag{2}$$

in which the multifunction fulfils the following conditions:

(F1) $\forall t\ \forall Z \in \sigma(R_+^{2n})(F_t(Z, 0) = Z)$

(F2) $\forall t\ \forall Z \in \sigma(R_+^{2n})\ \forall i^1 \geqq i^2(F_t(Z, i^1) \supseteq F_t(Z, i^2))$

(F3) $\forall t\ \forall Z^1, Z^2 \in \sigma(R_+^{2n})\ \forall i \geqq 0(Z^1 \supseteq Z^2 \Rightarrow F_t(Z^1, i) \supseteq F_t(Z^2, i))$

Their interpretation is presented in the article by Panek (2022). The economy is closed in the sense that the inputs $x(t+1)$ (incurred in period $t+1$) may be derived exclusively from the outputs $y(t)$ (generated in the previous period reduced by the investments $i(t)$:

$$x(t+1) \leqq y(t) - i(t)$$

Hence, taking into account (G3), we obtain the following condition:

$$(y(t) - i(t), y(t+1)) \in Z(t+1) \tag{3}$$

The production space $Z(0)$ and also the initial production vector $y(0)$ are given:

$$Z(0) = Z^0 = R_+^{2n}, y(0) = y^0 \geq 0 \tag{4}$$

The triple sequences $\{y(t)\}_{t=0}^{\infty}$, $\{i(t)\}_{t=0}^{\infty}$ and $\{Z(t)\}_{t=0}^{\infty}$ satisfying conditions (1)–(4) are said to be (Z^0, y^0, ∞) – feasible growth process in the Gale economy with investments. The $\{y(t)\}_{t=0}^{\infty}$ sequence is referred to as (y^0, ∞) – feasible production trajectory, the $\{i(t)\}_{t=0}^{\infty}$ sequence – the investments trajectory (corresponding to (y^0, ∞) – feasible production trajectory). The $\{Z(t)\}_{t=0}^{\infty}$ sequence describes (Z^0, ∞) – feasible sequence of production spaces in the Gale economy with investments.

Consider any production process $(x, y) \in Z(t)\backslash\{0\}$. The number:

$$\alpha(x, y) = \max\{\alpha | \alpha x \leqq y\}$$

is called the technological efficiency rate of the process (x, y). Function α: $R_+^{2n} \to R_+^1$ is a positively homogeneous function of degree 0 on $R_+^{2n}\backslash\{0\}$ and (with assumptions (G1)–(G4)):

$$\forall t\, \exists(\overline{x}, \overline{y}) \in Z(t) \backslash \{0\} \left(\alpha(\overline{x}, \overline{y}) = \max_{(x,y) \in Z(t)\backslash\{0\}} \alpha(x, y) = \alpha_{M,t} \geq 0 \right)$$

Panek (2022, th. 1). If $\alpha\left(\overline{x}(t), \overline{y}(t)\right) = \alpha_{M,t}$, then the process $\left(\overline{x}(t), \overline{y}(t)\right)$ is called the optimal production process and number $\alpha_{M,t}$ – the optimal technological efficiency rate in period t in the Gale economy with production space $Z(t)$. Since the production spaces in (Z^0, y^0, ∞) – feasible growth processes satisfy condition $Z(t + 1) \supseteq Z(t)$, thefore:

$$\forall t(\alpha_{M, t+1} \geq \alpha_{M, t} \geq 0)$$

So as to exclude the unrealistic case of, on the one hand, zero optimal technological production efficiency in any period of time t, and, on the other, growth that is unlimited/infinite in time in technological production efficiency, it is assumed that:

(F4) (i) $\alpha_{M,0} > 0$

(ii) There is a convex closed set $Z \subset R_+^{2n}$, which contains all the sets (cones) $Z(t)$ belonging to any of the (Z^0, ∞) – sequences of the production spaces in any (Z^0, y^0, ∞) – feasible growth process.

(iii) Set Z is the smallest set satisfying condition (ii), so if $(x, y) \in Z$ and $x = 0$, then $y = 0$.

Under conditions (F1)–(F4), the set Z is a Gale space (satisfies conditions (G1)–(G4), Panek (2022, th. 2). It is called a limit production space. Condition $(x, y) \in Z$ means that in light of the limit technology, input x can be used to obtain production y. If $(x, y) \in Z\backslash\{0\}$, then number $\alpha(x, y) = \max\{\alpha | \alpha x \leqq y\}$ is called the technological efficiency rate of the process (x, y) in the Gale economy with limit technology (the limit production space). Number $\alpha(\overline{x}, \overline{y}) = \alpha_M = \max_{(x,y) \in Z\backslash\{0\}} \alpha(x, y)$ is called the optimal technological efficiency in the Gale economy with limit technology. With the assumptions made above, indicator α_M exists and $\forall t(\alpha_M \geq \alpha_{M, t+1} \geq \alpha_{M, t} > 0)$. If , then the process $(\overline{x}, \overline{y})$ is called the optimal production process in the Gale economy with limit technology.

2. Multilane production turnpike

Let

$$Z_{opt} = \left\{(\overline{x}, \overline{y}) \in Z \setminus \{0\} \,|\, \alpha(\overline{x}, \overline{y}) = \alpha_M\right\} \neq \varnothing$$

be a set of all optimal production processes in the Gale economy with limit technology. With the assumptions made, this set is a convex closed cone in R_+^{2n}, not including 0 and if $(\overline{x}, \overline{y}) \in Z_{opt}$, then also $(\overline{x}, \alpha_M \overline{x}) \in Z_{opt}$, as well as $(\overline{y}, \alpha_M \overline{y}) \in Z_{opt}$. The vector $\overline{s} = \frac{\overline{y}}{\|\overline{y}\|}$ is said to characterize the production structure in the optimal process $(\overline{x}, \overline{y}) \in Z_{opt}$ in the Gale economy with limit technology (more briefly: the optimal production structure). By:

$$S = \left\{ s \,|\, \exists\, (x, y) \in Z_{opt} \left(s = \frac{y}{\|y\|} \right) \right\}$$

we denote the set of vectors of the production structure in all the optimal processes in the Gale economy with limit technology; if $a \in R^n$, then $\|a\| = \sum_{i=1}^{n} |a_i|$, if also $a \neq 0$, then $\frac{a}{\|a\|} = \left(\frac{a_1}{\|a\|}, \ldots, \frac{a_n}{\|a\|} \right)$. It is noticeable that under conditions (G1), (G3), equivalently $S = \left\{ s \,|\, \exists (x, y) \in Z_{opt} \left(s = \frac{x}{\|x\|} \right) \right\}$. The set S is a nonempty under the same assumptions as the set Z_{opt} and it is convex and compact. If $s \in S$, then the ray:

$$N_s = \{\lambda s \,|\, \lambda > 0\}$$

is called a von Neumann ray (a single-lane production turnpike) in the Gale economy with limit technology. The bundle of turnpikes:

$$\mathbb{N} = \bigcup_{s \in S} N_s \ \left(= \left\{ \lambda s \,|\, \lambda > 0,\, s \in S \right\} \right)$$

is referred to as a multilane production turnpike in the Gale economy with limit technology. The multilane turnpike is a convex cone in R_+^{2n}, not including 0.

If, in the process $(x, y) \in Z(t) \setminus \{0\}$, or in the limit process $(x, y) \in Z \setminus \{0\}$ the structure of inputs $\frac{x}{\|x\|}$ or outputs $\frac{y}{\|y\|}$ is different from that in the turnpike, its technological efficiency is lower than the optimal one:

$$\left((x,y)\in Z(t)\setminus\{0\}\vee(x,y)\in Z\setminus\{0\}\right)\&\left(\frac{x}{\|x\|}\notin S\vee\frac{y}{\|y\|}\notin S\Rightarrow\alpha(x,y)<\alpha_M\right)$$

(Panek, 2022, lemma 1).

Taking the limit space Z and putting it in (2) $Z(0) = Z^0 = Z$ and $i(t) = 0$ for $t = 0, 1, \ldots$ we obtain $Z(t) = Z = \text{const}$. If $\overline{y} \in \mathbb{N}$, then also $(\overline{y}, \alpha_M\overline{y}) \in Z_{opt} \subset Z$ and (under (G1)) $(\alpha_M\overline{y}, \alpha_M^2\overline{y}) \in Z_{opt} \subset Z, \ldots$, etc. Then the sequence $\left\{\overline{y}(t)\right\}_{t=0}^{\infty}$, where:

$$\overline{y}(t)=\alpha_M^t\overline{y},\ t=0,1,\ldots \tag{5}$$

defines $(\overline{y}, \infty)$ – feasible production trajectory in the Gale economy with limit technology, the initial production vector $y(0) = \overline{y} \in \mathbb{N}$, investments trajectory $i(t) = 0$, $t = 0, 1, \ldots$, and the sequence of production spaces $Z(t) = Z = \text{const}$, $t = 0, 1, \ldots$ On trajectory (5), the economy achieves the maximum production growth rate α_M. The structure of production on trajectory (5):

$$\frac{\overline{y}(t)}{\|\overline{y}(t)\|}=\frac{\overline{y}}{\|\overline{y}\|}=\overline{s}\in S$$

is constant in all periods of time $t = 0, 1, \ldots$ The trajectory (5) is called an optimal stationary production trajectory. If $\left\{\overline{y}(t)\right\}_{t=0}^{\infty}$ is an optimal stationary production trajectory, then $\forall\lambda > 0$ also $\left\{\lambda\overline{y}(t)\right\}_{t=0}^{\infty}$ is an optimal stationary production trajectory. If $\left\{\overline{y}^1(t)\right\}_{t=0}^{\infty}$, $\left\{\overline{y}^2(t)\right\}_{t=0}^{\infty}$ are optimal stationary production trajectories, then their sum $\left\{\overline{y}(t)\right\}_{t=0}^{\infty}$:

$$\overline{y}(t)=\overline{y}^1(t)+\overline{y}^2(t),\ t=0,1,\ldots$$

is also an optimal production trajectory. All of them are located on the multilane turnpike $\mathbb{N}$.

3. Von Neumann equilibrium

Let $p = (p_1, \ldots, p_n) \geq 0$ denote a vector of prices and $(x, y) \in Z\setminus\{0\}$. Then $\left\langle p,y\right\rangle=\sum_{i=1}^{n}p_iy_i$ is the production value, and $\left\langle p,x\right\rangle=\sum_{i=1}^{n}p_ix_i$ the value of inputs in the process (x, y) (expressed in prices p). The number:

$$\beta(x,y,p)=\frac{\left\langle p,y\right\rangle}{\left\langle p,x\right\rangle}$$

($\langle p, x\rangle \neq 0$) is called the rate of economic efficiency of the process (x, y) (with prices p). If there prices $\bar{p} \geq 0$ and process $(\bar{x}, \bar{y}) \in Z\backslash\{0\}$ exist, such that:

$$\alpha_M \bar{x} \leqq \bar{y} \tag{6}$$

$$\forall (x, y) \in Z(\bar{p}, y \leq \alpha_M \bar{p}, x) \tag{7}$$

$$\bar{p}, \bar{y} > 0 \tag{8}$$

then the triple $\{\alpha_M, (\bar{x}, \bar{y}), \bar{p}\}$ is called an optimal von Neumann equilibrium state in the Gale economy with limit technology. Vector $\bar{p}$ is called a von Neumann (equilibrium) price vector. If the conditions (6)–(8) are fulfilled, then:

$$\beta(\bar{x}, \bar{y}, \bar{p}) = \frac{\langle \bar{p}, \bar{y}\rangle}{\langle \bar{p}, \bar{x}\rangle} = \max_{(x,y)\in Z\backslash\{0\}} \beta(x, y, \bar{p}) = \alpha(\bar{x}, \bar{y}) = \alpha_M > 0$$

therefore, the von Neumann equilibrium is a state of the economy, in which the economic efficiency equals the technological efficiency (at its highest possible level). Both the equilibrium prices $\bar{p}$ and the production processes $(\bar{x}, \bar{y})$ in equilibrium are defined up to the structure (i.e. up to multiplication by a positive constant). Under (G1)–(G4), (F1)–(F4), as well as under the following condition:

(FG1) $\forall (x, y) \in Z \setminus \{0\} \big(\alpha(x, y) < \alpha_M \Rightarrow \beta(x, y, \bar{p}) < \alpha_M\big)$

the optimal von Neumann equilibrium state exists (Panek, 2022, th. 3). Condition (FG1) means that in the Gale economy with limit technology a process that does not have the highest technological efficiency does not achieve the highest economic efficiency. Since $\forall t\big(Z(t) \subseteq Z\big)$, this condition also holds for any other production process $\big(x(t), y(t)\big) \in Z(t) \setminus \{0\}$ admissible in any period of time $t = 0, 1, \ldots$

4. The optimal growth processes. "Very strong" turnpike theorem

Let us set a time horizon $T = \{0, 1, \ldots, t_1\}$, $t_1 < +\infty$. Sequences of production vectors $\{y(t)\}_{t=0}^{t_1}$, investments $\{i(t)\}_{t=0}^{t_1-1}$ and production spaces $\{Z(t)\}_{t=0}^{t_1}$ satisfying conditions (1)–(4), are said to define (Z^0, y^0, t_1) – feasible growth process in the Gale economy with investments and limit technology. Sequence

$\{y(t)\}_{t=0}^{t_1}$ is called (y_0, t_1) – feasible production trajectory, sequence $\{i(t)\}_{t=0}^{t_1-1}$ – feasible investments trajectory (corresponding to (y^0, t_1) – feasible production trajectory). The sets (cones) $Z(0), Z(1), ..., Z(t_1)$ form (Z^0, t_1) – feasible sequence of production spaces. Under the conditions assumed, (Z^0, y^0, t_1), the feasible processes $\forall t_1 \leq +\infty$ exist.

Let $u : R^n_+ \to R^1$ be a utility function, defined on the production vectors in the last period t_1 of horizon T, satisfying the following conditions:

(U1) Function $u : R^n_+ \to R^1_+$ is continuous, positively homogenous of degree 1, concave and increasing.

(U2) $\exists a > 0 \, \forall y \in R^n_+ \left(u(y) \leq a\langle \overline{p}, y\rangle\right)$ and $\forall s \in S\left(u(s) = a\langle \overline{p}, s\rangle > 0\right)$

Under (U2), the standard utility function (satisfying condition U1)) can be approximated from above by a linear form with the vector of coefficients $a\overline{p}$, tangential to the graph of $u(\cdot)$ along the multilane turnpike $\mathbb{N}$. The subject of the paper is the following maximization problem of the target growth (maximization of the production utility in the final period of the horizon T):

$$\max u(y(t_1))$$
under conditions (1)–(4) (9)
(space Z^0 and vector y^0 – fixed)

(Z^0, y^0, t_1) – feasible growth process, a solution to this problem, is called (Z^0, y^0, t_1) – optimal process. The sequence of the production vectors in this process is called (y^0, t_1) – optimal production trajectory and is denoted by $\{y^\star(t)\}_{t=0}^{t_1}$. Corresponding to (y^0, t_1) – optimal production trajectory, the sequence of the investments vectors $\{i^\star(t)\}_{t=0}^{t_1-1}$ is called the optimal investments trajectory. $\{Z^\star(t)\}_{t=0}^{t_1}$ denotes the sequence of the production spaces in (Z^0, y^0, t_1) – optimal growth process. In accordance with (2), (4):

$$Z^\star(t+1) = F_{t+1}\left(Z^\star(t), i^\star(t)\right), \; t = 0, 1, ..., t_1 - 1,$$
$$Z^\star(0) = Z^0$$

Multifunction $F_t : \sigma(R^{2n}_+) \times R^n_+ \to \sigma(R^{2n}_+)$ is assumed to fulfill the following condition (of semi-continuity):

(FG2) If $\{y^k(t)\}_{t=0}^{t_1}, \{i^k(t)\}_{t=0}^{t_1-1}, \{Z^k(t)\}_{t=0}^{t_1}$ $(k = 1, 2, \dots, \infty)$ is such a sequence of (Z^0, y^0, t_1) – feasible growth processes that:

$$y^k(t) \underset{k}{\to} \overline{y}(t), \; t = 0, 1, \dots, t_1, \quad i^k(t) \underset{k}{\to} \overline{i}(t), \; t = 0, 1, \dots, t_1 - 1$$

($\overline{y}(0) = Z^0$) and:

$$\overline{Z}(t) = F_t\left(\overline{Z}(t-1), \overline{i}\,(t-1)\right), \quad t = 1, 2, \ldots, t_1$$

($\overline{Z}(0) = Z^0$), then the triple $\left\{\overline{y}(t)\right\}_{t=0}^{t_1}$, $\left\{\overline{i}\,(t)\right\}_{t=0}^{t_1-1}$, $\left\{\overline{Z}(t)\right\}_{t=0}^{t_1}$ is (Z^0, y^0, t_1) – feasible growth process.

Condition (FG2) means that the limit of the sequence (Z^0, y^0, t_1) – feasible growth processes is also a feasible process, hence, if:

$$\left(y^k(t-1) - i^k(t-1), y^k(t)\right) \in Z^k(t),\ t = 1, 2, \ldots, t_1$$

$$0 \leqq i^k(t) \leqq y^k(t),\ t = 0, 1, \ldots, t_1 - 1$$

$$Z^k(t) = F_t\left(Z^k(t-1), i^k(t-1)\right),\ t = 1, 2, \ldots, t_1$$

$$Z^k(0) = Z^0, y^k(0) = y^0$$

the following conditions apply:

$$\forall t \in \left\{0, 1, \ldots, t_1\right\}\left(\lim_k y^k(t) = \overline{y}(t);\ \overline{y}(0) = y^0\right)$$

$$\forall t \in \left\{0, 1, \ldots, t_1 - 1\right\}\left(\lim_k i^k(t) = \overline{i}\,(t)\right)$$

and such a sequence of production spaces $\left\{\overline{Z}(t)\right\}_{t=0}^{t_1}$ is created that:

$$\forall t \in \left\{0, 1, \ldots, t_1\right\}\left(\overline{Z}(t) = F_t\left(\overline{Z}(t-1), \overline{i}\,(t-1)\right);\ \overline{Z}(0) = Z^0\right)$$

then:

$$\left(\overline{y}(t-1) - \overline{i}\,(t-1), \overline{y}(t)\right) \in \overline{Z}(t), \quad t = 1, 2, \ldots, t_1$$

(where $0 \leqq \overline{i}\,(t) \leqq \overline{y}(t), \quad t = 0, 1, \ldots, t_1 - 1; \quad \overline{Z}(0) = Z^0,\ \overline{y}(0) = y^0$).

Theorem 1. If conditions (G1)–(G4), (F1)–(F4), as well as (FG1), (FG2) and (U1), (U2) are satisfied, then problem (9) has a solution, i.e. there exists such (y^0, t_1) – optimal production trajectory $\left\{y^\star(t)\right\}_{t=0}^{t_1}$, that:

$$u\left(y^\star(t_1)\right) \geq u\left(y(t_1)\right).$$

where $y(t_1)$ is the vector of the production in period t_1 in any (Z^0, y^0, t_1) – feasible growth process.

Proof. Let us introduce the following notation:

$$R_{y^0,0} = \{y^0\}$$

and for $t \geq 1$:

$$R_{y^0,t} = \Big\{ y = y(t) \,|\, \exists \{i(\theta)\}_{\theta=0}^{t-1} \,\exists \{y(\theta)\}_{\theta=0}^{t} \,\forall \theta \in \{0, 1, \ldots, t-1\} \Big(0 \leqq i(\theta) \leqq y(\theta),$$
$$\big(y(\theta) - i(\theta), y(\theta+1)\big) \in Z(\theta+1) = F_{\theta+1}\big(Z(\theta), i(\theta)\big);\; y(0) = y^0,\, Z(0) = Z^0\Big)\Big\}$$

$R_{y^0,t}$ denotes the set of all the production vectors achieved in the economy in period t in a certain (Z^0, y^0, t_1) – admissible growth process. It will be demonstrated that $\forall t < +\infty$ sets $R_{y^0,t}$ are compact (bounded and closed).

The singleton set $R_{y^0,0}$ is obviously compact. The proof of the compactness of the $R_{y^0,t}$ sets for $t \geq 1$ will be conducted by means of induction.

(I) The proof that set $R_{y^0,1}$ is compact is the following.

(*Boundedness*) Let us assume that the set:

$$R_{y^0,1} = \Big\{ y \,|\, \exists i(0) \geqq 0 \Big(i(0) \leqq y^0, \big(y^0 - i(0), y\big) \in Z(1) = F_1\big(Z^0, i(0)\big)\Big)\Big\}$$

is unbounded. Hence:

$$\exists \{i^k(0)\}_{k=1}^{\infty} \,\exists \{y^k\}_{k=1}^{\infty} \Big(0 \leqq i^k(0) \leqq y^0 \;\&\; \big(y^0 - i^k(0), y^k\big) \in Z^k(1) =$$
$$= F_1\big(Z^0, i^k(0)\big) \subseteq Z;\; \|y^k\| \underset{k}{\to} +\infty \Big)$$

(Z is the limit production space satisfying conditions (G1)–(G4)). If

$$(\xi^k, \eta^k) = \left(\frac{y^0 - i^k(0)}{\|y^k\|}, \frac{y^k}{\|y^k\|} \right)$$

then:

$$\forall k \Big((\xi^k, \eta^k) \in Z,\, \xi^k \underset{k}{\to} 0,\, \|\eta^k\| = 1 \Big)$$

hence:

$$\exists \{\xi^{k_j}, \eta^{k_j}\}_{j=1}^{\infty} \Big(\xi^{k_j} \underset{j}{\to} 0, \eta^{k_j} \underset{j}{\to} \overline{\eta} \neq 0 \Big)$$

The limit production space Z is a closed set, so $(0, \overline{\eta}) \in Z$, which contradicts (G2). Set $R_{y^0,1}$ is bounded.

(***Closedness***) Let us take the set $\{y^k\}_{k=1}^{\infty}$ of vectors $y^k \in R_{y^0,1}$ convergent to $\overline{y}$. Then:

$$\exists\left\{i^k(0)\right\}_{k=1}^{\infty}\left(0 \leqq i^k(0) \leqq y^0 \,\&\left(y^0 - i^k(0),\, y^k\right) \in Z^k(1) = F_1\left(Z^0, i^k(0)\right)\right)$$

The nonnegative sequence $\left\{i^k(0)\right\}_{k=1}^{\infty}$ is limited, so it includes a convergent subsequence:

$$\exists\left\{i^{k_j}(0)\right\}_{j=1}^{\infty}\left(0 \leqq i^{k_j}(0) \underset{j}{\rightarrow} \overline{i} \leqq y^0\right)$$

If $x^{k_j} = y^0 - i^{k_j}(0)$, then:

$$\forall j\left(\left(x^{k_j}, y^{k_j}\right) \in Z^{k_j}(1) = F_1\left(Z^0, i^{k_j}(0)\right)\right)$$

and $x^{k_j} \underset{j}{\rightarrow} \overline{x} = y^0 - \overline{i}$, $y^{k_j} \underset{j}{\rightarrow} \overline{y}$. In compliance with (FG2):

$$(\overline{x}, \overline{y}) = (y^0 - \overline{i}, \overline{y}) \in \overline{Z}(1) = F_1(Z^0, \overline{i})$$

therefore $\overline{y} \in R_{y^0,1}$. Hence, set $R_{y^0,1}$ is closed, and since it is also bounded, it is compact.

(II) It will be proved that if sets $R_{y^0,0}, \ldots, R_{y^0,t}$ are compact, then set $R_{y^0,t+1}$ is also compact.

(***Boundedness***) Let us assume that $R_{y^0,t+1}$ set is unbounded, i.e.:

$$\exists\{y^k\}_{k=1}^{\infty}\left(y^k \in R_{y^0,t+1} \,\&\, y^k \underset{k}{\rightarrow} +\infty\right).$$

Then:

$$\forall k \exists\left\{i^k(\theta)\right\}_{\theta=0}^{t} \exists\left\{y^k(\theta)\right\}_{\theta=0}^{t+1} \exists\left\{Z^k(\theta)\right\}_{\theta=0}^{t+1} \forall \theta \in \left\{0, 1, \ldots, t\right\}\left(0 \leqq i^k(\theta) \leqq y^k(\theta),\right.$$
$$\left(y^k(\theta) - i^k(\theta),\, y^k(\theta+1)\right) \in Z^k(\theta+1) = F_{\theta+1}\left(Z^k(\theta), i^k(\theta)\right) \subseteq Z;\, Z^k(0) = Z^0,$$
$$\left.y^k(0) = y^0;\, y^k(t+1) = y^k \underset{k}{\rightarrow} +\infty\right) \tag{10}$$

Let $x^k = y^k(t) - i^k(t)$. Set $R_{y^0,t}$ is compact by assumption, so sequence $\left\{y^k(t)\right\}_{k=1}^{\infty}$ is bounded, and since $0 \leqq i^k(t) \leqq y^k(t)$, sequence $\{x^k\}_{k=1}^{\infty}$ is bounded as well, and

$$\forall k\left\{(x^k, y^k) = \left(y^k(t) - i^k(t),\, y^k(t+1)\right) \in Z^k(t+1) \subseteq Z\right\}$$

where (remember) Z is the limit production space. Denoting:

$$(\xi^k, \eta^k) = \left(\frac{x^k}{\|y^k\|}, \frac{y^k}{\|y^k\|} \right) = \left(\frac{y^k(t) - i^k(t)}{\|y^k\|}, \frac{y^k}{\|y^k\|} \right)$$

we arrive at a conclusion, like in (I), that:

$$\exists \left\{ \xi^{k_j}, \eta^{k_j} \right\}_{j=1}^{\infty} \left((\xi^{k_j}, \eta^{k_j}) \in Z \ \& (\xi^{k_j}, \eta^{k_j}) \underset{j}{\rightarrow} (0, \overline{\eta}) \in Z \right)$$

where $\overline{\eta} \neq 0$, which is impossible (in contradiction to (G2)). Hence, set is bounded.

(*Closedness*) Let $y^k = y^k(t+1) \in R_{y^0,\, t+1}$, $k = 1, 2, \ldots,$ $y^k \underset{k}{\rightarrow} \overline{y} = \overline{y}(t+1)$. Since the sets $R_{y^0, 0}, \ldots, R_{y^0,\, t}$ are compact by assumption, hence $\forall \theta \in \{0, 1, \ldots, t\}$ sequences in $\left\{ i^k(\theta) \right\}_{k=1}^{\infty}, \left\{ y^k(\theta) \right\}_{k=1}^{\infty}$ (10) have convergent subsequences:

$$\exists \left\{ i^{k_j}(\theta) \right\}_{j=1}^{\infty} \exists \left\{ y^{k_j}(\theta) \right\}_{j=1}^{\infty} \left(0 \leqq i^{k_j}(\theta) \underset{j}{\rightarrow} \overline{i}(\theta),\, y^{k_j}(\theta) \underset{j}{\rightarrow} \overline{y}(\theta) \right)$$

$$0 \leqq \overline{i}(\theta) \leqq \overline{y}(\theta),\ \theta = 0, 1, \ldots, t$$

$$y^{k_j}(0) = \overline{y}(0) = y^0$$

In compliance with (FG2):

$$\left(\overline{y}(\theta) - \overline{i}(\theta),\, \overline{y}(\theta+1) \right) \in \overline{Z}(\theta+1) = F_{\theta+1}\left(\overline{Z}(\theta),\, \overline{i}(\theta) \right),\ \theta = 0, 1, \ldots, t$$

($\overline{Z}(0) = Z^0, \overline{y}(0) = y^0$), hence the sequences of the production vectors $\{\overline{y}(\theta)\}_{\theta=0}^{t+1}$, investment vectors $\{\overline{i}(\theta)\}_{\theta=0}^{t}$ as well as the production spaces $\{\overline{Z}(\theta)\}_{\theta=0}^{t+1}$ form $(Z^0, y^0, t+1)$ – feasible growth process, i.e. $\overline{y} = \overline{y}\,(t+1) \in R_{y^0,\, t+1}$. Set $R_{y^0,\, t+1}$ is bounded and closed in R^n, so it is compact.

Problem (9) is equivalent to the problem of the maximization of the continuous function $u(\cdot)$ on the compact set $R_{y^0,\, 1}$:

$$\max_{y \in R_{y^0, t_1}} u(y)$$

which, according to the Weierstrass theorem, has a solution. Therefore there exists (y^0, t_1) – optimal production trajectory $\left\{ y^*(t) \right\}_{t=0}^{t_1}$, the solution to problem (9). ■

The article by Panek (2022) presents a proof of the "weak" turnpike theorem, according to which each (y^0, t_1) – optimal production trajectory $\left\{ y^*(t) \right\}_{t=0}^{t_1}$

always, except for a limited number of time periods, independent of the horizon length T, remains in an arbitrarily close neighbourhood of the multilane turnpike $\mathbb{N}$. Let us now study the properties of (y^0, t_1) – optimal production trajectory, which in a certain period $\check{t} < t_1$ reaches the multilane turnpike $\mathbb{N}$, i.e. when:

(FG3) $\exists \check{t} < t_1 \left(\alpha\left(y^*(\check{t}-1), y^*(\check{t}) \right) = \alpha_M \right)$

(equivalently: $\exists \check{t} < t_1 \left(\alpha\left(y^*(\check{t}-1), y^*(\check{t}) \right) = \alpha_M \ \& \ i^*(\check{t}) = 0 \right)$

Lemma 1. Under condition (FG3) then there exists a (Z^0, y^0, t_1) – feasible growth processes $\left\{ \check{y}(t) \right\}_{t=0}^{t_1}$, $\left\{ \check{i}(t) \right\}_{t=0}^{t_1-1}$, $\left\{ \check{Z}(t) \right\}_{t=0}^{t_1}$ of the following form:

$$\check{y}(t) = \begin{cases} y^*(t), & t = 0, 1, \ldots, \check{t} \\ \alpha_M^{t-\check{t}} y^*(\check{t}), & t = \check{t}+1, \ldots, t_1 \end{cases} \tag{11a}$$

$$\check{i}(t) = \begin{cases} i^*(t), & t = 0, 1, \ldots, \check{t}-1 \\ 0, & t = \check{t}, \ldots, t_1 - 1 \end{cases} \tag{11b}$$

$$\check{Z}(t) = \begin{cases} Z^*(t), & t = 0, 1, \ldots, \check{t} \\ Z^*(\check{t}), & t = \check{t}+1, \ldots, t_1 \end{cases} \tag{11c}$$

$(Z(0) = Z^0$ and $y(0) = y^0)$

Proof. By the definition of (Z^0, y^0, t_1) – optimal growth process we have:

$$y^*(0) = y^0, Z^*(0) = Z^0$$

$$(y^*(t-1) - i^*(t-1), y^*(t)) \in Z^*(t)$$

$$Z^*(t) = F_t(Z^*(t-1), i^*(t-1)),$$

$$0 \leqq i^*(t-1) \leqq y^*(t-1)$$

$$t = 1, 2, \ldots, t_1$$

Especially, $\left(y^*(\check{t}-1) - i^*(\check{t}-1), y^*(\check{t}) \right) \in Z^*(\check{t})$ and then (according to (G3)):

$$\left(y^*(\check{t}-1), y^*(\check{t}) \right) \in Z^*(\check{t})$$

and (as per (FG3)):

$$\alpha_M y^*(\check{t}-1) \leqq y^*(\check{t})$$

That is $y^\star(\check{t}-1) \leqq \frac{1}{\alpha_M} y^\star(\check{t})$, therefore (against (G3)):

$$\left(y^\star(\check{t}), \alpha_M y^\star(\check{t})\right) \in Z^\star(\check{t})$$

Condition $i(\check{t}) = i(\check{t}+1) = \ldots = i(t_1 - 1) = 0$ indicates $\check{Z}(t) = Z^\star(\check{t}) \subseteq Z, \quad t = \check{t}+1, \ldots, t_1$, and hence (according to (G1)):

$$\left(\alpha_M y^\star(\check{t}), \alpha_M^2 y^\star(\check{t})\right) \in \check{Z}(\check{t}+1) = Z^\star(t) \subseteq Z$$

…………

$$\left(\alpha_M^{t_1-\check{t}-1} y^*(\check{t}), \alpha_M^{t_1-\check{t}} y^*(\check{t})\right) \in \hat{Z}(t_1) = Z^\star(\check{t}) \subseteq Z$$

or otherwise, equivalently:

$$\left(\overline{y}(t-1), \overline{y}(t)\right) \in \check{Z}(t) = Z^\star(\check{t}) \subseteq Z, \quad t = \check{t}, \quad \check{t}+1, \ldots, t_1$$

where

$$\overline{y}(t) = \alpha_M^{t-\check{t}} y^\star(\check{t}) \in \mathbb{N}$$

Then the production trajectory (11a) together with the corresponding investment trajectory (11b) and the sequence of production spaces (11c) form(Z^0, y^0, t_1) – feasible growth processes. In this process, the economy, from period $\check{t}$ to the end of horizon T, remains on the turnpike. ■

Let $d(x, \mathbb{N})$ denote the following measure of the (angular) distance between vector $x \in R^n_+\backslash\{0\}$ and the multilane turnpike $\mathbb{N}$:

$$d(x, \mathbb{N}) = \inf_{x' \in \mathbb{N}} \left\| \frac{x}{x} - \frac{x'}{x'} \right\| \tag{12}$$

Drawing on the example of Radner lemma (1961), it can be proved that under conditions (G1)–(G4), (F1)–(F4) and (FG1):

$$\forall \varepsilon > 0 \, \exists \delta_\varepsilon \in (0, \alpha_M) \, \forall (x, y) \in Z \setminus \{0\} \left(d(x, \mathbb{N}) \geq \varepsilon \Rightarrow \beta(x, y, \overline{p}) = \right.$$
$$\left. = \frac{\langle \overline{p}, y \rangle}{\langle \overline{p}, x \rangle} \leq \alpha_M - \delta_\varepsilon \right) \tag{13}$$

Panek (2022), lemma 2. In accordance with (13), if in a production process $(x, y) \in Z\backslash\{0\}$ the structure of inputs $\frac{x}{\|x\|}$ differs from the turnpike structure $\frac{x'}{\|x'\|}$ by at least $\varepsilon > 0$, the economic efficiency of such a process is lower than the optimal one by at least $\delta_\varepsilon > 0$. Since:

$$\forall t\left(Z(t)\subseteq Z\right) \tag{14}$$

the characteristic (13) also refers to any production process $\left(x(t), y(t)\right)\in Z(t)\setminus\{0\},\quad t=0, 1, \ldots, t_1$.

Theorem 2. Under conditions (G1)–(G4), (F1)–(F4), (U1), (U2) and (FG1)–(FG3):

$$\forall t\in\left\{\check{t}, \check{t}+1, \ldots, t_1-1\right\}\left(y^*(t)\in\mathbb{N}\right)$$

Proof. The definition of the (y^0, t_1) – optimal production trajectory $\left\{y^*(t)\right\}_{t=0}^{t_1}$, in compliance with (3), (7) (under (14)) leads to the condition:

$$\left\langle\overline{p}, y^*(t+1)\right\rangle\le\alpha_M\left\langle\overline{p}, y^*(t)-i^*(t)\right\rangle,\quad t=0, 1, \ldots, t_1-1$$

therefore, in particular:

$$\begin{aligned}&\left\langle\overline{p}, y^*(t_1)\right\rangle\le\alpha_M\left\langle\overline{p}, y^*(t_1-1)-i^*(t_1-1)\right\rangle\le\alpha_M^2\left\langle\overline{p}, y^*(t_1-2)\right\rangle-\\&-\alpha_M^2\left\langle\overline{p}, i^*(t_1-2)\right\rangle-\alpha_M\left\langle\overline{p}, i^*(t_1-1)\right\rangle\le\cdots\\&\cdots\le\alpha_M^{t_1-\hat{t}}\left\langle\overline{p}, y^*(\check{t})\right\rangle-\sum_{k=1}^{t_1-\check{t}}\alpha_M^k\left\langle\overline{p}, i^*(t_1-k)\right\rangle\end{aligned} \tag{15}$$

If in a certain period $t'\in\{\hat{t}+1, \ldots, t_1-1\}$:

$$y^*(t')\notin\mathbb{N}$$

then

$$\exists\varepsilon>0\left(d\left(y^*(t'), \mathbb{N}\right)\ge\varepsilon\right) \tag{16}$$

Indeed, let us assume *a contrario* that:

$$d\left(y^*(t'), \mathbb{N}\right)=\inf_{y'\in\mathbb{N}}\left\|\frac{y^*(t')}{y^*(t')}-\frac{y'}{y'}\right\|=0$$

and $s^*(t')=\dfrac{y^*(t')}{\left\|y^*(t')\right\|},\quad s'=\dfrac{y'}{\left\|y'\right\|}$. Then:

$$\inf_{y'\in\mathbb{N}}\left\|\frac{y^*(t')}{y^*(t')}-\frac{y'}{y'}\right\|=\inf_{s'\in S}\left\|s^*(t')-s'\right\|=0$$

which, in the view of the compactness of set S and continuity of the norm $||\cdot||$ means that $s^*(t')=s'$, i.e. $y^*(t')\in\mathbb{N}$, contrary to the assumption. Hence, if $y^*(t') \notin \mathbb{N}$, the condition (16) applies, so (under (13)) there is such a number $\delta_\varepsilon > 0$ that:

$$\langle \overline{p}, y^*(t'+1)\rangle \leq (\alpha_M - \delta_\varepsilon)\langle \overline{p}, y^*(t') - i^*(t')\rangle$$

Combining this condition with (15) leads to:

$$\langle \overline{p}, y^*(t_1)\rangle \leq \alpha_M^{t_1-\check{t}-1}(\alpha_M - \delta_\varepsilon)\langle \overline{p}, y^*(\check{t})\rangle - \sum_{k \neq t_1 - t'}^{t_1-\check{t}} k=1\ \alpha_M^k \langle \overline{p}, i^*(t_1 - k)\rangle -$$
$$-(\alpha_M - \delta_\varepsilon)^{t_1-t'}\langle \overline{p}, i^*(t')\rangle$$

That is, in particular $\langle \overline{p}, y^*(t_1)\rangle \leq \alpha_M^{t_1-\hat{t}-1}(\alpha_M - \delta_\varepsilon)\langle \overline{p}, y^*(\hat{t})\rangle$ and hence (under (U2)):

$$u\left(y^*(t_1)\right) \leq a\alpha_M^{t_1-\hat{t}-1}\left(\alpha_M - \delta_\varepsilon\right)\langle \overline{p}, y^*(\hat{t})\rangle = \sigma a\alpha_M^{t_1-\hat{t}-1}(\alpha_M - \delta_\varepsilon)\langle \overline{p}, s^*\rangle \quad (17)$$

where $s^* = \dfrac{y^*(\check{t})}{\left\|y^*(\check{t})\right\|} \geq 0, \quad \sigma = \dfrac{1}{\left\|y^*(\check{t})\right\|} > 0$

The production trajectory $\left\{\check{y}(t)\right\}_{t=0}^{t_1}$ in the form (11) is (y^0, t_1) – feasible, so:

$$u\left(y^*(t_1)\right) \geq u\left(\check{y}(t_1)\right) = u\left(\alpha_M^{t_1-\check{t}} y^*(\check{t})\right)$$

and, in according to (U1), (U2):

$$u\left(y^*(t_1)\right) \geq \alpha_M^{t_1-\check{t}} u\left(y^*(\check{t})\right) = \sigma a\alpha_M^{t_1-\check{t}} u(s^*) = \sigma a\alpha_M^{t_1-\check{t}}\langle \overline{p}, s^*\rangle > 0 \quad (18)$$

Conditions (17), (18) lead to the inequality:

$$\sigma a\alpha_M^{t_1-\check{t}-1}(\alpha_M - \delta_\varepsilon)\langle \overline{p}, s^*\rangle \geq \sigma a\alpha_M^{t_1-\check{t}}\langle \overline{p}, s^*\rangle > 0$$

which means that $\delta_\varepsilon = 0$. The obtained contradiction concludes the proof.

■

According to the theorem, if in an optimal growth process the production trajectory $\left\{y^*(t)\right\}_{t=0}^{t_1}$ in a period $\check{t} < t_1$ reaches the multilane turnpike , then, regardless of the length of horizon T, it remains on it from then on, except for possibly one (the last) period t_1. As in the non-stationary Gale economy without investments (with the exogenous technological progress), also now, in the Gale economy with investments, the multilane turnpike is a specific "express road", which is approached (in accordance with the "weak" turnpike theorem), or reached (in the light of the "very strong" turnpike theorem) by all the optimal production trajectories. On the multilane turnpike, the economy develops at a maximum rate, at the same time remaining in the Neumann equilibrium of growth. It is not difficult to notice that in the special case when the solution to the problem (9) is unequivocal, then under the assumptions of theorem 2, the (y^0, t_1) – optimal production trajectory $\{y^*(t)\}_{t=0}^{t_1}$ remains on the turnpike in all periods of the horizon T starting from the period $\check{t}$ (including in the end period t_1):

$$\forall t \in \{\check{t}+1, \ldots, t_1\}\left(y^*(t) \in \mathbb{N}\right).$$

Conclusions

In mathematical economics, there are a number of "turnpike theorems" proved mainly on the basis of multiproduct von Neumann-Leontief-Gale-type models of economic dynamics. According to these theorems, all optimal paths of economic growth over a long period of time converge to a certain path (turnpike), in which the economy achieves the highest growth rate while remaining in a specific dynamic (von Neumann) equilibrium. In the standard model of the Gale economy, it is assumed (in the stationary version) that the production technology does not change over time or (in the non-stationary version) that its changes are exogenous. This is, of course, a great simplification. The main result of the paper is the construction of the Gale-type economy model with investments and the proof of the „very strong" turnpike theorem in such an economy. The work refers to the article by Panek (2022) and shows that the inclusion of the investment mechanism in the Gale economy does not deprive it of fundamental asymptotic/turnpike properties.

While the concept of the non-stationary nature of the economy (the volatility of the technology) complies with the real processes, the hypothesis of the existence of a limit technology may raise some doubts, or at least is difficult to verify. It gives rise to a new direction for research into the course of the optimal growth processes in the non-stationary Gale economy with investments, the multilane turnpike, and with the increasing production efficiency, but without the assumption about the existence of a limit technology. The findings of the similar research into the non-stationary Gale economy without the investment mechanism are presented in Panek (2019a,c, 2020a,b), among other works.

A weakness of this model is its disregard for the depreciation of capital. In its present form, the only result of the suspension of investments is that in the next period $t + 1$ the production technology remains stable, $Z(t + 1) = Z(t)$. An interesting research challenge will be tracing the turnpike qualities of the optimal growth processes in the Gale economy, where the suspension of investments leads to the reduction in its production capability. This requires including in the model both net investments (multiplying the production capital), and the restitution investments (recovering the used production capital).

What remains to be studied is the turnpike effect in the Gale economy with investments, as well as the discounted utility in specific periods of horizon T (not just in its last period t_1). In the classic version of the economic dynamics of the Gale type with limit technology (without the investments mechanism), the results were presented in the study by Panek (2019b), among other studies. What is also probably true is the “strong” version of theorem of the multilane turnpike in the Gale economy with investments, which is similar to the one presented in theorem 3 in the study by Panek (2018). The verification of this hypothesis requires further research.

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Analyst herding—whether, why, and when? Two new tests for herding detection in target forecast prices

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Abstract

This study proposes two novel tests for security analyst herding based on binomial correlation and forecast error volatility scaling, and applies it to investigate herding patterns in analyst target prices in 2008–2020 in the UK. Analysts robustly herd in their valuations, with results consistent across years, sectors, in terms of panel fixed effect, quantile, instrumental variable regressions, and when controlled for optimism and conservatism. Herding becomes prominent for stocks followed by at least five analysts and towards the long sides of Fama-French sorts, reinforcing its non-spurious and behavioral nature.

Keywords

- behavioral finance
- financial econometrics
- herding
- stock analyst

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Introduction

The question of whether, why, how and when security analysts herd in their forecasts and valuations has been a subject of active and intense academic debate at least since the early 1990s (Scharfstein & Stein, 1990). The literature on institutional and analyst herding has substantially expanded since then, with a plethora of theoretical and empirical studies having emerged (see, e.g., Clement & Tse, 2003, 2005; Frijns & Huynh, 2018; Hong & Kacperczyk, 2010; Lee & Lee, 2015; Trueman, 1994; Welch, 2000). However, researchers disagree on the causes and consequences of herding or sometimes with regard to its very existence. Early research either hypothesised that herding is purely irrational and of a behavioral nature (Welch, 2000), or reputational, stemming from information asymmetry and differing ability of analyst (Scharfstein & Stein, 1990; Clement & Tse, 2005). Further research proposed a conflict-of-interest explanation, introducing a principal-agent problem dimension into the analysis (Hong & Kacperczyk, 2010; James & Karceski, 2006; Lee & Lee, 2015), and analyst competition as the herding-mitigating factor. Other studies argue that herding is spurious due to analysts and market participants relying on similar valuation models and the same fundamental information or demonstrating other biases, yielding herding nothing more than a statistical artefact (Guo et al., 2020). Hence, the literature does not reach a consensus on the issue, with assessing the presence and the degree of herding being increasingly difficult both theoretically and econometrically, and often requiring large, specialised, disaggregated, high-frequency, and analyst-level datasets (Bernhardt et al., 2006; Blasco et al., 2018).

Therefore, this study seeks to contribute to the literature on analyst herding by developing two conceptually and computationally simple yet flexible and powerful econometric tests capable of determining herding patterns in analyst target forecast prices using non-specialised and aggregated data and introducing a battery of robustness tests generating testable implications for the competing theories of analyst herding, and applying them to the UK stock market in 2008–2020, utilising a sample of over 2,000 followed companies, over 12,000 stock-year observations, and in excess of 85,000 individual analyst forecasts. We propose non-parametric and parametric tests. The non-parametric test has its foundations in a binomial default correlation framework and the second, the parametric one, is the main test we propose here. This second test exploits the logic of variance scaling for dependent and independent variables.

This study establishes that analyst herding is robustly present in analyst valuations. The findings are consistent with the behavioral theories of herding rather than conflict-of-interest or reputational theories; they reinforce its non-spurious nature, and highlight the greater prominence of herding behaviour subject to lower volatility and uncertainty. The results persist in subsamples, and when concerns regarding heterogeneity, endogeneity, spurious herding, and outliers are addressed. The contribution of this study is therefore two--fold, highlighting both the financial econometrics of herding detection and the policy implications of the observed herding patterns.

The rest of the paper is organised as follows: First, the literature on herding in individual stock market participants, institutional investors, and security analysts is reviewed. Next, the data this study utilises is presented and the two econometric tests it applies are derived. The findings section presents the estimation results and robustness checks, discussing them in the context of the literature and the competing theories of analyst herding. The final section presents conclusions.

1. Literature review

The literature on individual investor, analyst, and institutional herding is yet to reach a consensus on whether herding or contrarianism are more prominent on financial markets. An agreement is also missing on their implications for market efficiency and quality, and with regards to the robustness of herding, its spurious, reputational, or behavioral nature, and interactions with other behavioral biases such as overconfidence, optimism, and conservatism. This state of affairs is confirmed by generally mixed and inconclusive findings in both econometric and experimental studies.

Early research on analyst target forecasts tended to illuminate their informational value and implications for investing. O'Brien (1988) showed that, on average, analyst earnings predictions are better than those of econometric time-series models. However, there was also evidence of analyst conservatism, with lagged analyst forecast errors having predictive power over current earnings. Doukas et al. (2005) report more nuanced findings: while analyst coverage in their sample alleviates agency problems, it also leads to persistent over- and under-valuations of strongly and weakly covered stocks, respectively. Imam et al. (2013) show that analyst target price forecast accuracy depends on the underlying valuation model, with those forecasts based on return on equity and book value performing the best. Brav and Lehavy (2003) document the informativeness of analyst target forecast prices by studying market reactions to forecast announcements and revisions, while also reporting that one-year-ahead target prices are overly optimistic. While numeric information such as earnings management related can have an impact on valuation (Kałdoński & Jewartowski, 2017), Huang et al. (2009) demonstrate that analyst recommendations contain substantial information not available in numerical valuations, with strategies synthesising forecasts and recommendations delivering higher returns. Similarly, Feldman et al. (2012) argue that the best-performing strategy should incorporate both target price and earnings forecasts, as well as analyst recommendations. Ishigami and Takeda (2018) state that the accuracy of forecasts is conditional on the quality of security analysis firms. Moreover, Han et al. (2021) develop a robust measure of market reaction to target price announcements, showing a short-term price appreciation and a subsequent reversal. Recent literature has become more critical of analyst forecasting ability, with Bradshaw, Brown et al. (2013) and Bradshaw, Huang et al. (2014) showing how analysts are persistently optimistic, with buy-side analysts' ability slightly lower than that of sell-side analysts. Lin et al. (2016) establish a link between institutional trading and analyst recommendations, therein showing that trading activity increases subject to a target price revision, albeit such trades do not generate abnormal returns.

The concept of institutional herding has been introduced by Scharfstein and Stein (1990) in a theoretical model where managers can mimic the decisions of others, resulting in a privately optimal but socially suboptimal equilibrium. Scharfstein and Stein (1990) were inspired by both behavioral economics insights on group psychology and the corporate finance concept of the principal-agent problem, suggesting a reputational incentive to herd. In a seminal empirical paper, Trueman (1994) utilises a non-parametric test applied to sequential security analyst forecast releases to document herding in their valuations. Trueman (1994) shows that herding affects the apparent stock price reaction to earnings surprises and can lead to mismeasurements in conventional information dissemination models. Welch (2000) argues that herding leads to underestimation of volatility and increased fragility of financial markets and, as the degree of herding is not affected by the accuracy of prior consensus forecasts, the findings favour behavioral or informational asymmetry theories of the herding. Drehmann et al. (2005) design a laboratory experiment to study herding patterns and find that not overly consensual but rather contrarian valuations are more detrimental to market equilibrium stability, subject to informational cascades, while herding can be combatted with market design, particularly flexible pricing quotes. Additionally, they report herding patterns to be similar across market participants with varying roles. Contrastingly, in an empirical study, Clement and Tse (2005) argue that bold contrarian forecasts are more accurate and can be socially beneficial, while also relating herding and contrarianism to past analyst experience, ability, specialisation, and reputational incentives. Graham (1999) supports the reputational herding theory, showing that analysts tend to imitate their peers when their own reputation is not strong or when their private signal contradicts a strong public informational signal.

Roider and Voskort (2016) introduce employers into their experimental setting and confirm the reputational incentives for herding when rewards depend on forecast accuracy and ability is unobservable. Cote and Goodstein (1999) acknowledge the incentives which security analysts might have to herd and emphasise the ethical implications of herding and the virtue of bold contrarian forecasts. Chen and Jiang (2006) argue analysts are overconfident and contrarian in the sense they over-rely on their private information in comparison to private information. However, they show this is symptomatic of an incentive failure rather than persistent behavioral biases. Cheng et al. (2019) provide additional evidence in favour of agency-based analyst herding explanations, showing that target price accuracy is higher for firms with better corporate governance practices. Frijns and Huynh (2018) further confirm the privately rational nature of herding by exploiting the differential impact media sentiment has on analyst recommendations conditional on individual analyst characteristics. While not directly linked with the role of the analyst, herding is also found to be highly correlated with market sentiment, e.g., when it is measured by the VIX volatility index (Aharon, 2021).

Another strand in the literature investigates the effects of competition and conflict of interest including the role of volatility on analyst forecasts. James and Karceski (2006) provide evidence on excessively optimistic analyst coverage subject to underperforming IPOs, suggesting collusion between some analysts and the firm's underwriter. Hong and Kacperczyk (2010) and Wang et al. (2020) use broker mergers as natural experiments varying the level of competition between analysts, and document an increase in herding subject to such mergers. These findings are more consistent with behavioral than reputational herding explanations. Lee and Lee (2015) propose an explanation combining conflict of interest and informational asymmetry: analysts affiliated with the target stock are excessively optimistic and overly consensual, while others follow this signal as affiliated analysts can possess insider information. Loang and Ahmad (2021) emphasise the mediating role of volatility. They find that the release of analysts recommendation causes realised volatility to fluctuate and that investors are triggered by the volatility. They make use of realised volatility and the Parkinson estimator to measure it. Additionally, the literature tends to disagree on the impact that market conditions and other external variables have on the degree of herding between market participants. The conventional models developed by Christie and Huang (1995) and Chang et al. (2000) implicitly assume herding is most prominent subject to extreme market conditions. This is confirmed in early empirical research (Caparrelli et al., 2004) as well as in more recent analyst-focused studies, with Lin (2018) showing that herding intensifies when aggregate market uncertainty is high. Such uncertainties can be the result of several factors, including inefficiencies caused by the lack of experienced market participants or institutional rigidities restricting the flow of information (Wheeler et al., 2002). However, Hwang and Salmon (2004) find the opposite to be generally true, with herding associated to a greater extent with calm market periods. Welch (2000) also documents analyst herding towards the consensus being stronger under favourable market conditions. Galariotis et al. (2015) show herding is more pronounced when important macroeconomic or fundamental information is released, with this relationship heterogeneous across different markets.

Another major divide in the literature is manifested with regard to the herding of general stock market participants versus institutional investors and analysts. Since the 1990s, a wide range of powerful tests have been developed to detect herding of individual investors. These tests mainly make use of the stock price data, including the cross-sectional standard deviation (Christie & Huang, 1995), cross-sectional absolute deviation (Chang et al., 2000), and cross-sectional factor loading dispersion (Hwang & Salmon, 2004) tests, whose conceptual simplicity, wide applicability and flexibility has led to them gaining substantial popularity and enjoying continuous use in recent studies (see, e.g., Blake et al., 2017; Vidal-Tomas et al., 2019).

However, tests for the analyst and institutional herding suggested in the literature often require high frequency, specialised, or disaggregated data. As such, Welch (2000) studies the recency of real-time analyst forecast revisions to document herding. Bernhardt et al. (2006) propose a non-parametric S-statistic that conditions over- or undervaluations of individual analysts onto those of their peers. Friesen and Weller (2006) use Bayesian methods to assess consensus forecast precision by exploiting the ordering of analyst valuations. Nofsinger and Sias (1999), Sias (2004), Choi and Sias (2009), and Choi and Skiba (2015) exploit dynamic institutional holdings data to document herding in institutional investment decisions with regard to the US stock market, individual industries, and international financial markets. Guo et al. (2020) integrate individual analyst recommendations and institutional holdings to challenge prior findings and demonstrate that herding is most likely spurious.

Tests less demanding of the granularity of data, such as Olsen (1996) and De Bondt and Forbes (1999), which both exploit the shape of the forecast distribution and consensus estimate dispersion, have been subsequently criticised, as they are parametric and are thus not robust to cross-sectional correlations, irrational analyst optimism, and other behavioral biases (Blasco et al., 2018). This also corresponds to the findings of Hong and Kacperczyk (2010), who show that analyst forecasts in the absence of competition can be both excessively consensual and overly optimistic due to conflict of interest, and also to Nofsinger and Sias's findings (1999), who assert that the patterns in institutional holdings data are consistent with both herding and feedback trading by institutional investors. Additionally, Abarbanell and Lehavy (2003) argue that statistical artefacts in the distribution of analyst forecasts can explain most of the anomalies in the data that are usually interpreted in favour of analyst behavioral biases.

Therefore, there exists a notable gap in the financial econometrics literature on analyst herding, as no test so far has been developed that simultaneously a) can be applied to aggregated, low-frequency data; b) can distinguish between spurious, reputational, and behavioral herding; c) can be adjusted for other analyst behavioral biases; and d) addresses the conventional concerns surrounding parametric tests. This study seeks to address this gap by developing two tests for analyst herding—a non-parametric simplistic test inspired by binomial correlations, and a flexible regression-based test that is accommodative to a battery of robustness checks. The next section discusses the sample that this study utilises, and also provides the derivation and justification for the testing process

2. Data and methodology

2.1. The sample

This study considers an exhaustive sample of all stocks listed on the London Stock Exchange for at least one year in the time period 2008–2020 and that have had at least one security analyst issuing a target price forecast between 2008 and 2019. As analyst targets cover a 12-month, forward-looking period, target prices current as of 31st December are mapped onto closing stock prices as of 31st December the following year in order to calculate pricing errors and determine over- and undervaluation. Therefore, 2008–2019 analyst valuations correspond to the 2009–2020 market prices, respectively, with year-ends chosen to prevent overlapping of forecasts and to correctly associate price data with relevant annual fundamentals. The final sample constitutes 2,079 stocks, over 12,000 stock-year observations, and over 85,000 individual analyst valuations. All data used in this study were obtained from Bloomberg through the use of various relevant functions, such as "ANR" for analysts' recommendations, which shows recommendations and predictions for selected stocks. The historical data is available on an aggregated basis only, implying that correlations between individual analyst forecasts are unobservable and must be estimated indirectly. However, each stock-year observation includes both the average target price and the number of analysts whose individual valuations were aggregated to obtain it, which is crucial for the estimation strategy of the parametric regression-based herding test developed further in this section.

Next, the stocks are further assigned their GICS sectoral classifications and annual Fama-French-style factor sorts across market beta, size, value, momentum, profitability, and investment. Market beta is measured daily against the FTSE 250 index, momentum is conventionally defined using 12-month prior returns, and the investment sort is executed based on annual asset growth, as in Fama and French (2015, 2018). Stocks are subsequently grouped into top 30%, middle 40%, or bottom 30% categories. Table 1 provides a snippet of the data as an example. The full raw data sample is available upon request from the corresponding author.

Table 1. Data example

Year	2016	2017	2018	2019	2020
Forecast	19.98	23.40	26.43	28.06	26.58
Price	22.43	24.80	23.08	22.35	12.98
Number of analysts	24	30	28	27	25
Sector	energy	energy	energy	energy	energy
Beta	high	mid	high	mid	mid
Size	large	large	large	large	large
Value	value	neutral	neutral	neutral	neutral
Momentum	loser	winner	sideways	sideways	sideways
Profitability	weak	mid	mid	mid	mid
Investment	mid	bottom	aggressive	conserva-tive	mid

Source: Bloomberg. Various functions available in Bloomberg were applied to obtain the data presented above, such as "ANR" for forecast, "PX_LAST" for share price etc.

Next, the estimation strategy used by the study for inference of herding from such aggregated stock analyst target forecasts data is presented.

2.2. The non-parametric test: Binomial correlations

The first test proposed by this study is a non-parametric approach. It builds upon the binomial default correlation framework first conceptualised and derived in the CreditMetrics framework (JPMorgan, 1997). CreditMetrics suggested a simple statistical technique to infer binomial default correlations between obligors within homogeneous default probabilities from the volatility of average default rate across subsamples:

$$\hat{\rho} = \frac{\sigma^2}{\mu - \mu^2} \sim T\left(0, \sqrt{\frac{1-\hat{\rho}^2}{n-2}}, n-2\right)$$

where $\hat{\rho}$ is the estimated binomial correlation, σ^2 is the variance of the proportion across subsamples, and μ is the full sample average. The statistical significance of $\hat{\rho}$ can then be assessed using a Student's T distribution with mean zero, standard deviation $\sqrt{\frac{1-\hat{\rho}^2}{n-2}}$, and degrees of freedom $n-2$, where n is the sample size. This study suggests applying this concept to correlations between analyst target prices (herding) instead, using a very natural extension of the method. While the correlation of analyst *valuations* is not directly observable from the aggregated data, the CreditMetrics procedure can allow to infer the correlation of analyst *overvaluations* – a binary variable equal to one if the average analyst target price is higher than the realised stock price 12 months forward, and zero otherwise. σ^2 here can be interpreted as the variance of the proportion of overvaluations across subsamples (years or sectors), and μ as the average sample proportion of overvaluations. As regards the binomial distribution properties, the results are equivalent if the proportions of undervaluations are considered instead. If $\hat{\rho}$ is statistically significant, the null hypothesis of independence can be rejected in favour of the alternative hypothesis of herding. Note that a positive binomial correlation implies a higher positive correlation between valuations, fully analogous to the CreditMetrics case relating asset return correlations to default correlations. This simple model is advantageous, as it is non-parametric and allows to estimate overvaluation correlations intuitively interpretable as the degree of analyst herding in a wide range of samples. The two notable shortcomings of the method are that it can only return positive correlations, by not allowing the alternative hypothesis of contrarianism to be tested, while also assuming the rate of overvaluation is homogenous across sample stocks. Therefore, by addressing these limitations and allowing for the implementation of more thorough robustness checks, this study also develops a regression-based parametric test for analyst herding, which is discussed further below.

2.3. The parametric test: Forecast error volatility scaling

The second and the main test proposed by the study exploits the parametric approach and the logic of variance scaling for independent and dependent variables. Consider the forecast variance for the aggregated average target price $\overline{P}_{it}^{A}$ A for stock i in year t produced by m analysts, whose valuations X_j are correlated and each have variance σ^2. For a correlation coefficient ρ between such valuations:

$$V(\overline{P}_{it}^{A}) = \sigma^2(m) = V\left(\frac{1}{m}\sum_{j=1}^{m} X_j\right) = \frac{1}{m^2}(m\sigma^2 + C_m^2\rho\sigma^2) = \frac{(1-\rho)\sigma^2}{m} + \rho\sigma^2$$

For independent valuations:

$$\rho = 0 \Rightarrow \sigma(\overline{P}_{it}^{A}) = \frac{\sigma}{\sqrt{m}} \Rightarrow ln\ ln\ \sigma(\overline{P}_{it}^{A}) = ln\ \sigma - 0.5\ ln\ m$$

This leads to the baseline regression estimation design:

$$ln\ ln \left| \frac{\overline{P}_{it}^{A}}{P_{it+1}} - 1 \right| = \alpha + \beta\ ln\ N_{it}^{A} + \varepsilon_{it}$$

where P_{it+1} is the one-year forward market price, N_{it}^{A} is the number of analysts covering stock i in year t (observed value of m), α is the natural logarithm of the individual analyst prediction error $ln\ \sigma$, β is the volatility scaling exponent, and ε_{it} is the error term. The null hypothesis of independence ($\rho = 0$, $\beta = -0.5$) can then be tested against two alternative hypotheses of herding ($\rho > 0, \beta > -0.5$) and contrarianism ($\rho < 0, \beta < -0.5$) via a T-test:

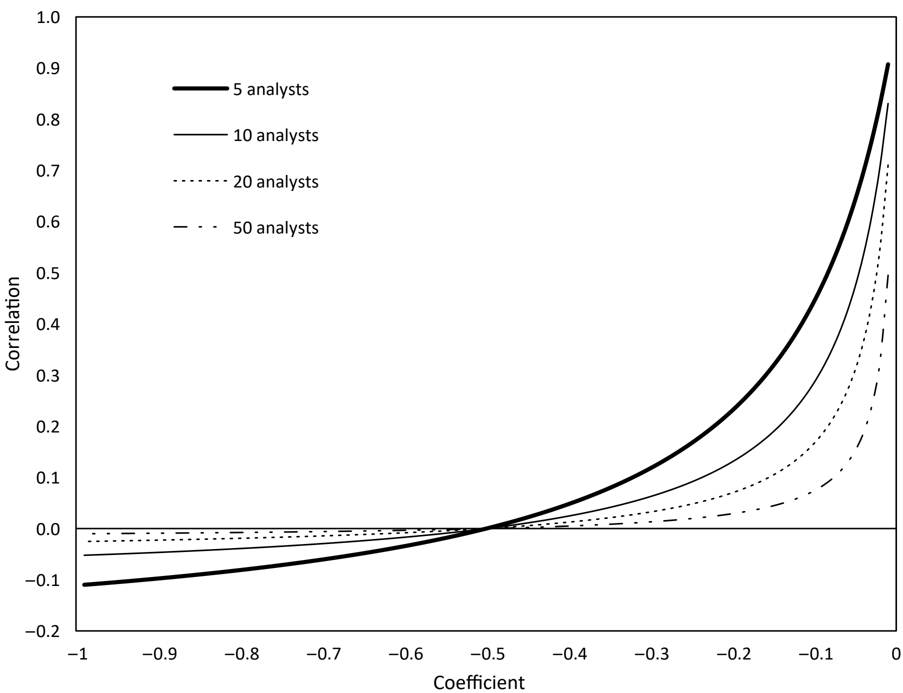

Figure 1. The correspondence between forecast volatility scaling and valuation correlations

Note: Plot created in MS Excel using data obtained from Bloomberg.

Source: Bloomberg.

$$t = \frac{\hat{\beta} + 0.5}{s(\hat{\beta})} \sim T(0, 1, n-2)$$

where $\hat{\beta}$ is the regression estimator of the volatility scaling exponent β, $s(\hat{\beta})$ is the heteroskedasticity-consistent standard error of $\hat{\beta}$ computed using the Huber-White covariance matrix, and n is the number of stock-year observations. The correspondence between the forecast volatility scaling estimator $\hat{\beta}$ and the valuation correlation coefficient $\hat{\rho}$ can be retrieved from the general-case relationship between $V(\overline{P}_{it}^{A})$ and N_{it}^{A}:

$$\beta = \frac{\partial \ln \sigma(\overline{P}_{it}^{A})}{\partial \ln N_{it}^{A}} = \frac{\rho - 1}{2(\rho N_{it}^{A} - \rho + 1)}$$

$$\hat{\rho} = -\frac{2\hat{\beta} + 1}{2\hat{\beta}(N_{it}^{A} - 1) - 1}$$

For the convenience of interpretation, the values of $\hat{\rho}$ for varying $\hat{\beta}$ coefficients and N_{it}^{A} are graphed in Figure 1. This allows to naturally construct confidence intervals for $\hat{\rho}$ alongside $\hat{\beta}$ to assess the magnitude and economic significance of herding or contrarianism between analysts more naturally and intuitively.

2.4. Robustness tests

The four major concerns that could compromise the validity of the results and thus are addressed in the robustness test employed by the study are heterogeneity, the impact of outliers, endogeneity, and spurious herding. Next, the procedures applied to address these are presented sequentially.

The heterogeneity of sample stocks is the major limitation for both the binomial correlation and the regression tests, as they assume the proportion of overvaluations μ and the individual analyst forecasting error σ, respectively, to be constant across the sample. If both individual analyst errors and analyst coverage are correlated with stock characteristics, the results obtained could be biased. To alleviate this concern, this study additionally conducts both tests in sectoral and yearly subsamples. For the parametric regression--based test, it also considers subsample estimations for Fama-French factor and panel regressions with the sector, year, and individual stock fixed effects. Such heterogeneity tests in subsamples are quite rare in the existing literature. The most notable findings here correspond to small stocks: Caparrelli et al. (2004) find herding in small stocks is more prominent during bullish markets, Lin (2018) documents an unproportionate increase in herding activity for small-caps subject to increased uncertainty, and Roger et al. (2018) find analysts to be more optimistic about small price stocks than large price stocks due to inherent cognitive biases in number processing. Additionally, Kremer and Nautz (2013) report herding depends on past stock returns justifying the subsample test based on momentum sorts. Sector-wise, Kim and Pantzalis (2003) show that herding activity is more pronounced for companies that are geographically or industrially diversified.

This study utilises logarithmic forecast errors $ln\left|\frac{\overline{P}_{it}^{A}}{P_{it+1}}-1\right|$ to partially address the impact that outliers could have on the stability of regression coefficients. As additional robustness checks, it also applies quantile regression as in Koenker and Basset (1978) to estimate conditional medians for the full sample and across all subsamples as well as a range of conditional quantiles for the baseline estimation. Further, this study considers non-parametric Spearman rank and Kendall's tau correlation tests for the number of analysts and prediction error scaled upwards by the square root of analyst coverage. If, when adjusted by the square root of the number of analysts, the prediction error shows a positive (negative) non-parametric correlation with coverage, the null hypothesis of independence can be rejected in favour of the alternative hypothesis of herding (contrarianism).

Endogeneity can be a concern, as both the number of analysts following the stock and its forecast error can be influenced by unobserved omitted variables. If a stock is difficult to forecast and analysts value individually accurate forecasts, fewer analysts might be willing to follow such a stock, which would bias $\hat{\beta}$ downwards and leading to false negatives for herding and false positives for contrarianism. Additionally, stocks from various sectors and those adhering to particular investment styles could attract disproportionate attention from analysts due to their specialisation or preferences. For example, O'Brien and Bhushan (1990) report that analysts are more likely to follow industries with a growing number of firms as well as regulated industries. Clement and Tse (2005) show that analysts concentrating on a few industries and having more experience covering similar stocks are more likely to issue bold and accurate forecasts, which might incentivise analysts to specialise narrowly. This finds some reinforcement in this study's sample, with notable heterogeneities observed in coverage across sectors and Fama-French sorts. As such, small-caps, mid-caps, and large-caps are followed each year by 1.35, 3.23, and 13.46 analysts on average. The most followed sector is consumer staples, with 10.36 analysts per stock per year, and the least followed are healthcare and funds, with 4.89 and 4.26, respectively. Growth stocks are more popular with analysts than value stocks, with 8.25 on average covering the former and only 5.34 the latter. These heterogeneities, however, are an excellent foundation for instrumental variable construction. Hence, this study resorts to two-stage least squares regressions with the log of average analyst coverage across similar stocks instrumenting for the log of the observed number of analysts. Three separate regressions are estimated, with coverage in the same sector, in the same sector and year, and in the same sector, year, and Fama-French styles. The validity of instrumental variable regressions is assessed using Durbin-Wu-Hausman endogeneity (Nakamura & Nakamura, 1981) and Anderson-Rubin weak instrument (Anderson & Rubin, 1949) diagnostic tests, as recommended in Young (2019).

Finally, this study considers potential spurious herding concerns. Spurious herding can be distinguished from herding proper in the sense that analyst forecasts might be correlated not due to imitation, but coincidentally due to the application of similar valuation models and techniques (Hwang & Salmon, 2004). Alternatively, a test might mistakenly recognise other analyst behavioral biases, such as optimism and conservatism (Blasco et al., 2018). To address the spurious herding criticism, this study utilises insights from prior research on "herding towards factors" (Hwang & Salmon, 2004), organisational psychology regarding the "magic number" of people that could constitute a group (Argenti, 2020; Collins & Poras, 1996), and studies on number processing biases (Roger et al., 2018). First, if the results are more pronounced for the long sides of Fama-French sorts, it can be interpreted as "herding towards factors" by analysts, augmenting the Hwang and Salmon (2004) perspective from the institutional side. Second, if the nature of herding observed is behavioral and not coincidental, it can be suspected that the herding patterns will be more pronounced after a certain breakpoint in the number of analysts that is sufficient to induce the possibility of imitation and groupthink. Such a "magic number" of group members is commonly assessed as being five or five to seven (Argenti, 2020; Collins & Poras, 1996). This can also separate behavioral herding from competition-driven herding as in Hong and Kacperczyk (2010) and Wang et al. (2020): if herding magnifies with the number of analysts, it is behavioral and caused by group psychology, whereas if herding diminishes with increased coverage, the conflict-of-interest explanation is more plausible. Therefore, this study considers estimations for subsamples based on analyst coverage, undertaking the Chow structural shift test (Chow, 1960) to determine whether such a breakpoint exists and if so, the number of analysts it corresponds to. The presence of herding above the breakpoint and absence thereof below it would reinforce the behavioral and non-spurious nature of detected effects. Finally, the study undertakes tests in subsamples based on the initial stock price. If the degree of herding varies in such estimations, the behavioral motivation of herding can be confirmed and linked with the number processing bias established in Roger et al. (2018).

As for the robustness of herding to other behavioral biases, this study also applies the following iterative procedure, sequentially adjusting the errors for optimism and conservatism, and then applying the regression herding test:

$$ln\frac{\overline{P}_{it}^{A}}{P_{it+1}} = \omega + \kappa\, ln\frac{\overline{P}_{it}^{A}}{P_{it+1}} + u_{it}$$

where ω and κ are the estimators of persistent analyst optimism and conservatism, respectively. This equation is estimated using weighted least squares, scaling each observation by the $(N_{it}^{A})^{-\beta}$, starting with $\beta = -0.5$ as per the null hypothesis of no herding. Next, the residuals u_{it} of the model are used in the conventional regression until convergence, in the full sample and across sectors and years for additional robustness:

$$ln\left|e^{u_{it}} - 1\right| = \alpha + \beta\ ln\ N_{it}^{A} + \varepsilon_{it}$$

Data and code for all estimation procedures and robustness tests are available upon request from the corresponding author. In the following section, test results are presented and discussed sequentially.

3. Findings and discussion

This section outlines the data this study uses alongside the application of developed statistical tests. Table 2 reports the descriptive statistics for the main variables, while Table 3 reports coverage across sectors, and Figure 2 visualises the full-sample relationship between the number of analysts and absolute prediction error in a scatterplot. Analyst coverage varies substantially across sample stocks from one to 50 analyst valuations per stock per year, allowing to sufficiently execute the regression-based test. Log absolute forecast error demonstrates behaviour close to normality. However, outliers are present and the concerns regarding their impact on the estimations are al-

Table 2. Descriptive statistics

	Number of analysts	Log forecast error	Log absolute error
Mean	6.9982	0.3564	–1.0413
Median	4	0.1792	–1.1212
Minimum	1	–5.8193	–8.1047
Maximum	50	8.1552	8.1549
Standard deviation	7.6036	0.7988	1.6016
Skewness	1.4811	1.5170	0.1603
Kurtosis	1.6589	8.0523	1.2317
Number of observations	12302	12302	12302

Source: Bloomberg.

Table 3. Sectoral data breakdown

Sector	Number of stocks	Stock-year observations	Analyst valuations
Communications	155	845	6,000
Consumer Discretionary	219	1,487	12,164
Consumer Staples	88	671	6,949
Energy	212	1,229	8,357
Financials	269	1,481	11,958
Funds	23	107	456
Health Care	144	756	3,699
Industrials	302	1,993	14,302
Materials	265	1,526	10,576
Real Estate	117	733	3,988
Technology	246	1,251	5,787
Utilities	39	223	1,617

Source: Bloomberg.

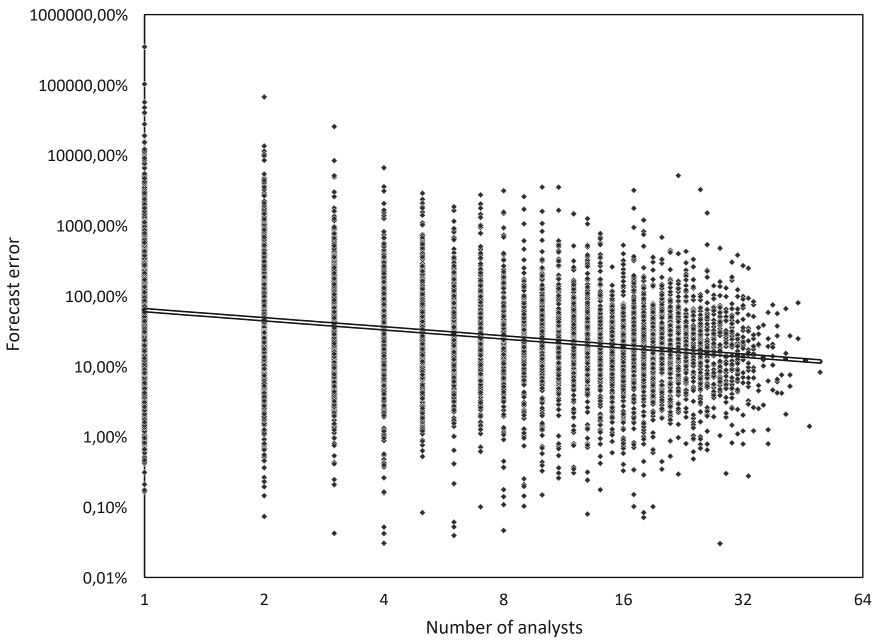

Figure 2. Full sample scatterplot

Source: Bloomberg.

leviated through the non-parametric binomial correlation test and in further robustness checks. Coverage does vary substantially across sectors, allowing for instrumental variable estimations to have sufficiently strong first stages. All the result output tables below report estimated coefficients alongside respective standard errors in parentheses, with ***, **, and * denoting statistical significance at 1%, 5%, and 10%, respectively.

Table 4 reports the binomial correlation test results. There is a significant positive correlation between analyst overvaluations in the full sample, in nine out of twelve sample years, and in most sectors. Herding is not observed for communications, health care, technology, funds, and utilities. This can be explained for the former three sectors, as they are generally technological-

Table 4. Binominal correlation test results

Panel A: Full sample	Correlation	Standard error	*T*-statistic	*p*-value
Across years	0.0449***	(0.0086)	5.2321	0.0000
Across sectors	0.0370***	(0.0086)	4.3066	0.0000
Across years and sectors	0.1188***	(0.0085)	13.9197	0.0000
Panel B: Individual years	**Correlation**	**Standard error**	***T*-statistic**	***p*-value**
2009	0.0562*	(0.0296)	1.8966	0.0581
2010	0.0305	(0.0293)	1.0410	0.2981
2011	0.0294	(0.0289)	1.0171	0.3093
2012	0.1288***	(0.0282)	4.5674	0.0000
2013	0.1778***	(0.0288)	6.1699	0.0000
2014	0.0973***	(0.0298)	3.2676	0.0011
2015	0.0813***	(0.0295)	2.7537	0.0066
2016	0.1010***	(0.0296)	3.4141	0.0007
2017	0.0846***	(0.0302)	2.8025	0.0052
2018	0.0471	(0.0302)	1.5567	0.1198
2019	0.0888***	(0.0306)	2.9009	0.0038
2020	0.0718**	(0.0319)	2.2549	0.0244
Panel C: Individual sectors	**Correlation**	**Standard error**	***T*-statistic**	***p*-value**
Communications	0.0542	(0.0329)	1.6457	0.1002
Consumer Discretionary	0.1301***	(0.0252)	5.1595	0.0000
Consumer Staples	0.1241***	(0.0376)	3.2989	0.0010
Energy	0.1012***	(0.0273)	3.7112	0.0002
Financials	0.1083***	(0.0250)	4.3313	0.0000
Funds	0.1480	(0.0922)	1.6043	0.1114
Health Care	0.0425	(0.0355)	1.2715	0.2039
Industrials	0.0746***	(0.0214)	3.4801	0.0005
Materials	0.1054***	(0.0241)	4.3669	0.0000
Real Estate	0.1733***	(0.0351)	4.9359	0.0000
Technology	0.0334	(0.0256)	1.3056	0.1919
Utilities	0.0627	(0.0642)	0.9771	0.3295

Notes: standard errors reported in parentheses; ***, **, and * denote statistical significance at 1%, 5%, and 10%, respectively.

Source: Bloomberg.

ly intensive and more difficult to value, enabling bold contrarian forecasts, and for the latter two, as funds and utilities have stable business models and simple valuation heuristics, yielding public information suitable for a forecast without imitating prior analysts.

The baseline regression test results presented below in Table 5 are generally consistent with these of the binomial correlation test. The null hypothesis of independent valuations is rejected in favour of the alternative hypothesis

Table 5. Regression test results across years and sectors

Panel A: Full sample	**Correlation**	**Standard error**	***T*-statistic**	***p*-value**
Full sample	–0.4291***	(0.0120)	5.9197	0.0000
Panel B: Individual years	**Correlation**	**Standard error**	***T*-statistic**	***p*-value**
2009	–0.4629	(0.0398)	0.9332	0.3509
2010	–0.4346*	(0.0355)	1.8416	0.0658
2011	–0.3273***	(0.0394)	4.3829	0.0000
2012	–0.4929	(0.0387)	0.1824	0.8553
2013	–0.3464***	(0.0364)	4.2245	0.0000
2014	–0.4141**	(0.0431)	1.9926	0.0466
2015	–0.3942**	(0.0454)	2.3305	0.0200
2016	–0.4976	(0.0402)	0.0597	0.9524
2017	–0.4150**	(0.0410)	2.0752	0.0382
2018	–0.4508	(0.0433)	1.1363	0.2561
2019	–0.5728	(0.0473)	–1.5376	0.1245
2020	–0.3796***	(0.0466)	2.5850	0.0099
Panel C: Individual sectors	**Correlation**	**Standard error**	***T*-statistic**	***p*-value**
Communications	–0.4339	(0.0434)	1.5248	0.1277
Consumer Discretionary	–0.3330***	(0.0347)	4.8122	0.0000
Consumer Staples	–0.4276	(0.0490)	1.4790	0.1396
Energy	–0.5252	(0.0398)	–0.6338	0.5263
Financials	–0.2608***	(0.0303)	7.9086	0.0000
Funds	–0.3321	(0.2464)	0.6814	0.4971
Health Care	–0.7693***	(0.0506)	–5.3266	0.0000
Industrials	–0.3855***	(0.0281)	4.0706	0.0000
Materials	–0.5008	(0.0347)	–0.0236	0.9811
Real Estate	–0.2696***	(0.0507)	4.5399	0.0000
Technology	–0.4149**	(0.0382)	2.2306	0.0259
Utilities	–0.7389***	(0.0813)	–2.9380	0.0037

Notes: standard errors reported in parentheses; ***, **, and * denote statistical significance at 1%, 5%, and 10%, respectively.

Source: Bloomberg.

of herding for the full sample, for seven out of twelve years, and five out of twelve sectors. Herding is most prominent for financials and real estate, potentially supporting the conflict-of-interest theory (Lee & Lee, 2015) or the groupthink theory.

Next, the prominence of herding is studied across Fama-French portfolio sorts. This is presented in Table 6. Analysts are rational, herding, ad contrarian for low-, medium- and high-beta stocks, respectively. This reiterates the "herding towards beta" concept of Hwang and Salmon (2004) and could also be explained in the context of the "betting against beta" investment strategy

Table 6. Regression test results across Fama-French portfolio sorts

Panel A: Market beta	**Coefficient**	**Standard error**	***T*-statistic**	***p*-value**
Low-beta (bottom 30%)	–0.4552	(0.0368)	1.2200	0.2226
Mid-beta (middle 40%)	–0.4136***	(0.0187)	4.6122	0.0000
High-beta (top 30%)	–0.5789***	(0.0228)	–3.4606	0.0005
Panel B: Size	**Coefficient**	**Standard error**	***T*-statistic**	***p*-value**
Small (bottom 30%)	0.0959***	(0.0932)	6.3930	0.0000
Mid (middle 40%)	–0.1024***	(0.0285)	13.9615	0.0000
Large (top 30%)	–0.1429***	(0.0235)	15.2180	0.0000
Panel C: Value	**Coefficient**	**Standard error**	***T*-statistic**	***p*-value**
Value (top 30%)	–0.4014***	(0.0264)	3.7319	0.0002
Mid (middle 40%)	–0.3670***	(0.0189)	7.0371	0.0000
Growth (bottom 30%)	–0.5183	(0.0213)	–0.8583	0.3908
Panel D: Momentum	**Coefficient**	**Standard error**	***T*-statistic**	***p*-value**
Winner (top 30%)	–0.3069***	(0.0195)	9.8887	0.0000
Mid (middle 40%)	–0.3445***	(0.0171)	9.1052	0.0000
Loser (bottom 30%)	–0.5318	(0.0261)	–1.2146	0.2246
Panel E: Profitability	**Coefficient**	**Standard error**	***T*-statistic**	***p*-value**
Robust (top 30%)	–0.2537***	(0.0201)	12.2532	0.0000
Mid (middle 40%)	–0.2523***	(0.0172)	14.3972	0.0000
Weak (bottom 30%)	–0.4556	(0.0315)	1.4075	0.1594
Panel F: Investment	**Coefficient**	**Standard error**	***T*-statistic**	***p*-value**
Conservative (bottom 30%)	–0.5128	(0.0241)	–0.5326	0.5944
Mid (middle 40%)	–0.3399***	(0.0175)	9.1350	0.0000
Aggressive (top 30%)	–0.4212***	(0.0223)	3.5300	0.0004

Notes: standard errors reported in parentheses; *** denotes statistical significance at 1%.

Source: Bloomberg.

(Frazzini & Pedersen, 2014). Analysts herd for all three sorts based on market capitalisation, although the magnitude of herding is smaller for large-caps. For value, momentum, and profitability, analysts are rational for the short sides of Fama-French factors (growth stocks, past year losers, and weak operating profitability companies) and herd towards their long sides, reinforcing the non-spurious nature of the detected phenomenon. For the investment sorts, the pattern is reversed, which can be explained by lower prominence and institutional reliance on the conservative-minus-aggressive factor documented in Shanaev and Ghimire (2021).

Figure 3 reports Chow structural shift *F*-statistic for candidate breakpoints in terms of the number of analysts. This estimation strategy allows econo-

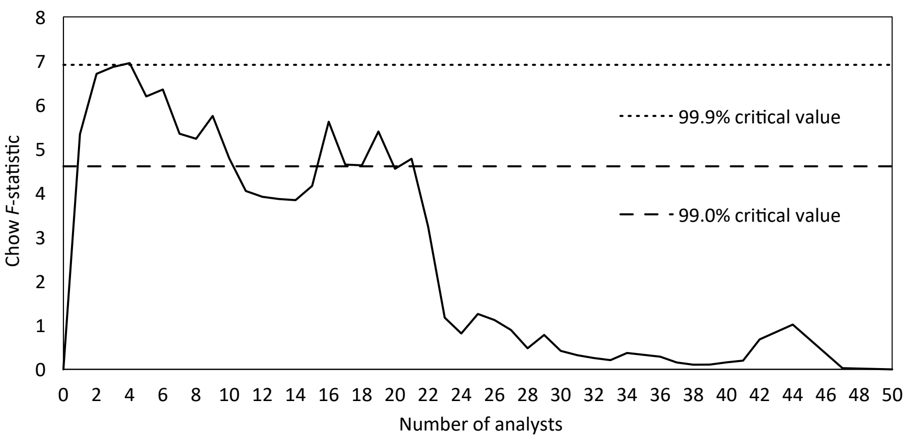

Figure 3. Chow structural break test for number of analysts

Source: Bloomberg.

mists, to distinguish between the conflict-of-interest explanation of herding, which predicts herding will be weaker for more followed stocks due to higher competition (Lee & Lee, 2015), and the behavioral theory relying on group psychology and hypothesising herding will become prominent, starting from a certain number of analysts covering the stock. The strongest structural break is observed for $N_{it}^{A} = 5$, demonstrating the relationship between coverage and log absolute prediction error is different for stocks followed by less than five analysts and by five analysts or higher. Interestingly, five is a commonly cited "magic number" for group formation (Collins & Poras, 1996), providing some early support for the behavioral group psychology explanation. This result dictates the methodological choice of estimating the baseline regression equation for subsamples based on the five analysts breakpoint.

Table 7 reports additional robustness checks for subsamples for varying analyst coverage (a breakpoint of five was chosen based on prior Chow structural shift test estimations) and stock price magnitude. The results support the behavioral nature of analyst herding, since the beta coefficient becomes significantly higher than –0.5 only when the stock is followed by at least five analysts, which is consistent with the group psychology theory and contradicting the conflict-of-interest and competition hypothesis; and for low- and mid-price stocks, supporting the number-processing bias (Roger et al., 2018).

Table 7. Regression test results: Additional robustness checks

Panel A: # of analysts	Coefficient	Standard error	*T*-statistic	*p*-value
Lower than five	–0.5380	(0.0370)	–1.0249	0.3055
Five or higher	–0.3530***	(0.0338)	4.3449	0.0000
Panel B: Stock price	**Coefficient**	**Standard error**	***T*-statistic**	***p*-value**
Low (below £1)	–0.2678***	(0.0334)	6.9414	0.0000
Mid (between £1 and £5)	–0.2773***	(0.0187)	9.9422	0.0000
High (above £5)	–0.4750	(0.0244)	1.0261	0.3049

Notes: standard errors reported in parentheses; *** denotes statistical significance at 1%.

Source: Bloomberg.

To further address heterogeneity and endogeneity bias concerns, Table 8 below reports estimation results in panel regressions with fixed effects and in TSLS regressions, where average coverage across sector, sector and year, and sector, year, and Fama-French factor sorts is instrumenting for the number of analysts, overwhelmingly reinforcing prior findings.

Table 8. Regression test results: Fixed effects and instrumental variable estimations

Panel A: Fixed effects	Coefficient	Standard error	*T*-statistic	*p*-value
Year effects	–0.4303***	(0.0119)	5.8457	0.0000
Sector effects	–0.4231***	(0.0119)	6.4442	0.0000
Sector and year effects	–0.4244***	(0.0119)	6.3687	0.0000
Stock effects	0.1153***	(0.0299)	20.5954	0.0000
Stock and year effects	0.1080***	(0.0302)	20.1474	0.0000
Panel B: IV estimations	**Coefficient**	**Standard error**	***T*-statistic**	***p*-value**
Sector	–0.3023***	(0.0632)	3.1278	0.0018
Sector, year	–0.2773***	(0.0598)	3.7215	0.0002
Sector, year, factor sorts	–0.4528***	(0.0127)	3.7175	0.0002

Notes: standard errors reported in parentheses; *** denotes statistical significance at 1%.

Source: Bloomberg.

The validity and informational value of the instrumental variable estimations discussed above is reinforced with Durbin-Wu-Hausman and Anderson-Rubin tests. It shows that TSLS estimators are significantly different from their OLS counterparts while having very strong first stages. This can be noted in Table 9.

Table 9. Diagnostic tests for instrumental variable estimations

IV estimation	Durbin-Wu-Hausman test		Anderson-Rubin test	
	T-statistic	*p*-value	*T*-statistic	*p*-value
Sector	4.2214**	0.0399	484.61***	0.0000
Sector, year	6.8055***	0.0091	545.36***	0.0000
Sector, year, factor sorts	50.2590***	0.0000	165827.90***	0.0000

Notes: *** and ** denotes statistical significance at 1% and 5%, respectively.

Source: Bloomberg.

Figure 4 reports the herding beta coefficient estimator alongside respective 90% confidence intervals in a quantile regression framework. Analysts are consistently herding when prediction error is low and around the median (up

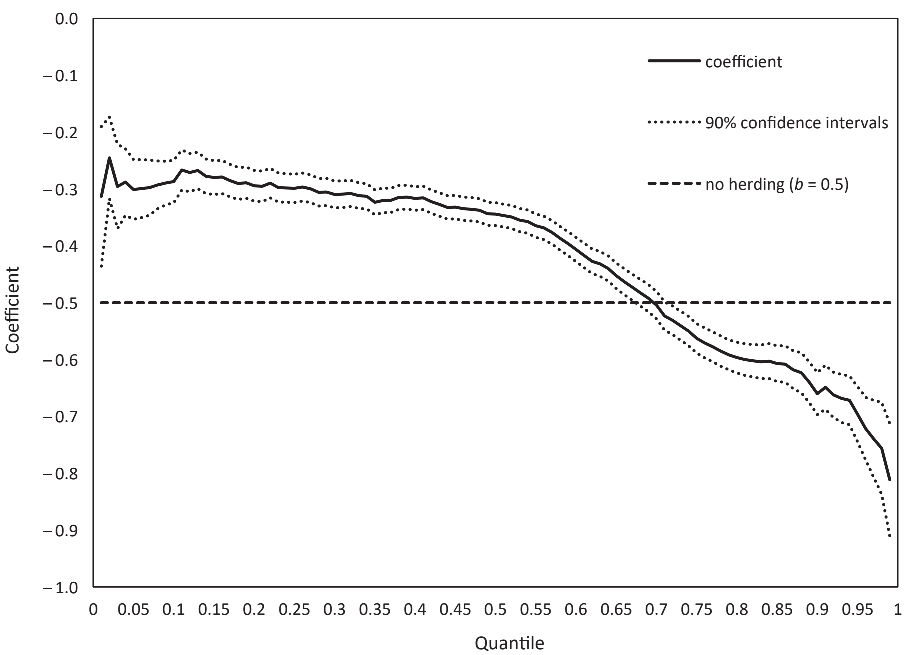

Figure 4. Quantile regression estimation results for the full sample

Source: Bloomberg.

to the 67th percentile), and are, on average, rational from the 68th until the 72nd percentiles and contrarian when forecast error is high (73rd percentile and above). These findings support Hwang and Salmon (2004), who report more prominent herding in investor behaviour during calm market periods, and Welch (2000), who finds a higher degree of analyst herding when market conditions are favourable, while contradicting Caparrelli et al. (2004) and Lin (2018).

To further account for the potential impact of outliers, all subsample-based tests are run in a quantile regression framework for conditional median estimations, with the results presented in Table 10. Consistent with previous findings, herding is confirmed in the full sample in all years except 2019, in all sectors apart from energy and funds (where analysts demonstrate rational behaviour), and utilities (where they are contrarian). The tendency of analysts to herd towards the long sides of Fama-French sorts (apart from the investment factor) and when coverage is sufficient also persists. An additional robustness check revolving around non-parametric Spearman and Kendall's tau correlation coefficients between analyst coverage and adjusted absolute prediction error also largely corroborates the previous results (see Table 11).

Table 10. Quantile regression conditional median estimations

Panel A: Full sample	**Coefficient**	**Standard error**	***T*-statistic**	***p*-value**
Full sample	–0.3442***	(0.0122)	12.7248	0.0000
Panel B: Individual years	**Coefficient**	**Standard error**	***T*-statistic**	***p*-value**
2009	–0.3320***	(0.0399)	4.2061	0.0000
2010	–0.3153***	(0.0342)	5.4006	0.0000
2011	–0.3105***	(0.0491)	3.8588	0.0001
2012	–0.4254*	(0.0437)	1.7066	0.0882
2013	–0.2428***	(0.0291)	8.8491	0.0000
2014	–0.4058*	(0.0523)	1.7997	0.0722
2015	–0.3170***	(0.0505)	3.6270	0.0003
2016	–0.3610***	(0.0472)	2.9440	0.0033
2017	–0.3043***	(0.0403)	4.8505	0.0000
2018	–0.3521***	(0.0464)	3.1888	0.0015
2019	–0.4279	(0.0512)	1.4095	0.1590
2020	–0.3405***	(0.0529)	3.0177	0.0026
Panel C: Individual sectors	**Coefficient**	**Standard error**	***T*-statistic**	***p*-value**
Communications	–0.3565***	(0.0460)	3.1207	0.0019
Consumer Discretionary	–0.2506***	(0.0316)	7.8938	0.0000
Consumer Staples	–0.3607***	(0.0528)	2.6404	0.0085
Energy	–0.5578	(0.0505)	–1.1440	0.2529
Financials	–0.2239***	(0.0320)	8.6288	0.0000

Funds	–0.4681	(0.2299)	0.1390	0.8897
Health Care	–0.7138***	(0.0670)	–3.1927	0.0015
Industrials	–0.2645***	(0.0264)	8.9114	0.0000
Materials	–0.4894	(0.0423)	0.2514	0.8016
Real Estate	–0.2715***	(0.0538)	4.2444	0.0000
Technology	–0.3465***	(0.0408)	3.7604	0.0002
Utilities	–0.6840*	(0.0946)	–1.9449	0.0531
Panel D: Market beta	**Coefficient**	**Standard error**	***T*-statistic**	***p*-value**
Low-beta (bottom 30%)	–0.3795***	(0.0424)	2.8412	0.0045
Mid-beta (middle 40%)	–0.3362***	(0.0197)	8.2929	0.0000
High-beta (top 30%)	–0.4893	(0.0219)	0.4886	0.6252
Panel E: Size	**Coefficient**	**Standard error**	***T*-statistic**	***p*-value**
Small (bottom 30%)	0.0699***	(0.1225)	4.6512	0.0000
Mid (middle 40%)	–0.0712***	(0.0285)	15.0249	0.0000
Large (top 30%)	–0.0991***	(0.0218)	18.3617	0.0000
Panel F: Value	**Coefficient**	**Standard error**	***T*-statistic**	***p*-value**
Value (top 30%)	–0.3778***	(0.0322)	3.7932	0.0002
Mid (middle 40%)	–0.2976***	(0.0194)	10.4448	0.0000
Growth (bottom 30%)	–0.3973***	(0.0209)	4.9139	0.0000
Panel G: Momentum	**Coefficient**	**Standard error**	***T*-statistic**	***p*-value**
Winner (top 30%)	–0.2434***	(0.0196)	13.1110	0.0000
Mid (middle 40%)	–0.2728***	(0.0178)	12.7876	0.0000
Loser (bottom 30%)	–0.6017***	(0.0321)	–3.1651	0.0016
Panel H: Profitability	**Coefficient**	**Standard error**	***T*-statistic**	***p*-value**
Robust (top 30%)	–0.1971***	(0.0201)	15.0565	0.0000
Mid (middle 40%)	–0.1958***	(0.0166)	18.3502	0.0000
Weak (bottom 30%)	–0.4750	(0.0383)	0.6532	0.5137
Panel I: Investment	**Coefficient**	**Standard error**	***T*-statistic**	***p*-value**
Conservative (bottom 30%)	–0.4627	(0.0271)	1.3782	0.1682
Mid (middle 40%)	–0.2715***	(0.0172)	13.2478	0.0000
Aggressive (top 30%)	–0.3362***	(0.0242)	6.7675	0.0000
Panel J: Number of analysts	**Coefficient**	**Standard error**	***T*-statistic**	***p*-value**
Lower than five	–0.4650	(0.0413)	0.8466	0.3972
Five or higher	–0.2445***	(0.0320)	7.9931	0.0000

Notes: standard errors reported in parentheses; *** and * denote statistical significance at 1% and 10%, respectively.

Source: Bloomberg.

Table 11. Non-parametric correlation tests

Panel A: Full sample	Spearman	*p*-value	Kendall's tau	*p*-value
Full sample	0.0743***	0.0000	0.0544***	0.0000
Panel B: Individual years	**Spearman**	***p*-value**	**Kendall's tau**	***p*-value**
2009	0.0713**	0.0198	0.0538**	0.0128
2010	0.1089***	0.0003	0.0790***	0.0002
2011	0.1407***	0.0000	0.0986***	0.0000
2012	0.0132	0.6561	0.0120	0.5657
2013	0.1927***	0.0000	0.1432***	0.0000
2014	0.0752**	0.0183	0.0550**	0.0138
2015	0.0755**	0.0164	0.0588***	0.0078
2016	0.0287	0.3599	0.0251	0.2552
2017	0.1027***	0.0011	0.0769***	0.0005
2018	0.0597*	0.0587	0.0439**	0.0476
2019	–0.0245	0.4463	–0.0149	0.5075
2020	0.0992***	0.0031	0.0695***	0.0030
Panel C: Individual sectors	**Spearman**	***p*-value**	**Kendall's tau**	***p*-value**
Communications	0.0666*	0.0529	0.0505**	0.0376
Consumer Discretionary	0.1660***	0.0000	0.1175***	0.0000
Consumer Staples	0.0727*	0.0597	0.0510*	0.0539
Energy	–0.0096	0.7371	–0.0078	0.6963
Financials	0.2367***	0.0000	0.1683***	0.0000
Funds	0.0577	0.5546	0.0400	0.5769
Health Care	–0.1669***	0.0000	–0.1198***	0.0000
Industrials	0.1313***	0.0000	0.0931***	0.0000
Materials	0.0074	0.7731	0.0075	0.6788
Real Estate	0.1744***	0.0000	0.1241***	0.0000
Technology	0.0662**	0.0193	0.0510**	0.0126
Utilities	–0.1925***	0.0039	–0.1424***	0.0027
Panel D: Market beta	**Spearman**	***p*-value**	**Kendall's tau**	***p*-value**
Low-beta (bottom 30%)	0.0306	0.1035	0.0230	0.1006
Mid-beta (middle 40%)	0.0823***	0.0000	0.0599***	0.0000
High-beta (top 30%)	–0.0173	0.2601	–0.0081	0.4386
Panel E: Size	**Spearman**	***p*-value**	**Kendall's tau**	***p*-value**
Small (bottom 30%)	0.1198***	0.0000	0.0953***	0.0000
Mid (middle 40%)	0.1985***	0.0000	0.1449***	0.0000
Large (top 30%)	0.2291***	0.0000	0.1587***	0.0000
Panel F: Value	**Spearman**	***p*-value**	**Kendall's tau**	***p*-value**
Value (top 30%)	0.0664***	0.0003	0.0484***	0.0002
Mid (middle 40%)	0.1223***	0.0000	0.0880***	0.0000
Growth (bottom 30%)	0.0255	0.1328	0.0208*	0.0768
Panel G: Momentum	**Spearman**	***p*-value**	**Kendall's tau**	***p*-value**
Winner (top 30%)	0.1980***	0.0000	0.1411***	0.0000

Mid (middle 40%)	0.1495***	0.0000	0.1066***	0.0000
Loser (bottom 30%)	–0.0272	0.1285	–0.0189	0.1387
Panel H: Profitability	**Spearman**	***p*-value**	**Kendall's tau**	***p*-value**
Robust (top 30%)	0.2308***	0.0000	0.1599***	0.0000
Mid (middle 40%)	0.2288***	0.0000	0.1624***	0.0000
Weak (bottom 30%)	0.0232	0.2349	0.0172	0.2258
Panel I: Investment	**Spearman**	***p*-value**	**Kendall's tau**	***p*-value**
Conservative (bottom 30%)	–0.0064	0.7217	–0.0025	0.8476
Mid (middle 40%)	0.1603***	0.0000	0.1135***	0.0000
Aggressive (top 30%)	0.0735***	0.0000	0.0534***	0.0000
Panel J: Number of analysts	**Spearman**	***p*-value**	**Kendall's tau**	***p*-value**
Lower than five	–0.0057	0.6340	–0.0043	0.6364
Five or higher	0.0789***	0.0000	0.0548***	0.0000

Notes: ***, **, and * denote statistical significance at 1%, 5%, and 10%, respectively.

Source: Bloomberg.

Table 12 presents the results of an iterative estimation adjusted for analyst optimism and conservatism. The security analysts have been excessively optimistic in all years apart from 2012 and 2019, when they were rational, and 2013, when they were overly pessimistic; and in all sectors apart from funds that are naturally easiest to value, and significantly conservative in all subsamples. Analysts are shown to consistently overestimate target forecast prices by 14% on average, which is consistent with the figures reported previously in the literature (Bradshaw, Brown et al., 2013; Brav & Lehavy, 2003). The results for herding when other prominent behavioral biases are accounted for become more pronounced, with the beta coefficient significantly higher than -0.5 in all sample years and in all sectors but funds and utilities. This robustness test reinforces the non-spurious nature of the herding detected by the regression test and illuminates the relationship between analyst herding and other biases that manifest in their valuations.

Conclusions

This study has developed two novel, flexible, and powerful tests based on binominal correlations and prediction error volatility scaling for herding in analyst target forecast prices. The purpose is to reinforce the existence and prominence of herding patterns among analysts observed over the 2008–2020 sample period in the United Kingdom. It contributes substantially to the de-

Table 12. Regression test results adjusted for analyst optimism and conservatism

Panel A: Full sample	**Optimism (ω)**	**Standard error**	**Conservatism ($\varkappa$)**	**Standard error**	**Herding (β)**	**Standard error**
Baseline	0.1404***	(0.0064)	0.5513***	(0.0188)	–0.2159***	(0.0116)
Panel B: Individual years	**Optimism (ω)**	**Standard error**	**Conservatism ($\varkappa$)**	**Standard error**	**Herding (β)**	**Standard error**
2010	0.0365**	(0.0180)	0.3894***	(0.0776)	–0.3060***	(0.0358)
2011	0.4142***	(0.0198)	0.5473***	(0.0698)	–0.1666***	(0.0314)
2012	0.0227	(0.0321)	0.5219***	(0.0716)	–0.2161***	(0.0385)
2013	–0.0959***	(0.0159)	0.7262***	(0.0439)	–0.2449***	(0.0340)
2014	0.2994***	(0.0187)	0.6927***	(0.0553)	–0.1998***	(0.0372)
2015	0.1107***	(0.0174)	0.8463***	(0.0461)	–0.2348***	(0.0417)
2016	0.0374*	(0.0277)	0.4691***	(0.0648)	–0.2410***	(0.0385)
2017	0.0410**	(0.0183)	0.4900***	(0.0697)	–0.2417***	(0.0405)
2018	0.3476***	(0.0153)	0.5823***	(0.0545)	–0.2867***	(0.0392)
2019	–0.0137	(0.0215)	0.7738***	(0.0571)	–0.2498***	(0.0429)
2020	0.1465***	(0.0160)	0.5647***	(0.0469)	–0.1806***	(0.0451)
Panel C: Individual sectors	**Optimism (ω)**	**Standard error**	**Conservatism ($\varkappa$)**	**Standard error**	**Herding (β)**	**Standard error**
Communications	0.1265***	(0.0201)	0.5131***	(0.0560)	–0.2219***	(0.0429)
Consumer Discretionary	0.1350***	(0.0154)	0.3975***	(0.0523)	–0.1760***	(0.0333)
Consumer Staples	0.0866***	(0.0150)	0.3822***	(0.0501)	–0.2553***	(0.0490)
Energy	0.3208***	(0.0255)	0.5570***	(0.0397)	–0.2675***	(0.0358)
Financials	0.1046***	(0.0126)	0.4627***	(0.0678)	–0.0924***	(0.0310)
Funds	0.0298	(0.0434)	0.5798***	(0.2196)	–0.4557	(0.3104)
Health Care	0.1433***	(0.0230)	0.6075***	(0.0552)	–0.3593***	(0.0454)
Industrials	0.1088***	(0.0117)	0.4900***	(0.0450)	–0.2271***	(0.0278)
Materials	0.1737***	(0.0259)	0.6577***	(0.0462)	–0.2089***	(0.0311)
Real Estate	0.1491***	(0.0212)	0.3683***	(0.0731)	–0.1361***	(0.0509)
Technology	0.1142***	(0.0169)	0.3900***	(0.0463)	–0.2030***	(0.0409)
Utilities	0.0630**	(0.0290)	0.4946***	(0.1211)	–0.5918	(0.0819)

Notes: standard errors reported in parentheses; ***, **, and * denote statistical significance at 1%, 5%, and 10%, respectively.

Source: Bloomberg.

bates on the presence, origins, and conditions of institutional herding prominent in the existing literature.

As such, the findings of the study confirm that herding is non-spurious and behavioral in nature, as analyst herding is more prominent towards the long sides of the Fama-French factor portfolio sorts (small and value stocks, past year winners, and companies with high operating profitability), consistent with the betting-against-beta strategy, exacerbates when a stock is followed by at least five analysts, corresponding to the insights from group psychology, and for low- and mid-price stocks, reinforcing the number processing bias hypothesis. The results are largely inconsistent with the conflict-of-interest explanation and the competition hypothesis, as herding does not diminish with increased analyst coverage. Subsample and conditional quantile estimations show that herding is more prominent when uncertainty and market volatility is low. The flexibility of the derived econometric tests allows them to be applied to aggregated, readily available data, and to simultaneously test for herding, optimism, and conservatism in an iterative regression framework, while also not requiring specialised, high-frequency, or analyst-level datasets.

For practitioners and policymakers, the study has confirmed that analyst forecasts, while potentially yielding informational value, are affected by mostly behavioral rather than institutionally driven biases, thus herding in security analysts might not be as easy to address with policy interventions, incentive design, or governance practices as previously thought. Furthermore, as herding is more prominent during calm market periods, its contribution towards market fragility and systemic risk can be found lower than presumed. Individual investors could use the findings of this study to assess the reliability of the analyst consensus for various stocks subject to different market conditions.

The validity and consistency of the obtained results is evidenced across both tests as well as being subject to a battery of robustness checks accounting for heterogeneity and endogeneity biases and also the effect of outliers. Findings persist in 1) sectoral and yearly subsamples; 2) in panel regressions with cross-sectional (sectoral and firm-level) and time fixed effects; 3) two--stage least squares estimations with average coverage across similar stocks instrumenting for the number of analysts observed; 4) conditional median models in the quantile regression framework; 5) in non-parametric correlation tests; and 6) when adjusted for other behavioral biases, such as optimism (pessimism) and conservatism (recency bias). Future research could apply the procedures derived in this study to other security analyst forecasts, such as earnings estimates, and also test for the robustness of this study's results on other prominent international markets, such as the United States, Japan, or the European Union.

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What drives the savings rate in middle-income countries?

Wiktor Błoch[1]

Abstract

The aim of this study is to examine the factors that influence the savings rate in middle-income countries and to compare the results with other studies devoted to different subgroups of countries. Among the potential determinants of savings the study considers: demography, income level, financial sector, international trade, inflation and the structure of the economy. The research sample is confined to 44 middle-income countries and covers the period between 2000 and 2019. Six model specifications are constructed using three different estimators: FE, FGLS and PCSE. In the next step, the same models are estimated using alternative dependent variables. Results suggest that industrial share in GDP has a positive impact on the savings rate. On the other hand, a negative relationship was diagnosed between the savings and unemployment rates, the share of labour compensation in GDP, military expenditure, inflation and the young dependency ratio.

Keywords

- savings rate
- Gross savings
- Gross domestic savings
- middle-income country

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Introduction

Savings are usually considered to be the difference between disposable income and consumption expenditure (Adelakun, 2015). Saving constitutes an important household economic activity and its significance may be perceived both from microeconomic and macroeconomic points of view. At the microeconomic level savings let households stabilize their consumption in the case of a decrease in income due to disability or job loss for example. At the macroeconomic level aggregated savings may be used as a source for investments (Zhuk, 2015).

Savings are closely related to investments. The positive role of savings and investments in boosting and maintaining economic growth is laid out in economic theory. Domar (1946) stated that savings and investments are the two main variables that determine equilibrium in the economy. This theory concentrates on how economic growth depends on the rate of savings and investments and also on the capital-output ratio. Solow (1956) indicated savings and investments as determinants of economic growth. According to this theory, a higher savings rate can facilitate higher growth of income and capital per capita during the transition to a steady state. They can also contribute to achieving a higher level of income and capital per capita. However an increase in savings does not influence economic growth in the long run. On the other hand endogenous growth models suggest that an increase in the savings rate and an increase in population positively affect the long-term growth rate (Samantaraya & Patra, 2014).

Apart from theoretical models, various studies have investigated the role of savings in the economy and their determinants. Most are devoted to Asian and developing countries (e.g., Aric, 2015; Horioka & Hagiwara, 2011; Jongwanich, 2010; Ma & Liu, 2022). Some also focus on developed countries (e.g., Cohn & Kolluri, 2003; Kandil, 2015).

This study is devoted to middle income countries. The World Bank distinguishes four income groups: low, lower middle, upper middle, and high. According to this classification, there are 108 middle income countries (including lower and upper middle income) out of 217. Felipe et al. (2012) classified 48 countries as middle income, 32 as low income and 40 as high income. Both classifications suggest that the group of middle-income countries is the biggest. These countries account for about five billion people (two-thirds of the world's population) and represent about one-third of global GDP. They are crucial for global stability and economic growth. The World Bank suggests positive spillovers of the development of of middle income countries to the rest of the world such as poverty reduction, international financial stability, trade, food and water security, and sustainable energy development (World Bank, 2022).

Gill and Kharas (2007) observed the development paths of middle-income countries and concluded that only a few reached the high income level. Based on these observations they created the concept of the middle-income trap, i.e. the transition from middle-income to high income is not automatic In order to reach high income it is necessary to implement an appropriate strategy that involves specializing and diversifying production or innovations. Ohno (2009) suggests that in order to reach high income level middle income economies have to transform their economic model. It is necessary to internalize skill and knowledge by accumulating industrial human capital. Local units are replaced by foreigners in all areas of production including management, technology, design, factory operation, logistics, quality control, and marketing. The theory of the middle-income trap suggests the existence of crucial differences between middle income countries and low and high income countries when it comes to engines of growth which justifies confining the analysis to these groups of countries. Joyasooriya (2017) and Aiyar et al. (2013) found a negative impact of investment share on the probability of being trapped. Building savings is the factor that makes investment expansion possible which is one of the key determinants of success for middle-income countries.

Many of the empirical studies that investigated the determinants of savings rate are devoted to low-income countries (mostly African) (Adelakun, 2015; Kapingura et al., 2015; Kudaisi, 2013). Middle income countries are analysed less frequently. Some middle income countries were included by Cansin Doker et al. (2016). However, their research sample included also low-income ones. Bhandari et al. (2007) investigated the determinants of private savings in five South Asian countries while Horioka and Hagiwara (2011) concentrated on those in developing Asia. Other studies on middle income countries are usually based on a narrow database. Therefore, there is a gap in terms of studies that analyze the determinants of savings rates in middle income countries. This article aims to find the determinants of the savings rate in middle income countries and compare the results with other studies that investigate different sub-groups of countries.

The structure of the article is as follows. Section 1 is a literature review devoted to determinants of savings. In Section 2 data, methodology and form expectations referring to sings of estimated parameters on the based of review of theoretical and empirical literature are presented. Section 3 is devoted to presenting and discussing results. Concluding remarks are provided in the last Section.

1. Conceptual underpinnings

An important strand of economic literature investigates the role of demographic factors in shaping the savings rate in the economy (Samantaraya & Patra, 2014). The basic concept that tries to explain the link between demographic factors and individuals' savings and consumption is the Life Cycle Income Hypothesis developed by Modigliani and Brumburg (1954). It is based on the assumption that individuals allocate their lifetime income to consumption in several periods in their life to maximize lifetime utility. The aim is to equalize the discounted marginal utility of consumption in each period. People seek to smooth their consumption throughout their life, borrowing when they have low income and saving when they have high income. The life cycle model was modified by adding childhood and retirement (Coale & Hoover, 1958).

The early life-cycle stage has a negative impact on public and private savings. The demographic transition of declining fertility and mortality affects savings patterns. The savings rate grows quickly in the first period after the transition and after a few decades it starts to decline because more and more people retire (Mason, 2001). This model was also extended by including microeconomic behaviour. Tobin (1967) added variables to the model such as a positive interest rate, probable life span, income profiles for men and women, two periods of dependency and profiles for men and women. Coale and Hoover (1958) assumed that mortality and fertility occur independently of life cycle savings behaviour. The life cycle income hypothesis implies that savings' behaviour depends on the growth rate of the national income, pension plans and the age structure of the population (Colak & Ozturkler, 2012).

An empirical study conducted by Tobing (2012) shows that demographic factors explain up to 68% of the differences in savings rates between countries. According to the Life Cycle Income Hypothesis, a high dependency ratio (young dependency as well as old dependency) means that there are more individuals who are at the stage of their life when they reduce much more than accumulate savings. So a high dependency ratio is supposed to have a negative impact on national savings. Using data for 14 north African countries and four middle eastern countries over the period 1960–2001. Yasin (2007) distinguished three groups of people: children (under 14), working group (15–65) and retired (over 65). He also showed that there are negative savings among children and retirees and positive savings among the working group.

Several studies indicate the negative impact of the dependency ratio (both young and old) on savings. Some are devoted to particular countries (e.g., Ahmed & Cruz, 2018; Jongwanich, 2010; Samantaraya & Patra, 2014) and others are conducted based on panel data for groups of countries (e.g., Kudaisi, 2013; Loayza & Shankar, 2000). Bosworth and Chodorow-Reich (2006) found that aging negatively impacts the savings ratio and that demographic factors have no influence on savings in industrial countries. In contrast, Horioka and Wan (2007) found no evidence of the link between variables connected with the age structure and savings rate in China. Bloom et al. (2002) showed that higher life expectancy positively affects savings at every age. Doshi (1994) also found a positive link between life expectancy and savings, but only for less-developed countries. For developed countries the results obtained by Doshi (1994) suggested the opposite relationship. Empirical studies also suggest the negative impact of population growth on savings (Ogbokor & Samahiya, 2014).

The absolute Income Hypothesis suggests that the savings ratio is connected with income level. Consumption and savings depend on disposable income. However, if income increases consumption also increases but less than income. Rich people save relatively more and consume proportionally less than poor people which is why the increase in savings caused by an increase in income is proportionally higher than the increase in consumption. A positive link between income and savings rate has been confirmed by various empirical studies (e.g., Agrawal, 2001). According to Friedman's (1957) Permanent Income Hypothesis, consumption is a continuous function of income. Consumption and savings depend on the expected long-term average income. People save when their current income exceeds their anticipated level of permanent income.

According to the concept of Ricardian Equivalence, savings also depend on fiscal policy. Expectations also play a major role in this theory. An expansionary fiscal policy that results in an increase in public debt causes an increase in savings. The reason is that households expect that taxes will increase in the future because it will be necessary to pay off debt. Consumers are rational and decide to save more now in order to be able to pay higher taxes in the future. This theory implies that the fiscal stimulation of the economy by fiscal policy is ineffective. Larbi (2013) confirmed the positive link between government deficit and private savings. According to Nasir and Khalid (2004), a fiscal deficit negatively impacts private savings. These results are contrary to the implications of the Ricardian Equivalence Theory.

The intensive development of the financial sector in recent decades has drawn researchers' attention to its implications for other macroeconomic indicators including savings rates. The relationship between financial development and savings was investigated by McKinnon (1973) who concluded that the development of the financial sector has a positive impact on savings because it raises the efficiency of financial intermediation. A developed financial sector can provide alternative savings' instruments that are more suitable for individual preferences (Schmidt-Hebbel & Serven, 2002). Quartey (2005) found a positive relationship between financial development and savings in Ghana between 1970 and 2001. Meanwhile Ang (2009) investigated the link between the financial system and savings in Malaysia between 1960 and 2007. He found a positive relationship between financial deepening and savings although the development of insurance markets and the liberalization of the financial system had a negative impact on savings. It implies that the consequence of financial development which may increase borrowing patterns will increase consumption at the expanse of savings (Kapingura et al., 2015).

The results of studies in this area are mixed. Analysing Pakistan, Khan and Hye (2010) found a positive relationship between financial development and savings. Similarly, Granville and Mallick (2004) employed the same model for the UK and found that financial sector development has a positive impact on savings and growth. Studies do not provide a clear explanation of the link between financial liberalization and savings. Reinhart and Tokatlidis (2001) stated that financial liberalization had positive effects mostly in developed countries. However, in low-income countries they did not identify any benefits. Loayza et al.'s (2000) empirical results suggest that financial liberalization does not boost private savings. Morgan and Long (2020) study example of Laos and prove the positive attitude of financial literacy on savings. While Cohn and Kolluri (2003) confirmed the positive impact of the interest rate on savings other studies suggest the opposite (e.g., Thanoon and Baharumshah, 2005) or find no significant impact of interest rates on savings (e.g., Kudaisi 2013).

Because of the liberalization of international trade external shocks are more easily distributed, causing fluctuations in small, open economies. The consequences of a deterioration in the terms of trade in small, open economies have drawn much attention. The Harberger-Laursen-Metzler effect suggests that a decrease in current income arising from an adverse shock in the terms of trade leads to a decrease in total savings and a deterioration of the current account balance (Wang et al., 2016). The effects of changes in the terms of trade on savings behaviour are affected by expectations formed by private agents. If they expect that the deterioration is temporary they may decrease their savings to compensate for a decrease in their purchasing power and keep expenditures constant. If the change is expected to be permanent, it could influence current and future income but have no effect on the savings rate (Jongwanich, 2010).

Empirical evidence on the link between inflation and savings rate is mixed. Several studies have found that inflation has a positive impact on savings (e.g., Ang, 2009; Loayza & Shankar, 2000). It is based on the assumption that inflation proxies for economic instability. The precautionary motive concept suggests that greater macroeconomic instability encourages people to save more of their income (Kapingura et al., 2015). On the other hand, high inflation may depress the value of real wealth and erode consumer income which ultimately discourages savings. Samantaraya and Patra (2014) suggest that inflation negatively impacts savings.

The structure of the economy is also expected to influence the savings rate. Samantaraya and Patra (2014) stated that the share of the agriculture sector in GDP may negatively influence household savings. They indicated a link between a significant decline in the share of the agricultural sector in India after the 1970s and an increase in savings. According to Abid and Afridi (2010), households in rural areas record a higher saving ratio than those in urban areas. A positive link between the percentage of the rural population and savings was also suggested by Niculescu-Aron and Mihaescu (2012). Cardenas and Escobar (1998) found that private savings significantly decrease with urbanization although the opposite was suggested by Yasin (2007). He found that increased urbanization leads to an increase in the savings rate.

Studies devoted to determinants of savings rate are mixed. Researchers look for determinants of savings in many different areas such as demography, the financial sector, etc. Many studies are devoted to analysis of particular countries (Samantaraya & Patra, 2014). In the case of a panel analysis of groups of countries the criterion of selecting them is geographical proximity (Kudaisi, 2013) or membership in an international organization (Aric, 2015). It is observed that there is shortage of studies devoted to groups of countries representing the same level of income and especially middle-income.

2. Data, methods and hypotheses

The data used for this study is from the period 2000 to 2019. The research sample contains middle-income countries.[2] The first step was to choose criteria to distinguish particular income groups. There are classifications based on absolute income levels (Felipe et al., 2012; World Bank, 2022) and classifications based on the relative income level compared to a technological leader which is usually the USA (e.g., Bulman et al., 2017; Im & Rosenblatt, 2013). This study applies the criteria proposed by Im and Rosenblatt (2013) whereby middle-income is between 15% and 60% of the GDP per capita of the USA. Small economies with populations not exceeding one million were excluded. Thus, the final sample comprised 44 middle-income countries with populations greater than 1 million. Table 1 contains the variables used in this study, their description and source of data. Table 2 presents descriptive statistics including the number of observations, mean value, sandart deviation, minimal and maximal value.

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[2] Research sample includes: Algeria, Argentina, Belarus, Botswana, Brazil, Bulgaria, Chile, Columbia, Costa Rica, Croatia, Czech Republic, Dominican Republic, Estonia, Eswatini, Gabon, Greece, Hungary, Iran, Iraq, Latvia, Lithuania, Malaysia, Mauritius, Mexico, New Zeland, North Macedonia, Oman, Panama, Poland, Portugal, Romania, Russia, Saudi Arabia, Serbia, Slovakia, Slovenia, South Africa, South Korea, Spain, Thailand, Trinidad and Tobago, Tunisia, Turkey, Turkmenistan, Uruguay, Venezuela.

Table 1. Variables descriptions

Variables	Description	Source of data
Gross_domestic_savings	gross domestic savings calculated as GDP less final consumption expenditure (total consumption)	*World Development Indicators*
Gross_savings	gross savings (% of GDP) calculated as GDP less final consumption expenditure (total consumption)	*World Development Indicators*
Young_dependency	ratio of people younger than 15 to working age population between 15 and 64 age	*World Development Indicators*
Old_dependency	ratio of people older than 64 to working age population	*World Development Indicators*
Labour_compensation	total compensation of employees given as a percent of GDP	*World Development Indicators*
Military_expenditure	ratio of military spending in country to GDP	*World Development Indicators*
Industry_share	share of industrial sector in GDP	*World Development Indicators*
Unemployment	unemployment rate based on nationally representative labour force surveys	*World Development Indicators*
Inflation	inflation measured on the basis of the consumer price index	*World Development Indicators*
Terms_of_trade	ratio between the index of export prices and the index of import prices	*World Development Indicators*

Source: (*World Development Indicators*, n.d.).

In order to find determinants of the savings rate the following regression model was used that includes nine explanatory variables and gross domestic savings (% of GDP) as the dependent variable:

$$\text{Gross\_domestic\_savings} = \beta_0 + \beta_1 \text{ Young\_dependency} + \beta_2 \text{ Old\_dependency} + \beta_3 \text{ Labour\_compensation} + \beta_4 \text{ Military\_expenditure} + \beta_5 \text{ Industry\_share} + \beta_6 \text{ Unemployment} + \beta_7 \text{ Inflation} + \beta_8 \text{ Terms\_of\_trade} + \text{StateFixedEffect} + \text{TimeFixedEffect} + \text{e}$$

The baseline model was estimated using a Fixed Effect (FE) model with time effects. Here there exists a choice between a fixed effect model and a random effect model. In order to make a decision estimation was preceded by performing the Hausman test. The p-value obteined in this test equals 0.02 and allows the rejection of the null hypothesis according to which the difference in coefficients is not systematic at the level of 0.05 which suggests

Table 2. Descriptive statistics

Variable	Obser-vations	Mean	Standard deviation	Min	Max
Gross_domestic_savings	887	26.03466	12.08013	1.584125	87.8268
Gross_savings	827	23.53766	8.541504	3.850888	57.41379
Young_dependency	920	35.58203	14.36083	17.65597	80.10817
Old_dependency	920	15.60766	8.01826	3.003785	34.72009
Labour_compensation	880	0.4840763	0.1146993	0.0896572	0.7062411
Military_expenditure	890	2.05129	1.846562	0	13.32567
Industry_share	909	5.569747	11.52382	0	66.56408
Unemployment	920	10.41883	6.86341	0.25	37.25
Inflation	867	6.330244	13.75285	–10.06749	254.9485
Terms_of_trade	920	118.9575	43.80566	50.19474	458.5745

Source: own elaboration.

the use of a fixed effect model. In order to check the robustness of the results two alternative estimators were used: FGLS and PCSE. FGLS is an useful method because it deals with OLS disturbances such as heteroskedasticity, autocorrelation and cross-panel correlation. According to Beck and Katz (1995), FGLS produces coefficient standard errors that are underestimated. They carried out Monte Carlo experiments suggesting that the PCSE estimator produces accurate standard error estimates with little, or no loss in efficiency comparing to FGLS.

The same three estimators were used in a model with an alternative dependent variable: gross savings:

$$\text{Gross\_savings} = \beta_0 + \beta_1 \text{ Young\_dependency} + \beta_2 \text{ Old\_dependency} + \beta_3 \text{ Labour\_compensation} + \beta_4 \text{ Military\_expenditure} + \beta 5 \text{ Industry\_share} + \beta_6 \text{ Unemployment} + \beta_7 \text{ Inflation} + \beta_8 \text{ Terms\_of\_trade} + \text{StateFixedEffect} + \text{TimeFixedEffect} + e$$

The Penn World Table 10.0 database was used to calculate GDP per capita for all countries which was necessary to be able to classify them into particular income groups and ultimately to create the research sample. This database was also the source of data on the share of labour compensation in GDP. The source of all other variables used is the World Bank database.

Models include eight independent variables. The first two variables refer to demography. In the case of the dependency ratio expectations were based on Life Cycle Theory, which suggests that the biggest savings are generated when people are of working age. Children and pensioners tend to have negative savings so a higher share of young and old people in the population negatively affects the overall savings rate. The literature provides evidence for a negative relationship between the dependency ratio and savings. The results for low-, middle-, and high income countries do not vary significantly. This link was confirmed by panel estimations for poor African countries (Kudaisi, 2013; Yasin, 2007). The same conclusions are suggested by Agrawal (2001) who included seven developing Asian countries (Singapore, South Korea, Taiwan, Thailand, Malaysia, India and Indonesia) and Horioka and Hagiwara (2011) who analyzed developing countries in Asia. Thanoon and Baharumshah (2012) drew similar conclusions and found no difference between Asian and Latin America Economies.

The next variable is labour compensation which constitutes the share of national income received by workers. On the other hand, there is capital income which goes to the owners of assets. A negative impact of the labour share on savings rate is expected because of the positive correlation between this variable and inequalities. This relationship is confirmed by several studies. For example, Daudey and Garcia-Penalosa (2007) found that a higher labour share is connected with lower Gini in 39 developed and developing countries. Checchi and Garcia-Penalosa (2008) obtained the same results when analysing 16 OECD countries. Wolff (2010) observed that capital ownership is mostly concentrated at the top of the income distribution and increasing the capital share increases income inequalities. The hypothesis that deeper income inequalities increase savings was confirmed by several studies (e.g., Bunting, 1991; Dynan et al., 1996). It is based on the assumption that people with a higher income have a higher propensity to save so the concentration of income is expected to positively affect savings.

Unemployment negatively affects personal income so the negative correlation between income and savings rate proposed by the absolute income theory suggests that it should have a negative influence on savings. Military spending is expected to have a negative impact on savings for three reasons. Firstly, the reallocating of public funds to the army causes a reduction in public services. Households need to reduce savings and increase consumption in order to compensate. Secondly, an increase in public spending diminishes public savings if it is not connected with an increase in taxation. Finally, armament imports lead to increased foreign debt reducing foreign savings (Deger, 1986). The literature review showed that results that refer to the link between GDP structure, inflation and savings are mixed. In the case of terms of trade a positive impact on the savings rate is expected which is based on the Harberger-Laursen-Metzler effect.

3. Results and discussion

Table 3 presents the results of three regression equations using the three alternative estimation methods. In all these specifications, the dependent variable is gross domestic savings. Table 4 presents the results of three estimations using the same methods as in Table 3 but with gross savings as the dependent variable.

Table 3. Results of estimations with gross domestic savings

Variables	FE	FGLS	PCSE
Young_dependency	0.0741637 (0.1349713)	–0.1307574*** (0.0201414)	–0.1867151*** (0.0479971)
Old_dependency	0.3272396 (0.34592)	–0.1595099*** (0.0342667)	–0.2454011*** (0.0976595)
Labour_compensa-tion	–45.42193*** (11.43854)	–25.7801*** (2.233605)	–38.86476*** (4.792349)
Military_expenditure	–0.9287919** (0.4252179)	–0.7814734*** (0.1384219)	–0.6036719*** (0.1630324)
Industry_share	0.5286666*** (0.0844803)	0.2610368*** (0.0311571)	0.2937169*** (0.044588)
Unemployment	–0.3958109*** (0.0705206)	–0.4049658*** (0.0246136)	–0.2665871*** (0.0415516)
Inflation	–0.0556894*** (0.0180001)	–0.0476124*** (0.01957)	0.0091707 (0131842)
Terms_of_Trade	0.0510722*** (0.0191073)	0.0055612 (0.0054968)	0.0577791*** (0.0103644)
R^2	0.64	–	0.9
Observations	785	785	785
Number of countries	42	42	42

Source: own elaboration.

Most model specifications suggest that both dependency ratios (young and old) have a negative impact on the savings rate but the results of the FE estimations are different. The young dependency ratios are significant at the level of 1% in four out of the six specifications and the old dependency ratio is significant in only two out of the six specifications. The dependency ratios are insignificant in both specifications where the FE model was applied. The results suggested by most model specifications that refer to links between these demographic variables are in line with expectations but not robust. The

Table 4. Results of estimations with gross savings

Variables	FE	FGLS	PCSE
Young_dependency	–0.0077072 (0.1038917)	–0.1047146*** (0.0226948)	–0.1324977*** (0.0422051)
Old_dependency	0.3082833 (0.2284177)	–0.0487773 (0.0375636)	–0.0121408 (0.1373445)
Labour_compensation	–35.23657*** (10.9188)	–24.37252*** (2.383591)	–24.41311*** (5.537424)
Military_expenditure	–1.47092*** (0.6082281)	–0.7152676*** (0.138579)	–0.9804139*** (0.207084)
Industry_share	0.4380464*** (0.1109569)	0.4553124*** (0.0259308)	0.4006672*** (0.0432615)
Unemployment	–0.226569*** (0.0793033)	–0.1238151*** (0.0243332)	0.0344441 (0.057358)
Inflation	–0.0493095*** (0.022284)	.003455 (0.0172889)	–0.0068487 (0.0164232)
Terms_of_Trade	0.0312775* (0.0182315)	–0.0228699*** (0.0042285)	0.0091622 (0.0123862)
R^2	0.53	–	0.91
Observations	779	779	779
Number of countries	42	42	42

Source: own elaboration.

labour_compensation variable which represents the share of labour compensation in GDP is significant at the level of 1% in all specifications. The conclusions arising from the estimation are in line with the results obtained in this study. The unemployment rate and military spending have both negative and significant impact on the savings rate which is also in line with expectations. In the case of unemployment, this relationship is significant at the level of 1% in five out of the six model specifications and in the case of military spending the relationship is significant in all estimated equations.The share of industry in GDP has a positive and statistically significant impact on the savings rate. This study provides evidence for an adverse relationship in middle-income countries. The results of this study also do not shed new light on the relationship between inflation and savings rate. The coefficient for inflation is not significant in three out of the six regression equations. The sign of the coefficient also varies when a different estimator is applied. In the case of the terms of trade the situation is similar. In most regression equations the sign of the coefficient for the terms of trade is positive. These results are in line with the Harberger-Laursen-Metzler effect. However, the results of the regression equations are not robust.

Results suggest that a high unemployment rate has a significant and negative impact on savings so it should be a crucial field of interest for policymakers in middle-income countries. The unemployment rate in middle income countries does not differ significantly from low- and high- income countries. In 2022 it was slightly higher: 6,1 vs 4,5 in high income countries and 5,4 in low income countries. The group of middle income countries is not uniform in this field. Unemployment constitutes big problem especially in African countries. In 2022 among the middle income countries included in the research sample the highest unemployment rate was recorded in South Africa (almost 30%). The unemployment rate exceeded 20% in other African countries such as Gabon, Eswatini and Botswana. A positive phenomenon is that the unemployment rate in middle income countries is quite low and stable. The negative effect of the pandemic in 2020 almost disappeared and in 2022 the unemployment rate was higher than in 2019 only by 0,4 percentage point (World Bank, 2022).

Military spending as a share of GDP in middle income countries are lower than in high income countries but significantly higher than in low income countries. On average they constitute 1,8%–1,9% of GDP. This value has remained quite stable in last decade. Military spending is determined mostly by non-economic factors such as the political and geopolitical situation. Military spending is high in the countries which face problems of civil war (e.g., Columbia) or are at risk of conflicts with neighboring countries. From the economic point of view military spending may be considered as an external factor which causes difficulty for policymakers. The necessity to invest large funds into the army caused by non-economic conditions reduces the possibilities of potential investmets in different sectors contributing to an increase in national welfare.

The role of the industrial sector in the economy is much greater than in high and low income countries. Su and Yao (2017) advocate that the industrial sector is especially important at middle-income level because it constitutes a key engine for economic growth. Apart from the size of the industrial sectorit is important as to how technologically advanced it is especially when it comes to the potential to reach a high income level. In this context an important fact is that in the research sample countries where the size of the industrial sector is the biggest are oil-exporting countries. So in these cases the main reason for the large size of the industrial sector is the contribution of the oil production sector instead of advanced industries. Results of these study suggest that in the case of middle income countries economic policy which prioritizes the industrial sector is favourable for savings accumulation.

A negative relationship between the share of labour compensation in GDP and the savings rate is problematic for policymakers because higher wages are usually favourable and supported by the majority of people. A policy which is aimed at keeping wages on a low level is difficult to implement especially under a democratic regime. There is a conflict of interest between short run goals to improve the standard of living of people and long run goals to increase production capacity. For sure a policy aimed at reducing inequalities including a fast increase of the minimum wage and social benefits is not favourable for the generation of savings.

Conclusions

This study provides evidence for the statistically significant influence of four explanatory variables (Labour_compensation, Military_expenditure, Unemployment and Industry_share) on the savings rate in middle income countries. In the case of the other variables the results are not clear and robust. Robustness of the aforementioned variables, is confirmed by estimations using alternative methods of estimation and alternative dependent variables. Results referring to the relationship between the first three variables and the savings rate are in line with expectations. They are not controversial and strongly justified by theory. An important conclusion arising from the study is the positive impact of the size of the industrial sector on the savings rate which was diagnosed. Strong robust results in this field constitute important an contribution to the discussion. The problem is lack of a clear answer about the relationship between inflation and terms of trade and the savings rate. This study does not provide robust results. The conclusion drawn based on the literature review of both theoretical and empirical evidence and also from this study is that the impact of a few factors on the savings rate is still not clearly justified. It means that there still exists a gap which may be filled by future studies. This study is confined to middle income countries but of course there is space for studies devoted to different group countries and a comparison of the results.

The limitation of the study was the lack of data or an incomplete dataset. This is why any variables that refer to the financial sector, which was widely discussed in the theoretical part, were not included in the model. Otherwise, the effect would be loss of many observations.

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Russian aggression against Ukraine and the changes in European Union countries' macroeconomic situation: Do energy intensity and energy dependence matter?

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Abstract

The study aims to assess whether there are significant differences among EU member states regarding the Russo-Ukrainian-conflict-driven changes in macroeconomic indicators and whether these differences are linked to the country's energy vulnerability. Applying *k*-means clustering, three country groups are distinguished, similar with regard to their energy intensity, energy dependence (including dependence on Russian gas), and household budgets' exposure to energy prices. Based on the Kruskal-Wallis and Wilcoxon pairwise comparison tests, the study reveals statistically significant differences among the distinguished country clusters in the level of inflation and interest rates at the time of this conflict as well as differences in the 2022 forecasts' changes for GDP, inflation, budget balance and unemployment. The results indicate that EU economies characterised by the most significant energy vulnerability economically suffer the most in the aftermath of the Russian invasion of Ukraine.

Keywords

- energy intensity
- energy dependence
- natural gas
- Russian aggression against Ukraine
- European Union member states
- macroeconomic indicators
- clustering

JEL codes: Q43, E31, E43, E01, H62, E24

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Introduction

A country's economic development cannot take place without the use of energy. Access to energy is one of the most critical aspects of the socio-economic and environmental well-being and sustainable development of modern countries as almost all mainstream goods are produced, delivered and used only with energy involvement (Chalvatzis, 2009; Chalvatzis & Ioannidis, 2017). Almost every country globally strives to achieve energy security a goal that can be defined and interpreted in various ways. Commonly it refers to reliable and affordable access to sufficient energy supplies (Colgan et al., 2023; Szulecki & Westphal, 2018). Fossil fuels as one of the most popular energy sources still occupy a dominant position in the heart of many economies, including developed countries (Leng Wong et al., 2013; Martins et al., 2018). European Union countries are substantially dependent on Russian energy suppliers, including natural gas. A country's development is vitally based on energy (Caetano et al., 2017; Martins et al., 2019; Sugiawan & Managi, 2019). The Russian aggression against Ukraine propelled energy security to the forefront of the European policy agenda (Giuli & Oberthür, 2023).

The paper examines whether the changes in European Union member states' economic indicators are linked to the Russo-Ukrainian military conflict. In contrast to the studies mentioned above the study is not only focused on the conflict-driven changes in macroeconomic indicators but also links these changes with the magnitude of countries' energy vulnerability. To the authors' knowledge it is the first study that groups all EU countries considering their energy intensity, energy dependence (mainly linked to Russian natural gas supplies), and household budget exposure to energy prices and then verifies whether the distinguished EU country groups differ significantly in terms of changes in leading macroeconomic indicators in the aftermath of this military conflict. The study is novel and relevant regarding the current significant challenges countries face.

The paper is organised as follows: Section 1 provides a review of the relevant scientific literature. Section 2 details the methodology, objectives of the study, research hypotheses, material descriptions and the research methods used. The next Section presents empirical findings, followed by a discussion. The paper ends with conclusions.

1. Literature review

Energy security based on guaranteed access to adequate supplies of energy carriers belongs to universal national objectives (Ericson, 2009). International Energy Agency defines energy security as the availability of a regular supply of energy at an affordable price taking into account physical, socioeconomic and environmental dimensions, both in long-term and short-term perspectives (Costantini et al., 2007). Energy security has become one of the primary concerns of countries worldwide, e.g., due to limited energy sources, limitations in energy supply and fluctuations in energy prices (Zhu et al., 2020). Energy security also belongs to priority challenges for all the European Union countries as access to energy carriers is crucial for each EU member's sustainable development (Bluszcz, 2017). Natural gas belongs to fossil fuels energy sources of electricity production for economic sectors of the countries worldwide. It is linked to lower CO_2 emission as compared to other fossil fuels energy sources (Azam et al., 2021). Moderate natural gas consumption contribute to the decarbonisation pathway and energy security over the complete transition toward a low-carbon economy based on renewables (Aguilera & Aguilera, 2020; Sadik-Zada & Gatto, 2021). Russia is one of the largest natural gas producers and exporters worldwide substantially affecting natural gas markets (Kutcherov et al., 2020). European markets have been the primary destination for the export of Russian natural gas (BP, 2019). Notably the increased European Union countries' import dependence on natural gas supply has often been highlighted (Flouri et al., 2015).

The Russia–Ukraine war has been raging since February 2014, i.e. the eruption of the dispute over the official status of Crimea and Donbas between the conflicting parties. Since the outbreak of a full-scale Russian invasion of Ukraine on February 24, 2022, tensions between the neighbours have exploded (Umar et al., 2022). The Russian invasion of Ukraine has brought about the worst military conflict in Europe since the Balkan wars (Astrov et al., 2022). Krickovic (2015) claims that the escalation of the conflict between Ukraine and Russia in 2014 has increased the European Union's security concerns about the future development of the energy supply from Russia. Nevertheless, the share of Russian energy carriers, including oil and natural gas, varies significantly across the EU (BP, 2021; Korosteleva, 2022). Energy security risk has surged particularly in Central and Eastern European countries which are mostly supplied by Russia (Mišík & Nosko, 2017). Reducing Russian natural gas dependency remains a critical challenge for the European Union economies (Korosteleva, 2022). The EU economies will need to diversify their energy sourcing to lessen dependency on Russian energy supplies (Khudaykulova et al., 2022). Hosseini (2022) argues that the current crisis, i.e. the Russia–Ukraine conflict has brought the dependability of non-renewable energy sources into question prompting considerations of what steps can be undertaken by authorities to quickly lessen the dependence on fossil fuels for those countries that are most susceptible as importers. In his opinion a global shift towards realizing net-zero goals will gradually reduce the usage and importation of fossil fuels.Before the conflict in Ukraine escalated European consumers were burdened by sharply increasing natural gas and electricity costs, jeopardizing the primary aspect of energy security, i.e. its affordability. The invasion intensified concerns about the accessibility of fossil fuels with mounting apprehension that Russia might leverage control over supply and costs to force political compromises and counter Western economic sanctions (Szulecki & Overland, 2023; Van de Graaf & Colgan, 2017).

The paper deals with energy intensity and energy dependence on Russian natural gas. The literature indicates that energy vulnerability and dependency on Russian energy carriers is country-specific. Thus the study's group of countries that are similar considering energy indicators. The Russian invasion of Ukraine in 2022 highlights the country's energy dependence on fossil fuels and energy supply from Russia. War brought about the rapid growth of uncertainty, declines in stock exchange values, rising commodity prices, supply chain blockages and a general worsening of countries' economic situations. The situation is complex as countries have not yet recovered from the COVID-19 pandemic and have now had to deal with another geopolitical-economic challenge, the recent 2022 Russian attack on Ukraine (Mbah & Wasum, 2022).

Boungou and Yatie (2022) reveal that the stock markets' reaction in countries geographically close to the Russo-Ukrainian conflict has been the most visible and adverse. Czech et al. (2023) demonstrate that, on the first day and subsequent days of the Russian aggression against Ukraine in 2022, stock market indices in countries with the strongest trade ties with Russia and Ukraine reacted the most adversely. Yousaf et al. (2022) observe the significant and adverse reaction of stock markets due to the Russian invasion of Ukraine on the event day and post-event days, particularly in Poland, Hungary and Turkey. Federle et al. (2022) find that the change in stock market prices in a four-week window around the start of the conflict is linked to a country's distance from Ukraine.

Ruiz Estrada (2022) claims that the adverse impact of the Russian invasion of Ukraine on inflation and unemployment is substantial but measuring such impact with any degree of certainty stays a challenge. Nevertheless, this military conflict has led to global inflation rooted in a rise in energy and food prices (Kilian & Murphy, 2014; Ozili, 2022). Dräger et al. (2022) find that the Russian invasion boosted short-run inflation expectations for 2022 and substantially changed recommendations for monetary policy. The Russian war in Ukraine and the subsequent trade restrictions have triggered rising inflation in European Union countries (Prohorovs, 2022).

Inflation represented a primary concern post COVID-19 and has gained even more momentum following the outbreak of the Russian invasion of Ukraine. One of the most vital channels through which inflation may affect the financial aspects of households and firms' functioning is higher interest rates (Aharon & Qadan, 2022). Liadze et al. (2022) indicate that the military conflict imposes further monetary policy tightening, i.e. ca. interest rates increase by one percentage point in 2022 in the United States and more than 1.2 percentage points in the Euro area.

Astrov et al. (2022) claim that there is so much uncertainty and so many contingencies that forecasting of macroeconomic effects of this military conflict for EU countries is challenging. Nevertheless, the short-term economic and financial effects are substantially negative. The unprovoked Russian aggression against Ukraine represents a considerable cost equivalent to 1% of global GDP in 2022. However, Europe (mainly European Union), due to its tight trade links with Russia and Ukraine and its dependence on Russian energy carriers is expected to shrink by more than 1% in 2022, and the developing European economies (including Ukraine) are expected to shrink by even 30% (Liadze et al., 2022). According to the spring 2022 World Bank forecast (World Bank, 2022), a conflict-driven worldwide recession and possible stagflation are expected. Such a negative macroeconomic phenomenon has not been observed since 1970.

The conflict is expected to increase public expenditure on defence particularly in the European Union countries. Moreover, the war creates an enormous problem of refugees in Europe leading to growing public spending for refugees mainly in Ukraine-neighbouring countries such as Poland (Liadze et al., 2022). This conflict is expected to worsen the difficult post-COVID-19 fiscal situation. Irtyshcheva et al. (2022) observe increased pressure on some countries' public finances. The slowdown in economic growth and even the expected recession will undoubtedly contribute to the deterioration of the labour market, i.e. an increase in the unemployment rate (Ruiz Estrada, 2022).

2. Materials and methods

The study aims to identify the groups of EU countries which are similar considering the indicators reflecting their energy intensity, energy dependence on Russian gas and household budget exposure to energy prices. Additionally, the paper aims to check whether the identified groups of EU member states differ significantly in relation to the selected macroeconomic indicators in the aftermath of the Russian invasion of Ukraine.

To cluster EU countries according to their energy intensity, energy dependence on Russian gas and household budget exposure to energy prices, the k-means clustering developed by Linde et al. (1980) is applied. The k-means procedure aims to find the closest distance of points from the cluster's centre (Ding & He, 2004). The k-means clustering has various benefits including straightforward implementation, easy interpretation and is capable of computing. The optimal number of clusters is identified based on the Silhouette coefficient (Tibshirani et al., 2001).

Given a dataset $C = \{x_1, ..., x_n\}$ with n samples and m features. The k-means clustering aims to minimise the following function:

$$F(U, Z) = \sum_{h=1}^{k} \sum_{i=1}^{n} \sum_{j=1}^{m} u_{ih} \times c(x_{ij}, z_{hj}) \tag{1}$$

where k represents the number of clusters; $U = [u_{ih}]$ is an $n \times k$ partition matrix that satisfies $u_{ih} \in \{0, 1\}$ and $\sum_{h=1}^{k} u_{ih} = 1 (1 \leq i \leq n; 1 \leq h \leq k)$; $Z = \{Z_h, h = 1, ... k\}$ is a set of cluster centres in which Z_h consists of m values $(z_1^h, z_2^h, \ldots, z_m^h)$, each is the mean of a feature j in cluster Z_h and is defined as $z_j^h = \frac{\sum_{x_i \in Z_h} x_{ij}}{|Z_h|}$; while $c(\cdot,\cdot)$ is the squared Euclidean between two feature values.

In the study n refers to EU member states and equals 27—the number of all European Union countries, while m equals six and represents clustering variables, i.e. indicators reflecting the country's energy intensity, energy dependence on Russian gas and household budget exposure to energy prices (equation 1). The variables are standardised before clustering to make them comparable between the EU countries.

All energy indicators applied in the clustering come from the Vulnerability matrix developed by European Commission and are presented in the European Economic Forecast Spring 2022 (European Commission, 2022). The energy part of the matrix includes the following indicators:

- total energy intensity—the ratio of total energy to gross value added (GVA), i.e. global value chains of products purchased by residents for final use;
- total gas intensity—the ratio of total gas to gross value added (GVA), i.e. global value chains of products purchased by residents for final use;
- total Russian gas intensity—the ratio of total Russian gas to gross value added (GVA), i.e. global value chains of products purchased by residents for final use;
- ratio of Russian gas in total available gas—the extent to which EU countries rely on Russian gas. Total available gas is measured as import + domestic production – export + stock changes;

- energy weight in the HICP consumption basket—the ratio of spending on energy to the total expenditures of households;
- contribution of energy to annual HICP inflation—the ratio of changes in energy prices to the changes in the prices of consumer goods and services acquired by households.

Then based on the clustering results it is assessed whether the distinguished country groups differ significantly in relation to the selected macroeconomic indicators in the aftermath of the Russian invasion of Ukraine. In the analysis seven macroeconomic indicators are selected. A detailed description of the selected indicators is as follows:

- stock prices change—a stock market reaction to the Russian invasion of Ukraine outbreak on 24 February 2022. It is estimated as the change of the country's leading stock market index between 23 February 2022 and 7 March. 7 March reflects the highest level of stock market uncertainty in the aftermath of the war outbreak measured by the S&P option implied volatility index (VIX). Data come from Refinitiv Datastream;
- inflation—the maximum level of HICP inflation (Y/Y) from March-August 2022, i.e. the first half of the year of the Russian invasion of Ukraine. Monthly data on inflation come from Eurostat;
- interest rates—interest rates for long-term government bonds in EU member states. Data come from Eurostat and the European Central Bank (ECB);
- GDP forecast change refers to the change in the projected 2022 GDP growth rate between autumn 2021 and spring 2022 forecasts. The change is calculated as a difference between the value from autumn 2021 and spring 2022 and is measured in percentage points. The positive value indicates an increase in the forecasted 2022 GDP growth rate (improvement of the macroeconomic situation) while the negative value indicates a decrease in the projected 2022 GDP growth rate (deterioration of the macroeconomic situation);
- inflation forecast change refers to the change in the projected average 2022 HICP inflation rate between autumn 2021 and spring 2022 forecasts. The change is calculated as a difference between the value from autumn 2021 and spring 2022 and is measured in percentage points. The positive value indicates an increase in the forecasted 2022 inflation rate, while the negative value indicates a decrease in the projected 2022 inflation rate;
- budget balance forecast change refers to the change in the projected 2022 budget balance between autumn 2021 and spring 2022 forecasts. The change is calculated as a difference between the value from autumn 2021 and spring 2022 and is measured in percentage points. The positive value indicates an increase in the forecasted 2022 budget bal-

ance (improvement of the forecasted fiscal situation), while the negative value indicates a decrease in the projected 2022 budget balance (deterioration of the predicted fiscal situation);
- unemployment forecast change refers to the change in the projected average 2022 unemployment rate between autumn 2021 and spring 2022 forecasts. The change is calculated as a difference between the value from autumn 2021 and spring 2022 and is measured in percentage points. The positive value indicates an increase in the forecasted 2022 unemployment rate (deterioration of the forecasted situation in the labour market), while the negative value indicates a decrease in the projected 2022 unemployment rate (improvement of the forecasted situation in the labour market). Data on the forecasted change in the value of macroeconomic indicators in 2022 come from two European Commission reports:
  - European Economic Forecast Autumn 2021 Economic Forecast: From recovery to expansion, amid headwinds (European Commission, 2021),
  - European Economic Forecast Spring 2022 Economic Forecast: Russian invasion tests EU economic resilience (European Commission, 2022).

Both reports have been developed and published by the European Commission. Economic forecasts are prepared and published quarterly (spring, summer, autumn, winter) for each European member state and for the EU as a whole. The autumn 2021 forecast was prepared in the declining phase of the COVID-19 pandemic and projected that despite existing obstacles the EU economies would experience prolonged and robust expansion over the post-pandemic time. The spring 2022 forecast was prepared just after the outbreak of the Russian aggression against Ukraine and projected that this military conflict would substantially affect EU economies posing new challenges facing the EU, i.e. further upward pressures on commodity prices, increasing supply disruptions and growing uncertainty.

The study checks the existence of significant differences among clusters by applying the Kruskal-Wallis test (Kruskal, 1952a, b) and the Wilcoxon rank-sum pairwise comparison test (Wilcoxon, 1992) with the p-values adjustment using the Benjamini and Hochberg method (Benjamini & Hochberg, 1995). In the Kruskal-Wallis test country groups represent the independent qualitative variable while the selected macroeconomic indicator is the dependent variable.

The null (H_0) and alternative (H_1) hypotheses in the Kruskal-Wallis test are as follows (Hecke, 2012; Ostertagová et al., 2014)

H_0: All k population medians are the same.
H_1: At least two population medians **differ**.

A calculation of the test statistic in the Kruskal-Wallis test is presented below:

$$H = \frac{12}{N(N+1)} \sum_{i=1}^{k} \frac{R_i^2}{n_i} - 3(N+1),\; N = \sum_{i=1}^{k} n_i \tag{2}$$

where R_i is the sum of the ranks calculated for each group i ($i = 1, 2, \ldots, k$), n_i is the size of i group, N is the number of observations in all k groups. H is approximately χ^2 distributed, with the number of degrees of freedom which equals $k - 1$. The coefficient $\frac{12}{N(N+1)}$ is a suitable normalization factor.

3. Results and discussion

European Union countries are highly dependent on Russian energy supplies. Before the Russian aggression against Ukraine in February 2022 Russia's share of Europe's energy supply amounted to 25% of oil and 40% of gas supplies. Figure 1 depicts a plunge in the import of Russian natural gas in the EU in the majority of pipelines in the aftermath of the outbreak of the military conflict and the implementation of economic sanctions against Russia (Statista, 2022). Moreover, according to Statista's report on natural gas in Europe the expected shortfall in natural gas demand due to the shutoff of pipe gas from Russia in 2022 will decrease. Nevertheless, the drop in natural gas consumption will differ among EU member states equalling 7% on average and up to 40% in Czechia, Slovakia and Hungary (Figure 1). Considering this diversity of EU economies there is an assumption that the countries differ in energy vulnerability.

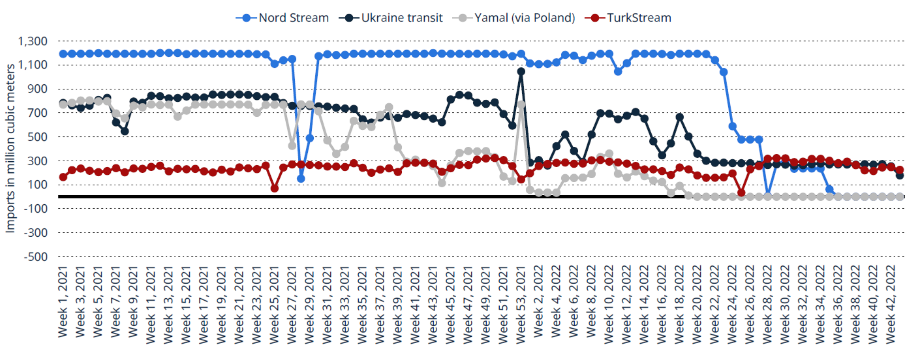

Figure 1. Natural gas import volume from Russia in the European Union in 2021–2022, by exporting route in million cubic meters

Source: (Statista, 2022).

The study groups EU countries according to their energy intensity, energy dependence on Russian gas and household budget exposure to energy prices. The k-means clustering reveals three groups of EU countries. The dendrogram depicts clusters in which countries are combined according to their similarity (Figure 2). Cluster I includes Portugal, Ireland, Sweden, France, Malta, Italy, Germany, Denmark, Austria, Spain, Luxemburg, Netherlands and Belgium. Cluster II contains countries such as Finland, the Czech Republic, Croatia, Slovenia, Poland, Greece, Cyprus and Romania. Cluster III contains Slovakia, Latvia, Bulgaria, Hungary, Lithuania, and Estonia (Figure 2).

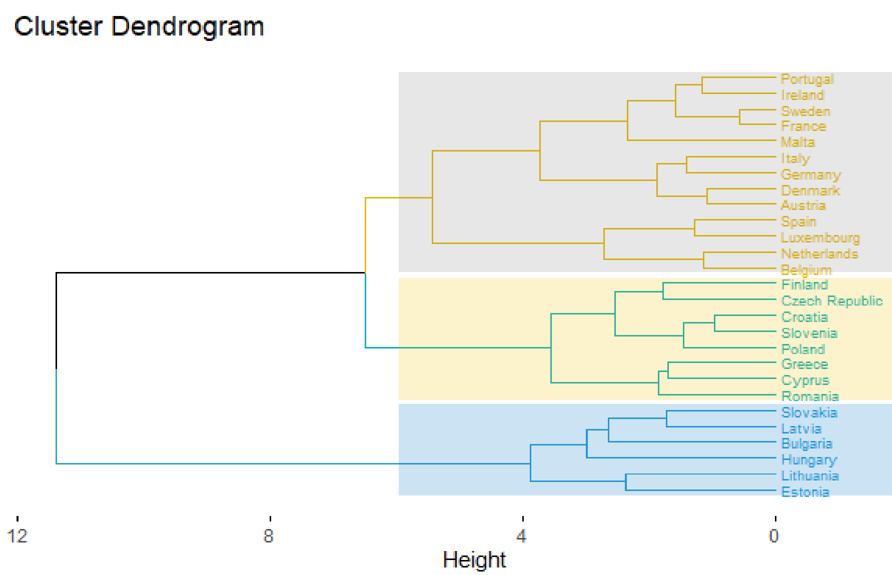

Figure 2. The k-means regional clustering results

Source: own calculations.

Table 1 shows mean and medium values in the distinguished clusters for all six indicators applied in the k-means analysis. Cluster I represents countries with the lowest energy intensity, energy dependence on Russian gas and energy weight in the HICP consumption basket. The average total energy intensity equals 4.45% GVA, of which gas-based energy accounts for approximately 20% (Table 1). Russian gas represents on average about 25% of all gas. The dependence on Russian gas varies in cluster I as in Germany, Austria and Denmark more than half of the natural gas comes from Russia while Ireland and Malta do not use Russian gas at all. Moreover, in EU member states from this cluster energy constitutes less than 10% of the HICP consumption basket and the contribution of energy to annual HICP inflation is close to 3%.

Table 1. Descriptive statistics of cluster features, i.e. energy intensity, energy dependence on Russian gas and household budget exposure to energy prices in the distinguished EU country groups

Indicator	Measure	I	II	III
Total energy intensity	mean	4.45	7.54	9.12
	median	4.40	7.75	8.55
Total gas intensity	mean	0.85	1.12	1.82
	median	0.90	1.15	1.80
Russian gas intensity	mean	0.23	0.55	1.27
	median	0.20	0.55	1.20
Ratio of Russian gas in total available gas	mean	25.78	51.79	82.58
	median	20.00	50.25	80.85
Energy weight in the HICP consumption basket	mean	9.95	11.93	14.12
	median	9.70	11.90	14.25
Contribution of energy to annual HICP inflation	mean	3.19	2.70	3.55
	median	2.80	2.60	3.25

Source: own calculations.

Cluster II contains the countries with on average, about 70% higher energy intensity and about 30% higher gas intensity than cluster I (Table 1). Moreover in this cluster the average ratio of Russian gas to gross available gas equals 50%. In detail, in Finland, the Czech Republic and Slovenia more than 80% of gas comes from Russia. In cluster II energy constitutes almost 12% of the HICP consumption basket (Table 1). Cluster III is characterised by the highest levels of all six indicators related to energy intensity indicators, energy dependence on Russian gas and household budget expo-sure to energy prices. In this country group the average ratio of total energy intensity is more than twice as high as in cluster I. Russian gas as a total of all available gas is as high as 82.58%. Moreover, Hungary and Latvia use only Russian gas. Energy weighs as much as one-seventh of residents' consumption basket while the contribution of energy to annual consumer inflation is about 3.5%. Table 1 data indicate that cluster III includes the European Union member states that seem the most exposed to the Russian invasion of Ukraine's adverse economic effects due to the highest energy intensity and most extraordinary Russian gas dependence.

Table 2 shows selected macroeconomic indicators' mean and medium values in the distinguished clusters. The estimated descriptive statistics indicate that cluster III includes countries that suffer the most in the aftermath of the Russian invasion of Ukraine. The short-term reaction of the stock market to this military conflict in all three clusters is visible and negative. Nevertheless, stock indices drop more in clusters that are more energy-intensive and Russian gas-dependent. The study results correspond to Boungou and Yatié (2022) and Yousaf et al. (2022). They reveal the instant and short-term negative effect of the Russian invasion of Ukraine on stock market prices mainly in countries geographically close to the parties of the conflict.

The average maximum HICP inflation (Y/Y) level in the March-August 2022 period in cluster III is more than twice as high as in cluster I (Table 2). In detail, inflation in cluster III is as high as 19.12%, compared to 12.51% in cluster II and 9.59% in cluster I. However, it should be stressed that the average inflation values in all clusters should be considered high. The highest levels of HICP, greater than 20%, are observed in Estonia, Latvia and Lithuania which are included in cluster III. In contrast France and Malta from cluster I experience the lowest inflation levels.

Surprisingly and despite the highest level of inflation in cluster III the highest level of interest rates is not observed there. However, four out of six cluster III countries, including Estonia, Latvia and Lithuania, belong to the eurozone which makes it impossible to mitigate inflation using a key country's monetary policy instrument, i.e. an increase in interest rates. In turn cluster II which is characterised by the highest interest rates includes as many as four countries that do not use the common European currency.

To picture the economic situation of the EU countries in the aftermath of the Russian invasion of Ukraine the changes in forecasts of macroeconomic indicators for 2022 are analysed. The forecast made in autumn 2021 with the forecast made in spring 2022, i.e. before and after the outbreak of the conflict are compared. Moreover, the analysis of macroeconomic forecasts allows for a better capture of the effect of Russian aggression against Ukraine and separates it from the COVID-19 pandemic effect. The forecast from autumn 2021 considers the coronavirus pandemic's negative impact on EU economies while the forecast from spring 2022 includes the effects of the outbreak of the military conflict .

Table 2 data indicates a deterioration of the economic growth rate forecast in all three analysed clusters from one percentage point in cluster I to more than two percentage points in cluster III. Interestingly there is almost no change in the budget balance forecast between autumn 2021 and spring 2022 in clusters I and II while the European Commission forecasts a substantial deterioration of the fiscal stance in cluster III. The forecast from spring 2022 significantly increases the assumed average annual inflation level for 2022. However, the change in the increase in the price level in countries from group III is greater by more than three percentage points than in group I. Significant changes in the unemployment rate in the analysed clusters are not observed. Compared to the forecast from autumn 2021 the forecast from spring 2022 indicates a deterioration in the labour market in 2022 in groups II and III and a slight improvement in group I.

Table 2. Descriptive statistics of indicators reflecting country's macroeconomic situation in the aftermath of the Russian invasion of Ukraine in the distinguished EU country groups

Indicator	Measure	I	II	III
Stock prices change	mean	–8.64	–11.10	–12.04
	median	–8.09	–11.40	–12.34
Inflation	mean	9.59	12.51	19.12
	median	9.5	12.20	19.85
Interest rates	mean	2.23	4.54	3.02
	median	2.13	3.68	2.47
GDP forecast change	mean	–0.98	–1.75	–2.40
	median	–1.00	–1.80	–2.35
Inflation forecast change	mean	3.78	4.89	6.87
	median	3.50	4.50	6.55
Budget balance forecast change	mean	0.11	–0.05	–1.17
	median	0.10	0.10	–1.20
Unemployment forecast change	mean	–0.28	0.23	0.70
	median	–0.20	0.30	0.75

Source: own calculations.

The descriptive statistics analysis shows that the impact of Russia's invasion of Ukraine hurts the EU economies. Most of the macroeconomic indicators deteriorate. However, the most substantial and adverse economic effects are observed in countries from cluster III and also from cluster II. To visualize and expand descriptive statistics analysis boxplots are applied. Figure 3 depicts boxplots for selected macroeconomic indicators in the distinguished EU country groups. The boxplots serve as a straightforward graphical representation in preliminary data analysis. They illustrate the complete spread of the dataset, offer insights into its extremities and highlight the data's distribution pattern.

The boxplots segment data into quartiles using a box and whiskers. The box covers the middle 50% of data with its edges (hinges) marking the first and third quartiles and its centre line indicating the median. The box's length is the interquartile range (IQR) a measure of spread. Whiskers extend from the quartiles to display the data range reaching up to 1.5 IQRs. Data beyond whiskers are outliers shown as individual points (Nuzzo, 2016). The boxplots visualize the changes in the analysed macroeconomic indicators among the distinguished clusters. The median line indicates the average trend for the group with a higher median suggesting an increase in the given indicator. The

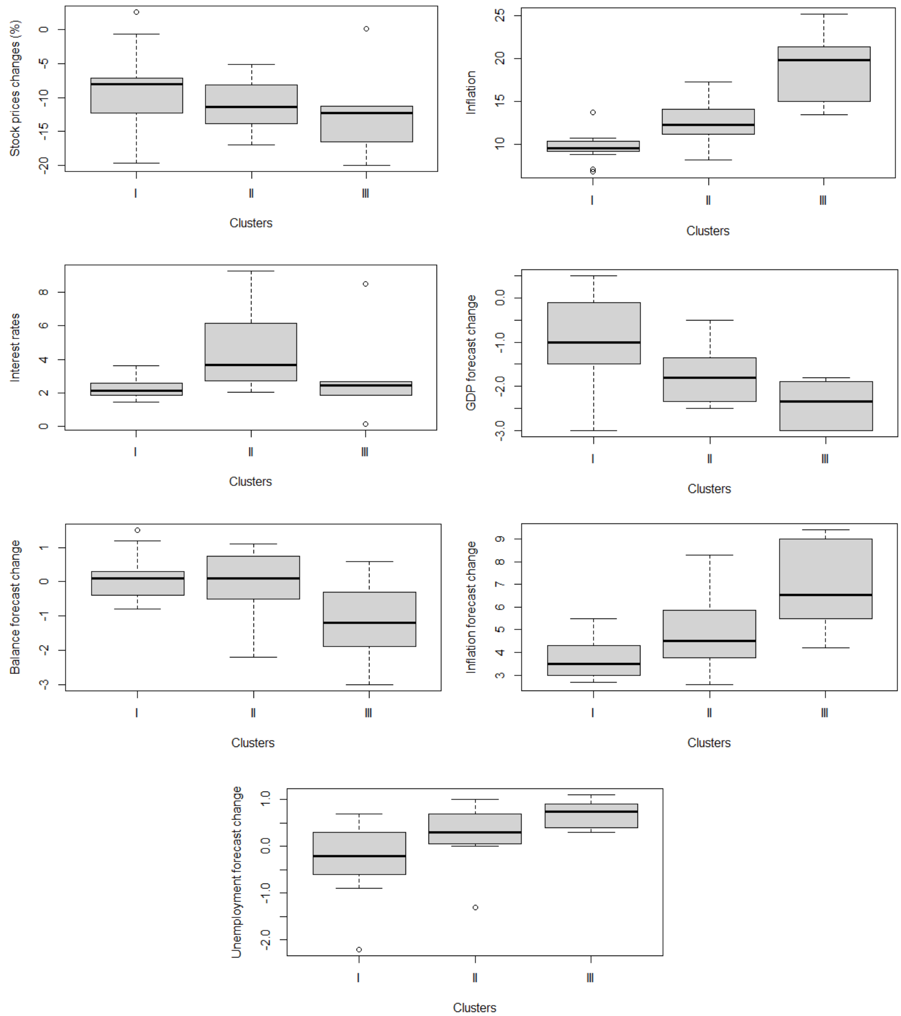

Figure 3. Boxplots for selected macroeconomic indicators in the distinguished EU country groups

Source: own calculations.

spread of the box and whiskers reflects its variability. Similar to Table 2 the boxplots presented in Figure 3 indicate visible differences in the data's distribution pattern between analysed clusters. In more detail they depict reduced economic growth predictions across all clusters with the steepest drop in cluster III. While clusters I and II see little change in the budget balance between autumn 2021 and spring 2022 a significant fiscal decline is projected for cluster III. The spring 2022 forecast elevates the expected 2022 inflation especially in group III. No major unemployment shifts are observed across clusters. However, while groups II and III anticipate a weaker labour market in 2022 group I expects a slight improvement.

In the next step the study verifies whether there are statistically significant differences between distinguished clusters regarding seven selected macroeconomic indicators. The distinguished clusters are not equal. In the situation of unequal samples sizes the nonparametric tests are recommended (Chan & Walmsley, 1997). In the paper the nonparametric Kruskal-Wallis test is applied. The results of the test are presented in Table 3.

Table 3. The results of Kruskal-Wallis test

Indicator	*H* test statistics	*p*-value
Stock prices change	1.810	0.405
Inflation	16.11	<0.001
Interest rates	6.257	0.044
GDP forecast change	9.003	0.011
Budget balance forecast change	4.690	0.092
Inflation forecast change	9.896	0.007
Unemployment forecast change	9.522	0.009

Source: own calculations.

Table 3 results imply statistically significant differences in the median values of six analysed macroeconomic indicators between at least one pair within three distinguished clusters. A significant difference between the distinguished EU country clusters applies to the inflation rate, inflation forecast change and unemployment forecast change—at a 1% significance level, interest rates, GDP forecast change—at a 5% significance level and budget balance forecast change—at a 10% significance level. A significant difference in the median level of stock market reaction to the Russian aggression against Ukraine between distinguished clusters is not revealed.

Additionally, a pairwise comparison Wilcoxon rank-sum test to check whether the significant differences in median values refer to all three distinguished country groups or selected ones is conducted. The results of the pairwise comparison test are presented in Table 4.

Table 4 results imply significant differences, at a 5% significance level, in the median level of inflation rate between country groups I, II and III. Moreover, both Figure 3 (boxplot for inflation) and Tables 1 and 2 show that countries characterised by high energy intensity and high dependence on Russian gas (clusters II and III) have the highest medium level of inflation. Additionally, it can be noticed that the higher the country's dependence on Russian ener-

Table 4. The results of Wilcoxon rank-sum pairwise comparison test

Indicator	I–II	I–III	II–III
Inflation	0.012	0.003	0.007
Interest rates	0.041	0.568	0.272
GDP forecast change	0.092	0.028	0.092
Budget balance forecast change	0.970	0.098	0.180
Inflation forecast change	0.169	0.009	0.089
Unemployment forecast change	0.118	0.013	0.118

Source: own calculations.

gy, the higher the HICP rate. The research results confirm the results of Ruiz Estrada (2022) and Prohorovs (2022) who show that this military conflict boosted inflation rates. However, the study offers a more complete and detailed picture, i.e. it indicates the existence of statistically significant differences in the level of inflation and conflict-driven increase in forecasted levels among EU countries. Moreover it reveals that the scale of this negative phenomenon is linked to the country's energy vulnerability including dependence on the Russian natural gas supply.

The Wilcoxon rank-sum pairwise comparison test results show that only clusters I and II differ significantly in terms of interest rates at a 5% significance level. However the results for interest rates are not fully transparent due to the existence of common currency and a common monetary policy in the Eurozone. The results correspond to Aharon and Qadan (2022) and Liadze et al. (2022) who indicate the need for monetary policy tightening by increasing interest rates.

The distinguished EU country groups differ significantly (at a 10% significance level) in GDP forecast change for 2022. Moreover both Figure 3 and Tables 1 and 2 indicate a negative relationship between the clustering energy indicators (energy intensity, including gas intensity, Russian gas dependence, the share of energy in the HICP basket and the average contribution of annual energy inflation to headline HICP) and change in GDP growth. The results reveal that the most significant deterioration of the GDP forecast is observed in cluster III. The research results correspond to Liadze et al. (2022) and Astrov et al. (2022) who find that the countries characterised by tight trade links with Russia and Ukraine and their dependence on Russian energy carriers are expected to experience the greatest decrease in GDP growth rate.

The study results reveal statistically significant differences in forecast changes in budget balance, inflation rate and unemployment rate between clusters I and III. The boxplots in Figure 3 depict a substantial worsening of the three above-mentioned indicators' levels in cluster III and a slight improvement of the forecast for budget balance and unemployment rate. It is in line with Liadze et al. (2022) and Irtyshcheva et al. (2022) who indicate the increase of public expenditure on defence and refugees particularly in the conflict-neighbouring countries. Figure 3 clearly shows the relationship between energy intensity, Russian gas dependence and country groups' macroeconomic situation. Greater energy vulnerability (considering six energy indicators) is linked to a higher inflation rate and adverse changes in forecasts of the inflation rate, GDP growth, budget balance and unemployment rate.

Overall, the study results indicate that a group of EU economies characterised by the most significant energy vulnerability and measured by six energy indicators from the vulnerability matrix suffer the most in the aftermath of the Russian invasion of Ukraine in February 2022.

Conclusions

A country's economic development cannot take place without energy. European Union countries actively use Russian energy supplies, including natural gas. Nevertheless, the level of energy dependence varies among EU member states. The Russian invasion of Ukraine has increased countries' energy security concerns. Moreover, this unprovoked military aggression brought about adverse economic consequences for EU countries.

The paper aims to assess whether there are significant differences in Russo-Ukrainian-conflict-driven macroeconomic indicators among EU member states and whether these differences are linked to the country's energy vulnerability. Based on the k-means clustering, three country groups similar with regards to their energy intensity, energy dependence (including dependence on Russian gas), and household budget exposure to energy prices, are distinguished. The group with Bulgaria, Estonia, Hungary, Latvia, Lithuania and Slovakia represents that with the greatest energy vulnerability.

Based on the Kruskal-Wallis and Wilcoxon pairwise comparison tests the study results reveal statistically significant differences among the distinguished country clusters in the inflation and interest rates level during this military conflict (February-August 2022) and forecasts' change for 2022 of the level of GDP, inflation, budget balance and unemployment. The study finds that a greater country's energy vulnerability is related to the higher HICP rate and a more substantial deterioration of forecasts of GDP growth rate, inflation, budget balance and unemployment.

The results indicate that a group of EU economies characterised by the most significant energy vulnerability economically suffered the most in the aftermath of the Russian invasion of Ukraine in February 2022. It should be noted that both the European Union as a collective entity and the individual governments of each member state are making considerable efforts to reduce dependence on Russian energy carriers and ensure complete energy security. This situation underscores the necessity for state governments to employ a range of policy instruments to foster the development and use of renewable energy sources thereby ensuring energy security and reducing the susceptibility of the energy supply to external shocks.

Due to the research timeline complete macroeconomic data are not yet available. Therefore, the analysis is conducted not only on actual data but also on forecasts which should be considered as a limitation of the study. Moreover, the use of more complex econometric methods is constrained as they require a more extended time series, much longer than the several-month-long period since the Russian aggression against Ukraine. Overcoming the limitations mentioned above remains a challenge for future research.

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Assessment of immigrants' impact on the Slovak economy

Raman Herasimau[1]

Abstract

The migration process is becoming more and more intensive in the European region. Various opinions have been expressed about the effects of immigration on the country's economy. Most of these opinions reveal a positive impact via fulfilling deficits in the labour market and tax payments. On the other hand, a negative long-term effect on the social security system because of the poor integration of immigrants into the domestic population can be seen as a thread in this discussion. This paper analyses the impact of immigration, based on the United Nations National Transfer Accounts methodology developed by Lee and Mason. This methodology is employed to break down the System of National Accounts with respect to age groups and generations and, in addition, show the economic flows between them. The findings of this paper show that the earnings and consumption behaviour of immigrants and natives in Slovakia differ; immigrants tend to work after retirement age, earn more, and consume less, which results in positive effects on the aggregate life cycle deficit.

Keywords

- national transfer accounts
- immigration
- Slovakia
- income
- consumption
- life cycle deficit

JEL codes: J15, J18, J61, E24

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Introduction

Two problems in European countries are closely linked: ageing and migration. Ageing and migration outflows place a heavy burden on the social system, labour market, pension system, and state budget. Ageing and emigration both lead to a decrease in the number of effective taxpayers and effective earners in comparison to beneficiaries and consumers. While immigration can help to eliminate the negative effects of an ageing population and emigration by increasing the working-age population and boosting fertility, it also brings its own challenges.

The world is currently facing year-on-year growth in migration. The total number of migrants in 2020 was more than 280.5 million, or 3.9% of the total world's population. During that year, the total number of migrants to Europe has increased by 16% in comparison to 2015, from 75 million to 87 million people (International Organization for Migration, 2022). Since the outbreak of war in Ukraine, more than 8 million forced migrants have arrived in other European countries, and over 5 million have registered for the temporary protection schemes (UNHCR, 2023). The scientific literature rarely distinguishes between economic immigrants (voluntary) and forced immigrants. Nevertheless, these two types of immigrants are impacting the economy in different ways and vary in their behaviour (Cortes, 2004).

In this respect, Europe can perceive immigrants as an opportunity and improve immigration policies to eliminate the negative impacts of its ageing population and emigration. However, not all countries have an appropriate immigration policy regarding forced migrants (even highly skilled ones); e.g., in Slovakia, no changes in migration policy have been introduced since 2015 (Mara & Kovacevic, 2021). Lack of flexibility in the decision-making process leads to a decrease in the inflow of highly skilled workers and a drop in average economic productivity in comparison to neighbouring countries like Czechia, where where such flexibility exists.

Currently, in Slovakia, there are 102 thousand people registered for the temporary protection schemes, 57% of whom are in the 18–60 age group, and only 8% are over 60 (Ministry of Interior of the Slovak Republic, 2023). Frequently, forced migrants tend to occupy low-skilled positions; nonetheless, they register higher annual earnings growth as well as higher human capital investments compared to economic immigrants (Becker & Ferrara, 2019). In these terms, Slovakia is in a rather unique situation. It is heavily influenced by migration due to Russia's war against Ukraine, ageing, and emigration as its own endogenous factors.

Today, the phenomenon of immigration is more relevant than ever, and EU countries, including Slovakia, should clearly understand how it influences the economy, how immigrants integrate into the home economy, and how to maximize its positive effects. Increased migration flows are inducing researchers to assess the impacts of immigration. This paper aims to assess the effects of immigration in Slovakia by breaking down life cycle deficit (LCD) accounts for broad age groups, as well as examining the consumption structure of immigrants.

The reasoning behind looking into alternative ways to calculate national transfer accounts was impacted by the lack of data. The current study suggests compensating for missing survey data on immigrants by combining administrative data from different sources. An appropriate sample of administrative data enables the methodology to fill the gap created by missing immigrant data; it also includes the immigrants' data in per capita and aggregate accounts. Thanks to these administrative data, it is possible to calculate immigrants' consumption. The paper also proposes to use the same values of immigrants' private consumption as natives have in cases of similar incomes. In previous studies, data on immigrants were either used from surveys or ignored. Using administrative data gives the possibility of calculating national transfer accounts and following the changes every single year, which in fact expands the potential of this methodology.

This paper consists of the following sections: Section 1 provides a description of different scientific points of view on migration. Section 2 contains the methodological approach; data and limitations are discussed. Results after calculations are presented in Section 3, while in Section 4 and Section 5, the results are reviewed and summarized.

1. Literature review

The effects of immigration may be measured from different perspectives: fertility, education, the labour market, fiscal, social, income, and consumption. The topic of immigration is brought to the fore due to ageing populations. The current reality is characterized by a rapid shift towards an increase in average working age and a decrease in fertility rate. This trend is typical for the whole world. In Slovakia, the maximum fertility rate was 3.04 in 1960 and the minimum in 2002, which was 1.19. Nowadays, it stands at around 1.56 children per woman. There is a tendency to grow, but it is insufficient for the natural reproduction rate of population of 2.1, therefore the total population is slightly decreasing. In this regard, changes in population structure should be considered; a steady shift towards growth in average age occurs (OECD, 2023). Projections show that by the year 2100, the total population of Slovakia will have decreased by 20.3%, or by 1.1 million people, in comparison to 2019, while the dependency ratio will increase from the current 24.5% to 59.1%, with the same level of immigrants. In the absence of immigrants, the ratio is projected to reach 66.6%, resulting in a doubling of individuals aged 65 and over. Failure to implement appropriate adjustments would exert a significant strain on the public finance system (EUROSTAT (c), n.d.). Population ageing as a primary problem generates side effects such as the necessity to compensate employees in the labour market and the fiscal burden on the state budget. Thus, scientific literature looks precisely at native-immigrant differences in the labour market and tries to understand the inequalities in the outcomes. De la Rica et al. (2015) studied six European countries and found that foreigners have a higher unemployment ratio than natives; e.g., in Sweden and Spain, the differences are 9.6 p.p. and 11.7 p.p., respectively. The lowest difference is in the UK, standing at only 1.5 p.p. Unlike the unemployment rate, the participation gap is on the side of foreigners. The participation gap is the difference between foreigners' and natives' participation ratios. Foreigners register a higher participation ratio, meaning they are better represented in the labour market than natives (de la Rica et al., 2015).

Moreover, immigrants do not significantly affect the un/employment ratio of the host country in the long-run, although they do have a negative influence on low-skilled natives (Okkerse, 2008). Depending on the type of immigration (economic or forced migration), long-term immigrants can be net beneficiaries of social insurance transfers. Often the second generation of immigrants are the reason for that the poor integration in the host country society. At the same time, integration and assimilation of immigrants in childhood (second generation) demonstrates better results in productivity in comparison to the first generation of immigrants (parents) and those who were not born in host country (Bratsberg et al., 2014).

As always, the roots of any differences are deeper than they seem. The unemployment/employment ratio, participation level and wage size positively correlate with the level of education. An analysis of 15 Western European countries demonstrates the immigrants' tendency as having a lower level of education than natives. Even if their level of education is adequate and suited to the job, they have lower income than natives, especially non-EU immigrants. Moreover, immigrants have lower chances of occupying higher positions in comparison to natives. The second generation of immigrants are affected by these issues as well (Dustmann & Frattini, 2011).

Besides human capital characteristics (education, working skills etc.), other variables affect the wage level or occupation likelihood of immigrants: country of origin, reasons for immigration and duration of stay in the host country. The wage level is mirrored in independence period of immigrants. This period is shorter for immigrants than for natives, due to lower level of immigrants' wages, which even lower consumption is not able to compensate (Apostolova et al., 2022).

The different socio-cultural dimensions of immigrants in labour market directly reflect on consumption, savings and remittances. Immigrants' consumption is under-studied. Such datasets as European Union Statistics on Income and Living Conditions (EU-SILC) and Household Budget Survey (HBS) do not include immigrants' data, or they are presented in a statistically insignificant manner. Indirectly based on the literature related to saving behaviour, it can be assumed that immigrants tend to consume less than natives.

The saving behaviour of immigrants differs from that of the local population, e.g. for France, the average local savings for foreign employees in 1970 were 50% higher than those of French workers with the same income. Migrants save more in the host country if the price level is lower or if wages are higher compared to their home country. Furthermore, lower wages in the home country influence the amount and quality of effort that immigrants invest into their career in the host country (Dustmann, 1995).

Simultaneously, while saving, immigrants tend to use more conservative investment strategies. The reasons for this can be education level, gender and knowledge of language of the host country or local legislation (Hedesström et al., 2007).

Migrants not only earn and pay taxes in the host country but also send money to their home country, so outflows and inflows of remittances appear. Some of the money saved can be sent in the form of remittances. If immigrants are net senders, then they tend to consume less in the host country, and if they are net beneficiaries, then there are two possible options: 1) an increase in consumption, 2) an increase in savings with the same level of consumption. In 2020, the total remittances all over the world amounted to 702 billion dollars US (International Organisation for Migration, 2022).

There are several reasons why immigrants remit: altruism, exchange, a strategic motives, insurance and moral hazard, family loan arrangements, inheritance as an enforcement device, mixed motives (Rapoport & Docquier, 2005). In 2015, the total amount of remittance inflow was 2,134 million dollars US (2.4% of GDP). It is unlikely that the whole amount belongs to remits for immigrants, and it is more probable that the main proportion of this amount relates to Slovak emigrants abroad (World Bank, n.d.). At the same time, remittance outflows were 240 million dollars US. Unfortunately, there is no bilateral matrix for the year 2015, but there is one for 2021. Therefore, it can be assumed that the flows of remittance did not change dramatically between 2015 and 2021, where 93% of the whole remittance inflow belongs to EU countries, UK and Ireland. A very similar situation can be observed with remittance outflows, where 84% was sent to EU countries, with 47% of this being sent to the Czech Republic (KNOMAD/World Bank, a, b, c, n.d.). Based on that, immigrants from the third countries register a net remittance inflow—they received approximately 149 million dollars US from abroad and sent home a mere 38 million dollars US. In addition to income, immigrants receive remittances from their home countries, which can be treated as consumption, income and intra-/inter-transfers, respectively. For the purpose of the current work, remittances are excluded, but it is clear that remittances have an impact on life cycle deficit. The only question concerning this is how they should be treated.

All the effects of immigration in various parts of economy have fiscal effects at the end. The fiscal impact of immigration was studied with the assistance of generational accounts methodology (GAs), which was adjusted with respect to immigrants. The authors discovered that reducing immigration might increase or reduce future fiscal burdens, with the outcome depending primarily on the amount and type of overall future burdens (Auerbach & Oreopoulos, 2000).

The overall fiscal impact of immigration is still unclear, whether it is a gain or loss. There are several factors influencing this: when government purchases depend on the total population, then the effect of immigration will worsen the fiscal imbalance, and if they are not affected by population size, then immigration will improve the imbalance, as total spending is shared among a larger number of people (Lee & Mason, 2010).

Difference in the behaviour of immigrants and natives have been studied with the help of life cycle surplus (LCS) gap and calculating independence period of immigrants (Apostolova et al., 2022). The authors of the previously mentioned studies confirmed that immigrants have lower incomes than natives and identified a lower level of economic independence among immigrants. It can be said that the labour gap and participation gap between immigrants and natives have been studied thoroughly in comparison to consumption, remittances and savings, which can be found in fewer scientific studies.

Unfortunately, many papers related to National Transfer Accounts (NTA) ignore immigrants, while others simplify and assume that immigration is offset by emigration (Kuhn & Prettner, 2018). As a result, there is a research gap and a misunderstanding of immigration's influence. The lack of data about immigrants' income and especially consumption results in challenges when calculating LCD accounts for them and identifying the impact of every age group. Therefore, the current paper suggests implementing changes in NTA methodology with the aim of filling this gap.

2. Methodology and data

For the purpose of this paper, UN National Transfer Accounts methodology is used. NTA shows the income value each age group earns in the labour market and through the ownership of assets, and how income is reallocated between age groups via public and private transfers, in addition to how each age group uses its disposable income for consumption and saving.

NTA consists of age profiles inclusive of age-specific averages such as labour income, consumption, asset income, public transfers, private transfers, and savings. Because NTA combines macro and micro levels, it is necessary to create the aggregate values using the System of National Accounts (SNA) and, following this, to use microdata like surveys and administrative datasets to distribute over age groups. Surveys and administrative datasets do not cover the entire population. For that reason, age profiles should be adjusted appropriately so that the sum of per-capita averages for each age group will tie to aggregate values from the macro level.

In other words, the sample weights that are used need to balance the sample with the population structure. Finally, the smoothing procedure serves to eliminate random variations and provide a clear presentation of the age shapes. In order to exclude the effects of country heterogeneity, normalization should take place: NTA age profiles are divided by a simple average labour income for natives aged between 30 and 49.

Basic NTA methodology consists of four steps. *The first step* is to derive macro controls for each economic activity from the SNA. In order to create NTA categories SNA macro controls need to be derived based on different entities in the economy: households and non-profit institutions serving households; government; financial corporations; non-financial corporations and the rest of the world (ROW). It is worth pointing out that the SNA includes data related to the whole economy, and consequently, immigrants' impact is included as well. As the SNA does not capture flows (transfers) between age groups and flows between households, distinguishing them is necessary.

The second step is to calculate the age-specific averages of different economic categories. Age profiles are in the age range from 0 to 80+. This step is divided into two sub-steps: calculating the age-specific averages for immigrants; aggregating the age-specific averages of natives and immigrants.

- Macro controls (macro level); ⇐
  - System of National Accounts (SNA);
  - Demography;
- Age-profiles (micro level);
  - The Life Cycle Account (LCA)
    - Consumption
    - Income
  - The Transfer Account (TA)
    - Public transfers
    - Private transfers
  - The Asset base reallocation Account (ABR)
    - Public ABR
    - Private ABR
- ⇒ Synthetic cohort estimates
  - Support ratio (SR);
  - Fiscal support ratio (FSR)

Figure 1. Relationship between NTA elements

Source: author's own presentation.

For the native population, data from European Union statistics on income and living conditions is applied (EU-SILC, 2015) along with the Household Budget Survey (HBS, 2015). These data satisfy the conditions of NTA methodology, while for immigrants, administrative data should be used (Figure 1). Both results should be adjusted to macro controls in accordance with the SNA. Due to the fact samples in surveys differ from the SNA, it is necessary to prevent underestimation or overestimation of the actual values. The sum of products (age profiles multiplied by the number of persons by age group) should be equal to the aggregate value of each respective category.

Due to the random sampling employed in the survey, random variations can occur. To eliminate them, a smoothing procedure is implemented, and that is *the third step*. *The fourth step* is to make a proportional age profile adjustment to the macro controls.

There is a high risk of underestimating immigrants and overestimating the native population. Immigrants produce and consume within the host country, and if they are ignored, it means that the consumption and production belong in their entirety to the native population. For the sake of accuracy, the third and the fourth steps should be adjusted to the immigrants sample. For the full NTA methodology, see (Istenič et al., 2017; United Nations, 2013).

Like other accounting equations, NTA has equalization counterparts: inflows are matched with outflows. This budget identity is true for the household level, for individuals, every age group and for the whole economy:

$$C + S = YL + YA + \tau \tag{1}$$

where consumption (C) and saving (S) equal the disposable income consisting of labour income (YL), asset income (YA) and net transfer inflows (τ).

Equation (1) could be broken down in the following way:

$$C + I_K + I_M + T_g^- + T_p^- = YL + YK + YM + T_g^+ + T_p^+ \tag{2}$$

where the left side of the equation (2) (total expenditures) consists of private and public consumption (C), investment in capital (I_K), investment to credit and land (I_M), cash transfers to the government (T_g^-) and cash transfers to the private sector (T_p^-). The right-hand side, on the other hand, consists of labour income (YL), returns to capital (YK), returns to land and credit (YM), transfer income from the public and private sectors (T_g^+, T_p^+).

For the purpose of this paper only LCD accounts are calculated equation (3).

$$LCD_a = C_a - YL_a \tag{3}$$

where index a identifies age.

2.1. Datasets and methodology adjustments

In this paper, only LCD accounts are considered, thus transfer accounts, asset-based reallocation accounts and remittances are out of paper scope.

The reference year presented in this study is 2015, and this is done for the several reasons: there are full data of HBS, EU-SILC and administrative data from the Ministry of Interior and Ministry of Labour, Social Affairs and Family of the Slovak Republic (2015); year 2015 is not biased by any financial crisis or other exogenous and endogenous shocks like a pandemic or war; and the final reason is that as HBS is done every five years, the final version should be published in 2020 and integrated with EU-SILC. However, it is not yet available for Slovakia.

The weak point of the NTA methodology is its sensitivity to data quality. Standardized EU-SILC and HBS data give the possibility of accurate results, while the absence of the data brings a set of problems in the creation of NTA. Neither dataset includes immigrants, which makes it necessary for NTA adjustments with the assistance of administrative data. A combination of the above-mentioned administrative data assists in compensating for the lack of data in EU SILC and HBS. Administrative data provided by the Ministry of Interior and Ministry of Labour are not publicly available and have been requested and presented here in a processed form.

The Ministry of Labour data provides age-based immigrants' income and consists of regular job contracts, irregular job contracts, personal carers for the disabled, the self-employed and several more exotic and rare types of social insurance. Statistics and reality vary for self-employed entrepreneurs in Slovakia due to the common habit of showing less earnings, and paying lower taxes and social contributions in comparison to real earnings. Personal carers for the disabled are also not a significant indicator because of the small number of people in need of such a service. The dataset includes 52,677 observations, where 13,342 (25%) are females and 39,335 (75%) are males. Income is provided separately for females and males and combined by the author in the following way:

$$YL_a^T = \frac{(N_a^F \cdot YL_a^F) + (N_a^M \cdot YL_a^M)}{(N_a^F + N_a^M)} \tag{4}$$

where N_a^F – number of females of age a, YL_a^F – income of females at age a, N_a^M and YL_a^M represent number of males at age a and their income respectively.

The second administrative dataset provided by the Ministry of Interior shows current information of the number of immigrants in the country and the purpose of their stay. The dataset includes all immigrants in the country at the end of the year, their sex, age, citizenship, type of residence permission, purpose of stay, and region of residence in Slovakia. The dataset includes 91,456 observations, where 32,975 (36%) are females and 58,481 (64%) are males.

In order to implement administrative data, statistical data (DATACube a, n.d.) of the average income split by age group should be applied. Statistical data provide information on the age groups in the following way: 0-19, 20–24, 25–29, 30–39, 40–44, 45–49, 50–54, 55–59, 60+ and the average gross salary for each of these. They represent the gross salary in the country for the current year. Statistical data are used because administrative datasets and EU--SILC have different collection methodologies, thus they need to be converted to a comparable form. In this regard, the following steps are suggested: firstly, data about the number of immigrants from Ministry of Labour and Ministry of Interior should be reconciled. This step is necessary due to the fact that the Ministry of Labour observes only 57.6% of the actual number of immigrants and only the age group from 15–80. There are few reasons for the differences between the two datasets: the Ministry of Labour does not provide data on persons within the 0–15 age group, and in some cases, employers do not supply information about the immigrants they employ, instead paying salaries in cash, etc. Then, the differences in natives' income between EU-SILC and administrative data should be clarified. After this, EU-SILC income can be formatted in an administrative format and the difference between immigrants' and natives' income can be calculated. Finally, the administrative income of immigrants can be adjusted to EU-SILC.

Data is kept for the 0–19 age group, as it is from EU-SILC and from an administrative source for immigrants, since values are insignificant. For the 60+ age group, the average difference of the previous age groups between administrative data and EU-SILC data is utilized (Table 1).

When combining every single age group from EU-SILC in respect to statistics, five years groups should be created and a simple average of natives' income should be calculated. Following this, the statistical data are divided by EU-SILC data, producing a coefficient which shows to what extent they differ. Finally, EU-SILC immigrants' income can be calculated by dividing immigrants' income by the coefficient.

Once income has been adjusted, private consumption can be calculated. Private consumption includes health, education, housing, other standard consumption like food, tobacco and alcohol. Private education and health are assumed to be zero, for the reason that education and the health system in Slovakia are financed by the state. Public health consumption is 8–12 times higher than private, and public education consumption is 30 times higher than private. Based on this, it can be assumed with high probability that the average immigrant accounts for insignificant private health and education consumption, thus they can be taken as nil. For the other types of consumption, it is assumed that immigrants with a certain level of income have the same level of consumption as natives with the same income. Since income

Table 1. Adjustment of administrative salary data to EU SILC format, Slovakia, 2015

a	b	c	d	e = c/f	f = b/d
Age group	**Statistical salary, natives, euro**	**Admin. immigrants' salary, euro**	**EU SILC natives', euro**	**Immigrants' adj. salary to EU SILC. euro**	**Adj. coefficient to EU SILC, euro**
Average	997.00	41.73	22.80	41.73	
0–19	582.00	397.01	459.40	265.49	1.50
20–24	687.00	656.99	875.40	649.14	1.01
25–29	886.00	840.64	1,068.80	849.99	0.99
30–34	1057.00	951.35	1,088.80	934.90	1.02
35–39	1108.00	978.13	1,070.00	971.82	1.01
40–44	1077.00	935.15	1,060.60	983.96	0.95
45–49	1008.00	916.27	997.80	938.70	0.98
50–54	974.00	851.75	788.80	711.69	1.20
55–59	944.00	667.64	927.78	618.18	1.20
60+	1002.00	41.73	22.80	41.73	1.08

Source: author's own calculation.

data are fully available, it can be treated as a proxy for private consumption. Suggested adjustments are based on the fact that an individual with the same income has the same consumption behaviour despite their country of origin. Remittances, saving and investment behaviour could obviously affect private consumption, nevertheless, for the sake of eliminating the potential bias due to data availability, the aforementioned factors are excluded.

Immigrants behave differently in terms of both private and public consumption. Following variables are excluded from public consumption: Social Protection-Unemployment, (due to local legislation, foreigners are not able to receive unemployment benefits during temporary residence permission), Social Protection-Housing (foreigners tend to rent accommodation rather than receive financial support from the state). The rest of the public consumption variables are included as for the native population.

The suggested methodological adjustment introduces several advantages. In countries with a relatively small proportion of immigrants and a high turnover, separate surveys are more costly and including a statistically correct number of immigrants in the survey sample is more challenging. The second advantage is the possibility of calculating tax effects from income and consumption provided by immigrants.

These limitations are not crucial and the results of this paper are significant enough for the purpose of research work. For the purpose of the current research, an immigrant is defined as a person whose country of birth and primary citizenship is different from the research country. Only legal immigrants are taken into consideration.

2.2. Decomposition of accounts between natives and immigrants

For the purpose of this paper, income accounts for immigrants and natives are calculated separately. Accounts for natives are calculated as per standard NTA methodology process using EU SILC while immigrants accounts are calculated as follows.

Administrative data of income should be distributed among the whole immigrant population.

Equation (5):

$$YL_{awg} = (AWG \cdot YL_a^T) - (AWG \cdot YL_a^T) \cdot \frac{\frac{N_a^{MVSR}}{N_a^{UPSVaR}} \cdot employment\ ratio}{N^{MVSR}} \quad (5)$$

where AWG – is weighted average weighted by the number of immigrants from the Ministry of Labour dataset, YL_a^T – income Equation 4, N_a^{MVSR} – number of immigrants of age a from the Ministry of Interior dataset, N_a^{UPSVaR} – number of immigrants of age a from the Ministry of Labour dataset and N^{MVSR} – total number of immigrants from the Ministry of Interior.

When distribution is completed, administrative data can be transformed to the EU SILC with the help of the coefficients from Table 1.

Afterwards, natives' accounts and immigrants are combined and adjusted to the macro controls.

3. Results

3.1. Demographic state

In order to understand the immigration impact, it is first necessary to consider the demographic situation of the country. Slovakia has a unique position among other EU countries in that sense. On the one hand, the country shows a low number of immigrants compared to other EU countries, while on the other, the employment ratio of immigrants in Slovakia is higher. The countries included here represent all parts of Europe. The 2010 employment ratio of immigrants in Slovakia revealed a higher number in comparison to other EU countries. There are two reasons for this: legislation, and the cultural similarity of immigrants and natives.

The proportion of immigrants in Slovakia is increasing over time. During the 5 years from 2010 to 2015, the number of immigrants increased by 0.6 p.p., while in 2020 it increased by 1 p.p. and the proportion of the working-age group increased by 1.3 p.p. What is more important is that the proportion of working-age immigrants is growing faster than the total share of immigrants. This tendency will continue in the future because of two factors: emigration of the Slovak population and the low fertility rate of native Slovaks. According to the available data, the growth rate of immigrants as a share of total population between 2020 and 2022 is 0.6 p.p., while the growth rate of the 15–64 age group is 1 p.p. The year-on-year growth of immigrants is even more significant: 22 p.p. of the total number of immigrants and 20 p.p. of the working-age group, respectively (Ministry of Interior of the Slovak Republic, 2000–2022). The combination of high participation ratio and the growth of the working-age group results in increasing positive effects from immigration.

The employment ratio of immigrants in Slovakia is very high—in 2015 it was 80.4 and in 2022 it stood at 81.1–85.2, depending on the data used for the calculations, while the average ratio in EU countries was 61.3 and 69.4, respectively (EUROSTAT, a, b, n.d.; Ministry of Interior of the Slovak Republic, 2000–2022). This means that almost all immigrants are active in the labour market in Slovakia, whereas other countries show worse results. The employment ratio is also impacted by the geographical composition of immigrants. For Slovakia, it includes culturally close regions: EU, Ukraine, Serbia, Russia, Belarus (Ministry of Interior of the Slovak Republic, 2000–2022), in contrast to other EU countries, especially West and North Europe, which have a higher proportion of immigrants from African and Asian regions. In Slovakia, more than half of immigrants come from EU countries, and they are usually highly qualified employees, which also impacts the employment ratio positively.

3.2. LCD accounts

Slovak immigration statistics vary markedly in comparison to other countries, therefore the effects should differ as well. To visualize those effects, the income age profile has been constructed (Figure 2). The income age profile of immigrants reflects the state of the labour market, where immigrants have an earlier working age and work longer. The blue solid line represents the labo-

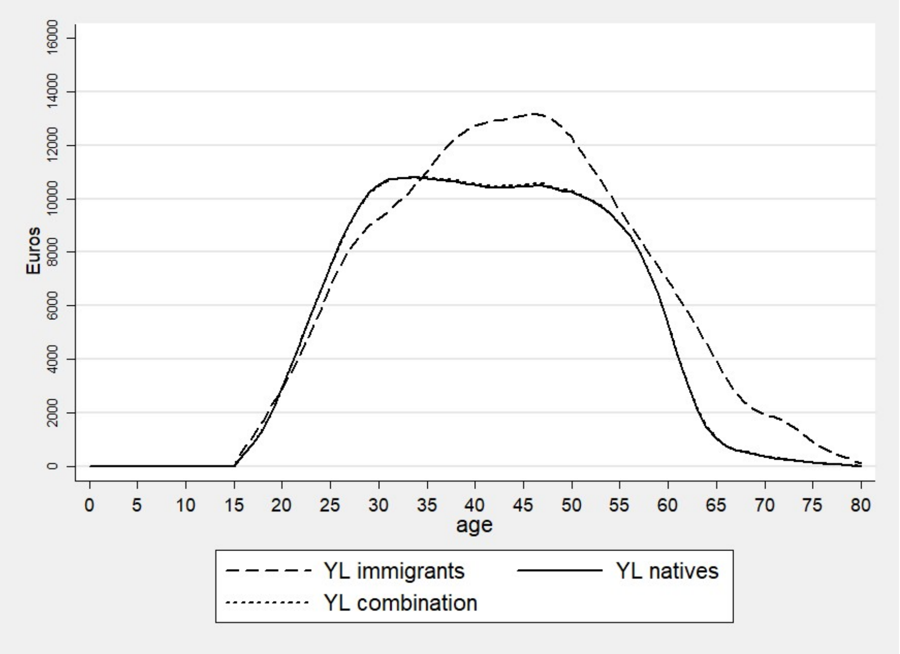

Figure 2. Income age profile of immigrants and natives per capita, Slovakia, 2015

Source: author's own calculation.

ur income per capita age profile of immigrants. Immigrants in Slovakia tend to stay in the labour market longer, thus the income decrease is less steep than among natives. The earnings of immigrants in the 35–55 age group are also higher. Before the age of 35, immigrants demonstrate a lower income than natives. This can be explained through the poor working experience of employees from Non-EU countries, while EU workforces in older age groups commonly occupy higher-paid positions. The total immigrants' impact on all age groups is positive (dot line) and generates approximately 1 p.p. growth. Higher immigrant incomes push up the incomes of the average person in the 35–79 age group living in the country. As mentioned previously, the 20–35 age group of immigrants pushes down the combined age profile slightly, and after this group immigrants have higher incomes (Figure 3).

Figure 3 shows the exact difference between combined income age profile and native income age profile. The first peak at age 40–45 can be explained by the higher income of immigrants from EU countries, who occupy higher positions; the second peak at age 60–70 demonstrates that immigrants tend to stay in the labour market longer than natives, which leads to a higher income age profile.

Income contrasts with consumption (public and private). By using an adjusted NTA methodology, levels of private consumption were split into: low,

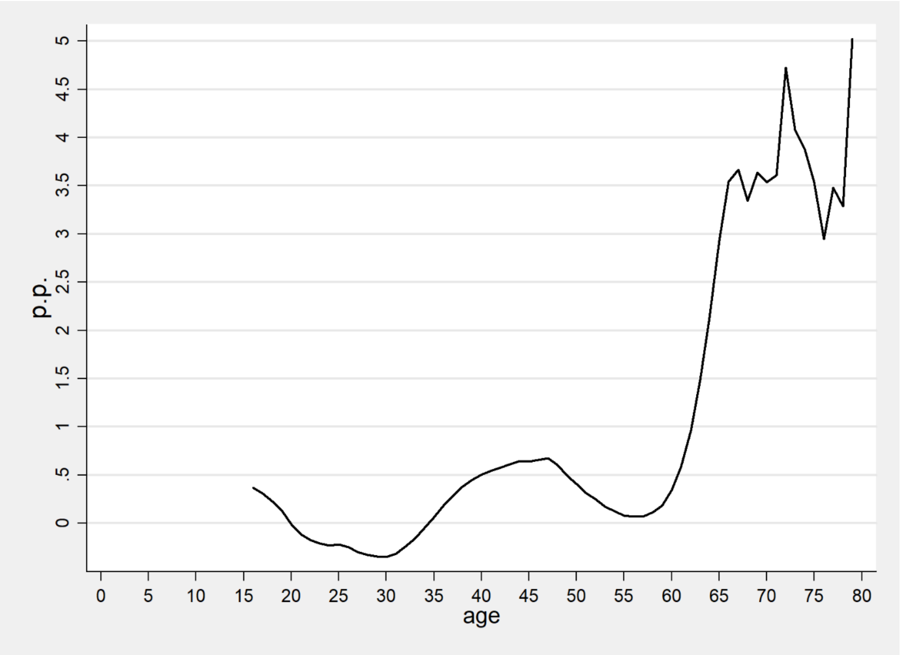

Figure 3. Impact of immigrants on combined income age profile, Slovakia, 2015

Source: author's own calculation.

mid, high and fixed (same). As per the standard NTA approach, people have consumption and either no or a small labour income at the beginning and the end of their lives, thus the orange line represents fixed private consumption. It is assumed that consumption during these periods is the same for immigrants and natives, and does not depend on income. Therefore, values are only for two groups: those who are not present in labour market and those who have left labour market. The remaining three solid lines correlate positively with income level: higher income—higher consumption. The dashed line is a combination of all four consumption levels (Figure 4). The highest consumption appears in the 30–35 age group, after which consumption declines slightly. The peak can be explained by a higher income gap because of differences in consumers' behaviour.

A detailed breakdown of private consumption shows that in Slovakia private consumption is presented mostly by other forms of consumption (food, fuel, tobacco and alcohol, etc.). Immigrants consume less than natives within the 0–30 and 55+ age groups. The first group's lower consumption can be explained by saving behaviour. Immigrants prefer consuming less and saving more, because of their uncertainty about returning to their home country. Moreover, the younger population in the workforce tend to send money home. Older

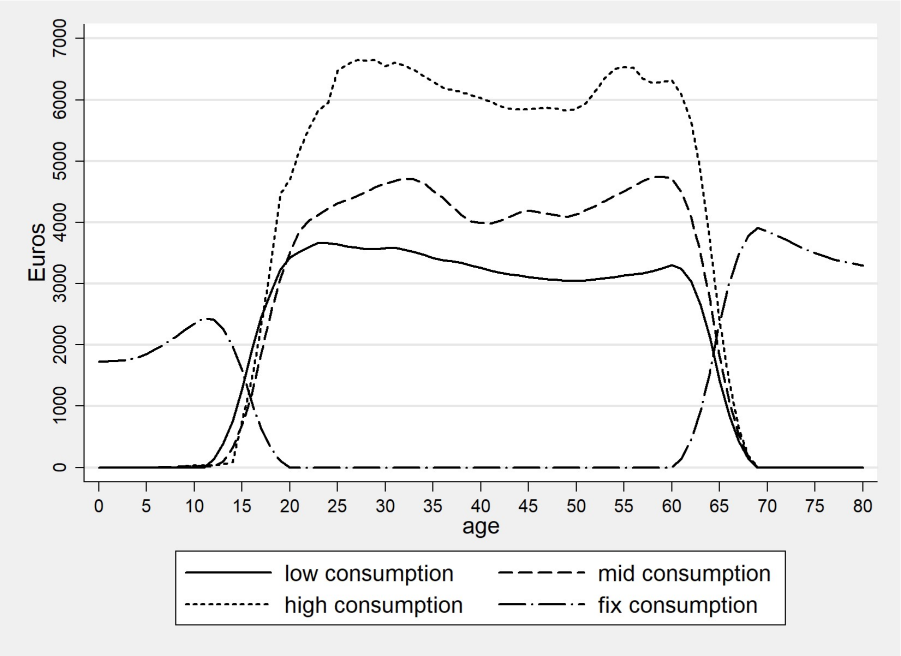

Figure 4. Private consumption age profiles derived by income level per capita, Slovakia, 2015

Source: author's own calculation.

immigrants have similar reasons and make inter- and intra-household transfers. The older generation helps younger generation of immigrants within the host country or outside. Axis *y* represents normalized values (see Section 2).

Meanwhile, a breakdown of public consumption is presented by education, health and other, and shows that the highest total input in total consumption is provided by public education. This is due to all levels of education system being financed by the state, while university studies are also free of charge for native students and foreigners alike. The private sector accounts for a very minor share in this field. Higher education consumption is explained in terms of the age structure of immigrants. They make up a bigger proportion of young age groups in their population. Health and other consumption represent transfers from the state in the forms of social security and healthcare. Because higher age groups of foreigners are rewarded better in terms of incomes, they tend to have higher future social benefits. This is a proxy from the previous salary size. On the other hand, immigrants do not have social security unemployment allowances and house allowances from the state because of Slovak legislation.

Countries with a high level of state participation in education, healthcare and social systems can see growth in government expenditures from very young age groups of immigrants (0–15) and older age groups (65+). Overwise, countries with a high share of the private sector in the mentioned systems will see growth in direct and indirect taxes from consumption. Education consumption is calculated based on data from OECD education and training, where expenditure at every single education level is presented and then adjusted to macro controls. Health consumption is based on the administrative data of total expenditures and adjustments to macro controls.

A combination of the private and public consumption is presented in Figure 5. During the most productive period from 35–50 years old, immigrants consume slightly more than natives, and then after the age of 50, they consume less, with some of them also leaving the host country. As a result, the average life cycle consumption of immigrants is lower than that of natives.

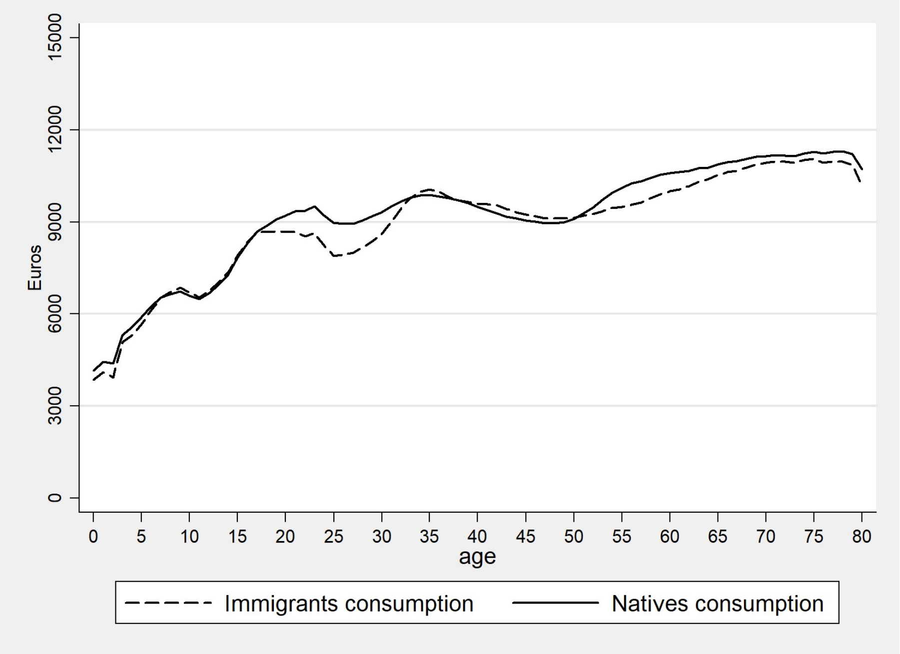

Figure 5. Natives' and immigrants' consumption age profiles per capita, Slovakia, 2015

Source: author's own calculation.

The age profiles of consumption and income give the possibility to calculate per capita and aggregate LCD age profiles. The difference in LCD per capita between natives and immigrants is shown in Figure 6. It shows that the average immigrant in the 45–50 age group earns more than the average native. The curve shows the difference between consumption and income. Negative values mean excess income over consumption and it is higher for immigrants;

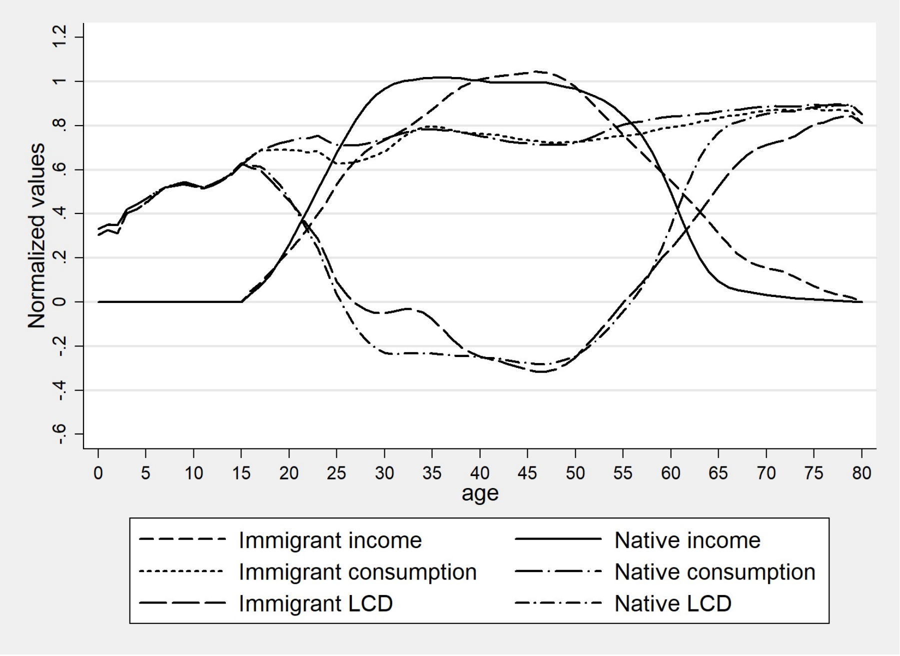

Figure 6. Comparison of immigrant and native LCD per capita, Slovakia, 2015

Source: author's own calculation.

in other words, the life cycle deficit curve is deeper. Its depth can be understo-od as a proxy for the two variables: productivity and independency. Greater LCD means effectiveness in the labour market as an employee, and the lon-gevity of LCD shows for how long a person will fulfil his/her consumption ne-eds without state support.

The total economic effect from immigration can be estimated by building aggregate LCD (Figure 7). Aggregation means that the whole immigrant popu-lation is included in the native population. The solid lines show immigrants' and natives' combinations of income, consumption and LCD, while bars re-present only natives' variables. The gap between solid lines and bars demon-strates the effect of immigration. The highest effect is on aggregate income, while aggregate consumption is almost the same. This confirms the statement that highly skilled employees are better compensated and ensure the posi-tive effect on the economy. Because of the small proportion of immigrants in the total population, their impact is eliminated by the native population.

The influence can be even more positive in the case of growth in the num-ber of highly educated persons who occupy productive working positions. An encouraging impact is already being observed from only 2% of immigrants, thus higher immigrant numbers will contribute to the additional positive ef-fect on aggregate values.

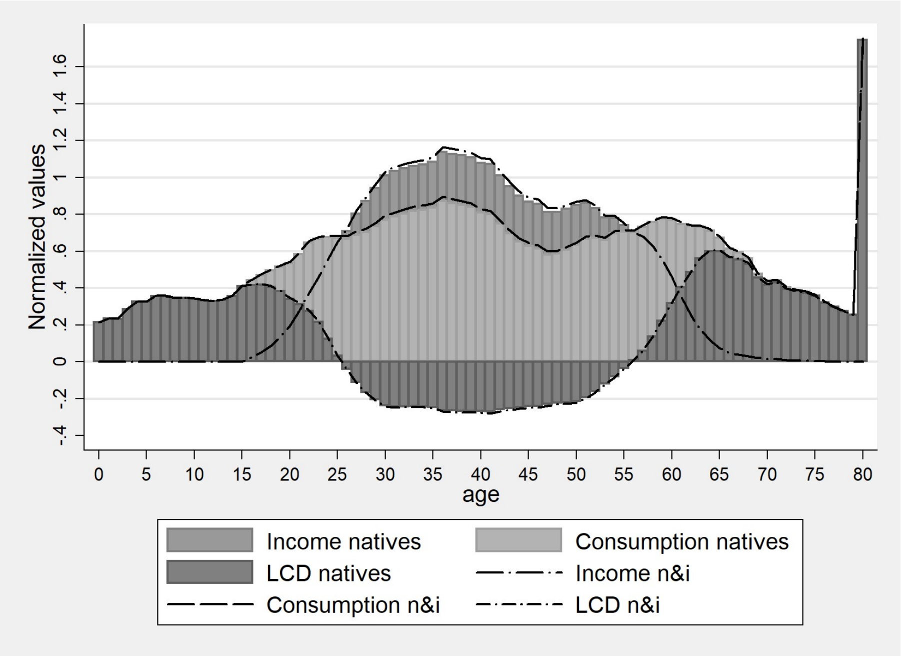

Figure 7. Aggregate LCD with and without immigrants, Slovakia, 2015

Note: The "tail" in the 80 age group appeared because NTA methodology only works with the 0–80+ age group, thus all people older than 80 years are included into this group.

Source: author's own calculation.

4. Discussion

The research results show that immigrants are heterogeneous. They have different education level, cultural patterns, gender structure and countries of origin. In the case of similar cultural environment and education level, immigrants are engaged more deeply in the integration process and generate greater positive effects for the host country's economy. Immigrants from countries with a vastly different cultural environment tend to be faced with a prolonged integration process and this can result in long-term negative impacts, e.g., on the social system through the childcare system. The results of this paper show that the second generation of immigrants receive more social allowances than they contribute to the system. Conversely, immigrants who occupy low-paid positions show higher wage growth in comparison to immigrants who occupy similar job positions to the native population.

Integration policy and migration policy are crucial factors for immigration effects. The results of this paper demonstrate that highly developed countries in Europe face challenges with regard to the participation level of immigrants in their labour markets, while less developed countries register better results. This happens because of stricter processes of legalization and lower social allowances in less developed countries.

Christl, Bélanger et al. (2022) confirmed the results that intra-EU and extra-EU immigrants have a different impact on the host country's economy. They found out that the average net fiscal impact of immigrants is lower than that of natives, while intra-EU immigrants have a favourable age and education structure, and thus their impact is enhanced. The authors also confirm the results of this paper, namely, that there is a high correlation between country of origin and integration in the labour market.

Integration in labour market can be impacted not only by country of origin but also by level of literacy. Christl, Köppl-Turyna et al. (2020) found out that people with an immigrant background and their children tend to have lower paid jobs, due to the poor language proficiency and literacy. Apostolova et al. (2022) supported this statement, adding that immigrants have a lower participation level in the labour market and a low independence ratio. However, the current paper does not confirm these statements. The majority of immigrants in Slovakia are originally from countries with similar language and culture, which plays a positive role in their labour market integration. On the contrary, immigrants in Slovakia have higher incomes, deeper LCD and longer labour market activity than natives. On the aggregate level, this is illustrated by visible effects from a small number of immigrants.

Negative or positive effects from immigration strongly correlate with the characteristics of immigrants. MaCurdy et al. (1998) built various models with different assumptions, which show that with regard to numerous immigrants, their saving and consumption patterns, education level and language knowledge, the influence on host country economy is different and vary from positive to negative effects in current and future periods. The current paper supports this statement and demonstrates that in comparison to other EU countries, Slovakia has different conditions, where immigrants are more favourable for the country and provide positive effects in the present-day economic reality. Compared to the aforementioned articles, this paper takes into consideration the lack of data about immigrants in EU-SILC and HBS, which can lead to decreased accuracy of the results. In addition, the author suggests a way to fill this gap. None of the studies presented above can be seen as the definite answer to the question "is immigration good or bad" but all of them clearly show that the characteristics of immigrants and the current state of politics define the results of immigration.

Conclusions

Slovakia experiences the same issues of ageing and low fertility ratio as other European countries. In addition, people in Slovakia are net consumers up to 25 years of age, and this age indicator is increasing. Slovaks extend their period of higher education and enter the labour market later, thus from year to year, the state has to face growing financial burdens. In Slovakia, today's critical expenditures in areas such as education and healthcare are covered to over 80% by the state budget. Thus, on the one hand, the average age of entering the Slovak labour market is rising, and on the other, longevity is increasing as well.

There are different opportunities of slowing down the negative processes, one of them is immigrants. The results in Slovakia show the positive impact that immigrants bring to the level of life cycle deficit accounts. Immigrants succeed in having both higher incomes than the native population and a higher participation rate in the labour market. Immigrants in Slovakia are younger and enter the labour market immediately after arriving there. The majority of immigrants come from culturally similar countries, which makes the integration process smoother and less costly. Moreover, Slovak scientists state that despite the high number of immigrants in Slovakia because of the war in Ukraine, they are still insufficiently numerous to satisfy the needs of the Slovak labour market (Morvay et al., 2023).

The aim of the present paper is to discover immigration's impact in Slovakia through LCD accounts and by examining the consumption structure of immigrants more precisely. To find answers for this hypothesis, the author employed a relatively new approach and adjusted existing NTA methodology to the immigrant population.

His findings show that in Slovakia, the number of immigrants grew by more than 120,500 people from 2010 to 2022. The share of working age group of immigrants increased from 2.0 in 2015 to 3.3% in 2020 and 4.3% of the population in 2022, respectively. Immigration in Slovakia is predominantly employment-related, with more than 80% of immigrants engaged in the workforce. This demographic dimension is reflected in the economy.

The income age profile for immigrants is superior to that of natives. This is the result of EU-country workforce occupying highly productive positions. At the same time, the proportion of immigrants in Slovakia's total population varied from 1.1% to 3.3% during the period between 2010–2022, which is a considerably low value in comparison to other EU countries. What is important, immigrants in Slovakia remain in the labour market for an additional 3 years, which also means a high independence ratio and the ability to fulfil their own needs and the needs of their families without additional income from the state budget.

At the same time, the life cycle consumption of immigrants is lower than that of natives. This is due to the fact that immigrants have smaller private consumption, while public consumption is higher. The higher public consumption of immigrants is explained by the younger population, which entails a higher educational cost for the Slovak state.

Private consumption in Slovakia stands at 80% of other consumption, in other words, everyday goods and services. In comparison to the native population, immigrants consume less in the period before 30 years of age and after the age of 55. This can be explained by remittances and intra-/inter-households transfers to members of the family within and outside the host country.

On the aggregate level, the low number of immigrants produces visible effects. LCD can be used as a proxy for estimating the productivity and independence of immigrants. For the countries like Slovakia, where the state participation in social system is relatively high, the most beneficial age group of immigrants is 30–55. Younger groups of immigrants have higher consumption of public goods and services like education, while older groups consume more social security system transfers. For countries with small state participation, the 0–15 and 55+ age groups are beneficial due to the growth of consumption and, as a result, tax outflows to the budget.

The full impact of every age group of immigrants will be visible after constructing a whole set of NTA accounts: LCD accounts, transfer accounts and asset-based reallocation accounts. The present paper provides a new point of view on immigration and also suggests filling the existing scientific gap by means of improvements in NTA methodology through the implementing administrative data of the immigrant population.

The case of Slovakia shows that the country has the potential to accept and integrate more immigrants than it currently has. Immigration is beneficial for the country, and increasing the number of immigrants will deliver positive effects for the whole economy and enable the state to implement a long-term policy for increasing the fertility rate and stabilizing the state budget. Despite all the benefits, immigration has its own limitations. The host country cannot substitute its own population with immigrants: it is impossible both from the technical side and political side. This study shows that the effects of immigration can be beneficial. The present research can prove valuable for different parties: a) for academic society via providing a new approach to thinking how the effects of immigration can be valued and how NTA methodology can be improved; b) for policymakers, by means of evaluating the effectiveness of policies aimed at regulating intergenerational transfers, identifying potential challenges and designing more targeted policies.

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Is value investing based on scoring models effective? The verification of *F*-Score-based strategy in the Polish stock market

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Abstract

The aim of the paper is to analyse the effectiveness of *F*-Score-like models using the example of the Polish stock market. *F*-Score is a scoring model based on a high B/M investing strategy, which uses fundamental signals to assess the economic condition of an entity. So far, its effectiveness has been generally proven in numerous stock markets worldwide. However, no comprehensive study focusing on the Polish market has been conducted. Therefore, *F*-Score and similar models (*FS*-Score and PiotroskiTrfm) were analysed in this regard. It was shown that companies with higher scores generated positive both raw and market-adjusted returns on average. However, they were lower than the mean returns of low-score companies (for *FS*-Score) or total high B/M portfolio (regarding *F*-Score and PiotroskiTrfm). The results of the study show that *F*-Score, *FS*-Score and PiotroskiTrfm are generally effective investing tools. However, it might be more advisable for value investors to choose a total high B/M portfolio instead of shares of high-score entities according to *F*-Score or PiotroskiTrfm.

Keywords

- *F*-Score
- high B/M
- investment strategy
- value investing

JEL codes: G11, M20, M41

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Introduction

The investing process should focus on identifying entities whose intrinsic value exceeds the market price at a given moment (Graham & Dodd, 1934). This was the conclusion reached by these authors, who are widely recognised as among the most significant figures connected with fundamental analysis. It characterises the value investing approach. In line with this conclusion is the idea of investing in shares in undervalued entities, which are often measured by using a B/M ratio (book value to market value; entities whose B/M is below 1 are considered undervalued).

A high B/M strategy is the foundation of the *F*-Score model developed by Piotroski (2000). He proposed a model that consists of nine fundamental signs, which is used to select entities with strong economic foundations, based on scoring, and build an investment portfolio from shares in them. Such a portfolio should generate returns that outperform the market. After the publication of the *F*-Score model, a few modifications of this construct were also made by other authors. Their aim was to improve the initial model or build a new model based on the example of other stock markets. So far, many analyses of *F*-Score's effectiveness have been conducted using examples from European countries and other emerging markets. However, as yet there is no comprehensive analysis based on the specificity of the Polish stock market, apart from research conducted on small samples of the largest listed entities.

The aim of the paper is to analyse the effectiveness of the *F*-Score and similar models using the example of the Polish stock market. The main research hypothesis is that the *F*-Score model is effective and companies with higher scoring outperform both low-score entities and all high B/M companies. The supportive hypothesis is analogous for *FS*-Score and PiotroskiTrfm.

The structure of the paper is as follows: Section 1 includes the overview of the high B/M investing strategy, *F*-Score model and its modifications (*G*-Score, *FS*-Score, PiotroskiTrfm), while Section 2 presents a literature review of the research focused on the assessment of the *F*-Score effectiveness. Section 3 includes a description of the methods used, Section 4—empirical research, and last Section concludes.

1. *F*-Score model and its modifications

1.1. High B/M strategy

A high B/M strategy fits into the framework of value investing. According to Chan et al. (1991), stock returns generated from the portfolio of entities with high B/M values outperformed other portfolios. This was also supported by Fama and French (1992), in whose view it is prudent to invest in a portfolio consisting of undervalued shares. The authors stated that the companies with high B/M might be generally treated as financially distressed, which causes a lack of interest in their shares among investors. Lakonishok et al. (1994) argued that B/M values relate to the behavioural aspect of investors. It refers to their tendency to be over-pessimistic when evaluating entities affected by temporary financial problems. Hence, investors are not willing to invest in shares of high B/M entities. As a result, these become undervalued. On the other hand, financial surprises, quite common among companies in poor financial condition, are most likely to be avoided by high B/M entities (La Porta et al., 1997).

Although the positive association between B/M and rates of return was generally accepted, the relationships between these variables were continuously verified. The positive correlation between the B/M factor and future stock returns was empirically confirmed, e.g., by Auret and Sinclaire (2006), Hasan et al. (2015), da Cunha Araújo and Veras Machado (2018), and Fahreza and Rizkianto (2021).

An analysis conducted by Auret and Sinclaire (2006) used the example of entities listed on the Johannesburg Stock Exchange. The results showed that the next month's return on the shares was positively correlated with the B/M factor. However, this correlation was noticeably weaker after the inclusion of other explanatory variables (cash flow to price, dividend yield, and price-to--net asset value).

Hasan et al. (2015) conducted their analysis using the data of selected companies listed on the Karachi Stock Exchange. They concluded that B/M was the most significantly connected with stock returns out of the all variables examined (the authors also included debt-to-equity, firm size, and sales-to--price as exogenous variables). However, the degree of correlation between B/M and stock returns was moderate.

The study by da Cunha Araújo and Veras Machado (2018) was conducted using the example of Brazilian listed companies. B/M combined with relative earnings (measured by return on equity) was found to be positively linked with future stock returns. Such an association was also maintained after the inclusion of controlling variables regarding firm size and liquidity.

Fahreza and Rizkianto (2021) focused on the companies listed on the Indonesia Stock Exchange. Their results showed that high B/M values were positively connected with higher future stock returns. Such an association applied to both value-weighted and equally weighted portfolios built by the authors.

Generally, the above-mentioned research proved the effectiveness of a high B/M investing strategy. These studies concerned emerging stock markets, like the Polish one, and based on them, it could be stated that it is sensible to invest in undervalued companies. With this regard, the key issue arises, namely, how to select the entities with good financial condition within this group?

1.2. *F*-Score

The main concept of the research procedure proposed by Piotroski was to use accounting-based variables to measure the future financial condition of high B/M companies (Piotroski, 2000). Such entities were usually recognised as financially distressed ones (Fama & French, 1995). Therefore, in Piotroski's view, the best way to provide insight into the future economic situation was to use accounting indicators (Piotroski, 2000). The author argues that: (1) high B/M companies with high profitability present an ability to generate financial surpluses, (2) increasing financial leverage or/and decreasing liquidity might be treated as a sign of a growing risk to a company, (3) operating effectiveness indicators relate to the changes in two factors affecting total profitability—sales volume and relative margin (Piotroski, 2000). Hence, nine variables were chosen to assess the entity three times, taking into account its profitability, financial leverage, liquidity and funding sources, and operating effectiveness. Variables that constitute *F*-Score are presented in Table 1.

The form of the *F*-Score model is a sum of binary values (0 or 1) for a given variable. ΔACCRUAL and ΔLEVER are destimulants (their negative values are recognised as 1 point), while the other variables are stimulants. Entities with a score of 8 or 9 points were selected for the investment portfolio as high-score entities. For low-score companies, Piotroski (2000) postulated short selling.

The construction of the investing portfolio was in line with the buy-and--hold strategy, which led to the generation of significantly different rates of return between high- and low-*F*-Score entities. The mean annual raw yields generated by the investment portfolio (high B/M entities with 8-9 points scoring) amounted to 31.3%, with 7.8% for low *F*-Score companies. However, it is worth noting that absolute rates of return are not sufficiently objective: in periods of a bull market, generating positive yields is more likely than during a slump. Therefore, more meaningful results are provided by comparing the returns generated with market returns or calculating market-adjusted returns. Such adjusted returns were negative in the case of low *F*-Score entities

Table 1. Variables constituting *F*-Score

Variable	Area	Variable type*
$ROA = \frac{\text{Net income}_t - \text{extraordinary operations balance}_t}{\text{Total assets at the beginning of a period}_t}$	profit-ability	S
$CFO = \frac{\text{Net operating cash flows}_t}{\text{Total assets at the beginning of a period}_t}$		S
$\Delta ROA = ROA_t - ROA_{t-1}$		S
$\Delta ACCRUAL = (ROA - CFO)_t - (ROA - CFO)_{t-1}$		D
$\Delta LEVER = \left(\frac{\text{Total liabilities}}{\text{Average total assets}}\right)_t - \left(\frac{\text{Total liabilities}}{\text{Average total assets}}\right)_{t-1}$	financial leverage, liquidity, source of funds	D
$\Delta LIQUID = \left(\frac{\text{Current assets}}{\text{Current liabilities}}\right)_t - \left(\frac{\text{Current assets}}{\text{Current liabilities}}\right)_{t-1}$		S
$EQ\_OFFER = \begin{cases} 1 \text{ for no issue of ordinary shares in a given period} \\ 0 \text{ otherwise} \end{cases}$		S
$\Delta MARGIN = \left(\frac{\text{Gross margin on sales}}{\text{Sales revenues}}\right)_t - \left(\frac{\text{Gross margin on sales}}{\text{Sales revenues}}\right)_{t-1}$	operating effective-ness	S
$\Delta TURN = \left(\frac{\text{Sales revenues}}{\text{Total assets at the beginning of a period}}\right)_t - \left(\frac{\text{Sales revenues}}{\text{Total assets at the beginning of a period}}\right)_{t-1}$		S

* In the case of stimulants, the positive value of a given variable is recognised as 1 point.

Notes: S – stimulant, D – destimulant.

Source: based on (Piotroski, 2000).

(–9.6%) and significantly positive regarding high B/M companies—at the level of 13.4% (Piotroski, 2000). These results explicitly indicated the benefits of using the *F*-Score model.

Piotroski (2000) provided empirical confirmation of his model, which was also based on the two subsamples – entities with a score below 5 points (‘Weak *F*-Score’) and 5 or more points (‘Strong *F*-Score’). Only in two years (1976 and 1994) out of 21 analysed did mean yields generated by weak *F*-Score entities outperform the rates of return of strong *F*-Score companies. The average difference between the two groups of entities analysed was 9.7 p.p. (arithmetic mean) or 9.3 p.p. (the average weighted by the number of observations in a given year) in favour of strong *F*-Score companies. These results could be treated as an initial empirical confirmation of the strategy proposed by Piotroski.

Despite the potential usefulness of using the *F*-Score strategy, it was not a popular model for several years after its development. However, its recognition significantly increased during the financial crisis that started in 2007. This model led to the generation of an average 32.6% yield. This was the best result from the strategies analysed by the American Association of Individual Investors (Comparic, 2017) and affected the model's popularity in subsequent years. As a result, several modifications to the *F*-Score were developed. These are models that took into account different sets of variables and markets developed in recent years and include G-Score, *FS*-Score and PiotroskiTrfm.

1.3. *G*-Score

G-Score is a model developed by Mohanram (2005). Like Piotroski, Mohanram divided the indicators used to construct the model into three subgroups. These were signals referring to earnings and cash flow profitability, naive extrapolation, and accounting conservatism (Mohanram partially included behavioural factors in the model as well). The variables related to financial streams are among the main measures of the economic effectiveness of business management. However, the inclusion of variables related to the two areas listed next may come as a surprise. The motivation for including such variables was that stock markets make a naive extrapolation of the current fundamental values of growth companies (whose business specificity is, after all, focused on maintaining a significant positive growth rate) (La Porta, 1996). Moreover, the valuation of this type of entity should take into account variables that are not subject to reporting under conservative accounting. According to Trueman et al. (2000), these are:

a) non-financial factors such as the number of users (especially in the case of Internet companies),
b) public interest in the entity,
c) the effectiveness of its marketing activities.

It is worth noting that Mohanram did not include the absolute values of the variables in his model. He relates them to the medians of observable values in a sample of companies from the same industry. This approach differs from the one adopted by Piotroski. In addition, the G-Score model was developed to construct portfolios of entities with low B/M, which is opposite to the original strategy that the *F*-Score was based on (Mohanram, 2005). The variables of the *G*-Score model are presented in Table 2.

Table 2. *G*-Score exogenous variables

Variable	Area	Variable type
$G1 = ROA_{i_t} - ROA_t^*$	profitability	stimulant
$G2 = CFO_{i_t} - CFO_t^*$		stimulant
$G3 = CFO_{i_t} - ROA_{i_t}$		stimulant
$G4 = ERN\_VAR_{i_t} - ERN\_VAR_t^*$	naive extrapolation	destimulant
$G5 = SAL\_GR_{i_t} - SAL\_GR_t^*$		destimulant
$G6 = \left(\frac{R\&D}{A}\right)_{i_t} - \left(\frac{R\&D}{A}\right)_t^*$	accounting conservatism	stimulant
$G7 = \left(\frac{CAPEX}{A}\right)_{i_t} - \left(\frac{CAPEX}{A}\right)_t^*$		stimulant
$G8 = \left(\frac{ADV}{A}\right)_{i_t} - \left(\frac{ADV}{A}\right)_t^*$		stimulant

Notes: *i* – variable value for a given and entity, * – median value for entities from one industry, ERN_VAR – earnings variability, SAL_GR – sales growth variability, R&D – research and development expenses, CAPEX – capital expenditures, ADV – advertising intensity.

Source: based on (Mohanram, 2005).

Low *G*-Score values were set as 0–1, while high values as 6–8 points. Based on back-testing, the construct was found to be more effective than the market. Adjusted annual yields accounted for 2.4% among a set of high-scoring entities and –16.4% for low *G*-Score companies. According to the author, the overall effectiveness of the model was particularly due to an accurate assessment of which companies to avoid. As a result, these entities should not be included in the investment portfolio. Short selling might be also applied to them (Mohanram, 2005).

1.4. *FS*-Score

The *FS*-Score model, developed by Gray, presents greater similarity to the original *F*-Score model than Mohanram's construct. Like the previously mentioned models, the *FS*-Score contains indexes assigned to three groups. In this case, they are current profitability, financial stability, and recent operational improvements. The variables from which the *FS*-Score is built are presented in Table 3.

Table 3. *FS*-Score exogenous variables

Variable	Area	Variable type
$ROA = \frac{\text{Net income}_t - \text{extraordinary operations balance}_t}{\text{Total assets at the beginning of a period}_t}$	current profitability	stimulant
$FCFTA = \frac{\text{Free cash flow}_t}{\text{Total assets at the beginning of a period}_t}$		stimulant
$ACCRUAL = ROA_t - FCFTA_t$		destimulant
$\Delta LEVER = \Delta\left(\frac{\text{Long-term liabilities}}{\text{Total assets}}\right)$	financial stability	destimulant
$\Delta LIQUID = \Delta\left(\frac{\text{Current assets}}{\text{Current liabilities}}\right)$		stimulant
NEQUISS = Number of own shares repurchased$_t$ – number of shares issued$_t$		stimulant
$\Delta ROA = ROA_t - ROA_{t-1}$	operational improvements	stimulant
$\Delta FCFTA = FCFTA_t - FCFTA_{t-1}$		stimulant
$\Delta MARGIN = \Delta\left(\frac{\text{Gross margin on sales}}{\text{Sales revenues}}\right)$		stimulant
$\Delta TURN = \Delta\left(\frac{\text{Sales revenues}}{\text{Total assets at the beginning of a period}}\right)$		stimulant

Notes: Δ – difference between the value of a given variable in the t period and its value in the t–1 period.

Source: based on (Gray, 2015).

The main indices modified by Gray compared to the *F*-Score model are variables relating to the cash flow (which also caused the different construction of the ACCRUAL variable) and stock issues. This author proposed also the inclusion of an index characterising the difference in the value of free cash flow (ΔFCFTA), while there was no similar variable (i.e. ΔCFO) in the *F*-Score model. As a result, there were three variables concerning current profitability, three related to financial stability, and four regarding operational improvements.

The comparison of the effectiveness of the *F*-Score and *FS*-Score models prepared by Gray was based on a sample from 1974–2014. The verification of the effectiveness of both models showed their superiority over the benchmark, which was the S&P500 index. Although both constructs analysed allowed higher returns than the market index, the use of the *FS*-Score led to better results. However, it is worth noting that, in general, the observable differences between returns were not particularly large. The average annual return on the S&P500 index during the period under review was 11.2%, on the investment portfolio built in accordance with the *F*-Score and *FS*-Score strategy—12.6% and 13.3%, respectively (Gray, 2015). Nevertheless, the use of both models seemed more expedient than investing passively in the S&P500 index.

In line with the previous findings were those of Mehta et al. (2019). According to their research, the *FS*-Score as well as *F*-Score models proved to be more effective than the market. Since the sample period (2006-2015) included the global financial crisis, the performance of the strategies tested could be considered robust.

1.5. PiotroskiTrfm

The analyses conducted by Piotroski (2000), Mohanram (2005), and Gray (2015) focused on the U.S. stock market. However, the empirical verification of the effectiveness of the *F*-Score was also prepared based on the example of the South African stock exchange (different from the U.S. in both geographical and stock market development dimensions). Such research was carried out by Nast, who examined the effectiveness of the various variables that make up Piotroski's model. According to his analysis, only 6 of the 9 indices proved to be statistically significant in discriminating companies with above-market returns from entities that generated unsatisfactory results. Surprisingly, in the case of two of these—ΔLEVER, ΔTURN—the author pointed out the advisability of using reverse scoring to the one proposed by Piotroski (Nast, 2017).

Nast verified the effectiveness of individual *F*-Score variables and constructed a model consisting of its selected components. Finally, he included six original variables (using reverse scoring for two of them: ΔLEVER and ΔTURN), discarding the others (ΔROA, ΔLIQUID, ΔMARGIN). The model built in this way (PiotroskiTrfm) was quite effective. Investing in shares of high-score companies brought average annual returns of 22%. On the other hand, the shares of entities with weaker economic situations generated on average a capital gain of less than 6% (Nast, 2017).

Based on Nast's research, it could be stated that the specificity of a given stock market plays an important role in the construction of *F*-Score-type models. A set of variables that accurately characterises the economic situation of companies in one market will not necessarily prove effective for another. This is another argument for conducting research focused on the Polish stock market.

2. Assessment of *F*-Score model effectiveness—literature review

Taking into account the aim of the research, a literature review focused on the effectiveness of the *F*-Score model was prepared. This focused on various markets in different time frames to ensure data comparability. The results are presented in Table 4.

Table 4. Examples of research focused on assessing *F*-Score effectiveness

Source	Market	Analysed period	Results/conclusions
Almas and Duque (2008, p. 25–26)	Belgium, French, Netherlands, Ireland, Portugal	1993–2003	among the three investment strategies analysed, only *F*-Score proved to be effective. Returns generated with its use outperformed the market by an average of 9.2 p.p.
Noma (2010)	Japan	1986–2001	investing in line with the *F*-Score strategy led to the construction of a portfolio that generated a return of 7.8 p.p. above the market average, generating an annual return of 17.6%
Rathjens and Shellhove (2011, p. 26, 58–59)	United Kingdom	1991–2008	entities with high *F*-Score ratings generated returns higher than those of low-rated entities (by an average of 11.7 p.p.), and from other companies (by an average of 4 p.p.)
Mohr (2012)	United States of America	1976–1996	a strategy based on buying the shares of companies with high *F*-Score and selling the securities of entities low-rated by the model yielded returns higher than the market
Hyde (2013)	25 countries (emerging markets)	2000–2011	a study based on the example of emerging markets empirically confirmed the effectiveness of using an *F*-Score-based investment strategy
Singh and Kaur (2015)	India	1996–2010	the returns generated in accordance with the *F*-Score strategy were 18.4 p.p. higher than the values achievable by investing in equity securities of companies with high B/M values

Source	Market	Analysed period	Results/conclusions
Krauss et al. (2015)	United States of America	1976–1996	investment strategies based on the *F*-Score, both on a monthly and weekly basis, led to the generation of excess returns
Safdar (2016)	United States of America	1973–2015	the *F*-Score-based strategy is generally effective, but the degree of its effectiveness varies between industries
Hyde (2016)	Australia	1992–2013	the investment strategy based on the *F*-Score has proven to be effective only for the segment of smaller listed companies. Significant sensitivity of its effectiveness due to the selection of a given sample and time frame was also found
Oyebode (2016)	South Africa	2005–2014	the investment portfolio built from the shares of companies with low *F*-Score ratings generated returns below the market by 6.6 p.p. on average. Thus, the short-selling strategy based on the values of the model analysed proved to be purposeful
Banerjee and Deb (2017)	India	2003–2013	investment portfolios composed of stocks of companies with high *F*-Score ratings generated significantly higher returns than collections of low-scoring shares
Tripathy and Pani (2017)	India	2009–2015	higher-rated companies yielded rates of return significantly higher than those achieved by entities rated low by the *F*-Score.
Sareewiwatthana and Janin (2017)	Thailand	2002–2016	all of the investment strategies analysed (including the *F*-Score) generated returns significantly exceeding the market yields
Turtle and Wang (2017)	United States of America	1972–2012	entities with high *F*-Score values generated significantly higher returns than companies with low ratings
Bülow (2017)	United States of America	2003–2015	buying stocks with a high *F*-Score rating allowed the generation of a return of more than 6 p.p. above the market. A portfolio built from equities with low *F*-Score values yielded a return of 4%

Source	Market	Analysed period	Results/conclusions
Eremenko (2017)	Brazil, China, India, Germany, Russia, United Kingdom	2013–2015	most of the high-rated entities generated returns significantly above the market values (by 8.2 p.p. on average)
Pätäri et al. (2018)	Germany	2000–2015	the inclusion of the *F*-Score in the investment strategy used results in a significant increase in the rate of return achieved
Lalwani and Chakraborty (2018)	India	2001–2015	the strategy based on Piotroski's concept led to an average annual return exceeding the market in the 2001–2005 and 2011–2015 periods. The 2006–2010 period, however, yielded returns slightly lower than the benchmark
Tikkanen and Äijö (2018)	16 European countries	1992–2014	the selection of companies using the *F*-Score model positively affected the returns achieved using multiplier-based investment strategies
Walkshäusl (2020)	35 countries, including 20 developed and 15 emerging markets	2000–2018	returns earned by companies with high *F*-Score ratings exceeded the values generated from securities of entities deemed by the model to be in poor financial health by ca. 10 p.p. per year
Pilch (2021)	Poland	2017–2019	high-scored entities generated higher returns than other public companies from the IT and video game industries
Brindelid and Nilsson (2021)	Denmark, Finland, Norway, Sweden	2012–2021	a comparison of investment strategies based on the *F*-Score and „The Magic Formula" showed an advantage for Piotroski's strategy
Kusowska (2021)	Poland	2014–2020	the research on a sample of the largest Polish entities empirically confirmed the *F*-Score effectiveness

Source: based on the literature review.

It is quite astounding that the results of most of the research presented in Table 4 are generally uniform. They lead to the findings regarding the confirmation of the model's effectiveness. On the other hand, there were also some analyses that pointed out one of the weaknesses of the *F*-Score model—its sensitivity to the time frame adopted (Hyde, 2016; Lalwani & Chakraborty, 2018). Therefore, the results that were obtained from the period 2000–2011 will not necessarily be reflected on the basis of the more recent analysis.

Regarding the Polish stock market, two analyses conducted in recent years were identified in the literature (Kusowska, 2021; Pilch, 2021). However, these concern only a few dozen listed companies. This research provides a more comprehensive empirical analysis based on the sample (total of 225 entities with the highest B/M out of 672 entities analysed, as indicated in section 3) and period (2012–2022) taken into account as well as the use of other *F*-Score-type models.

3. Methods description

3.1. Research design

The empirical part of this paper focuses on assessing whether the models analysed are effective and whether entities with higher scoring outperform companies assessed low (and the market) in terms of returns generated. *F*-Score, *FS*-Score, and PiotroskiTrfm were analysed in this regard. G-Score was excluded from the research due to the lack of sufficient data (especially regarding the estimation of G6 and G8 variables). Based on the financial data, scoring for each entity was computed and returns generated by these companies (in the following period, as described below) were analysed.

Entities that achieved 0 or 1 point (for each model) were considered as having low scores, while a high score was 8–9 points for the *F*-Score, 6 points for PiotroskiTrfm, and 9–10 points for the *FS*-Score. In the following part of the paper, "low" is understood as low-score entities and "high" as high-score companies. Descriptive statistics for variables constituting the *F*-Score and *FS*-Score were analysed, as well as returns generated by entities with each scoring. Statistical tests for the significance of differences regarding means were also employed. Finally, investment portfolios comprising shares in high- and low-score entities (separately) were built (under the assumption of simple diversification).

Among the returns, raw and market-adjusted ones were analysed. The formulas for calculating them are as follows:

$$RR = \frac{P_t}{P_{t-1}} - 1 \tag{1}$$

$$MAR = RR - \frac{P\_WIG_t}{P\_WIG_{t-1}} - 1 \tag{2}$$

where:

RR – raw return,

MAR – market-adjusted return,

P – share price (at closing),

t – last working day in June,

t–1 – first working day in July the previous year,

P_WIG – level of WIG (Warszawski Indeks Giełdowy) index (at closing).

The financial data for a given year were used to explain returns from a year-long period starting six months after the closing date. For instance, scoring was based on the financial data from 2020, while respective returns were for the period 1.07.2021–30.06.2022. The aim of such a time shift was to ensure that the financial data were already known by investors. Hence, the period under analysis is 2011–2020 regarding the financial data used. Returns concerned the period from 2.07.2012 (the first working day of this month) to 30.06.2022.[2]

The financial data as well as share prices were obtained from the Orbis BvD Info database. Due to the data limitations, the following simplifications were implemented:

- Extraordinary operations balance was equal to extraordinary and other profit/loss (regarding ROA calculation),
- Free cash flow was estimated as operating income multiplied by 0.81 (as the Polish base CIT rate is 19%) plus depreciation and amortisation less change in net working capital (measured as inventory plus trade receivables less trade payables) and additions to fixed assets as CAPEX-related variable (regarding FCFTA calculation).

The outliers (the highest 2% and the lowest 2% values of each continuous explanatory variable analysed) were also removed from the sample.

3.2. Sample

The initial sample covered by the study comprised companies from several industries. Entities with core business activity connected with financial services (K – Financial and insurance activities under NACE Rev. 2 classification) were excluded, especially due to the different layouts of their financial statements. It is worth noting that the final sample (which is the focus of the following part of the study) refers to the set of 20% of entities with the highest B/M. They were considered undervalued, in line with Piotroski's approach.

[2] On the following pages, '2022' regarding stock returns means the period between 1.07.2021 and 30.06.2022 (analogous for other years).

The breakdown of entities constituting both the initial and final sample by industry is shown in Table 5.

Table 5. Sample – breakdown by industry

Industry (according to NACE Rev. 2 classification)	Initial sample	Final sample
C – Manufacturing	232	64
G – Wholesale and retail trade; repair of motor vehicles and motorcycles	100	35
J – Information and communication	86	21
M – Professional, scientific and technical activities	69	22
F – Construction	43	17
L – Real estate activities	24	16
D – Electricity, gas, steam and air conditioning supply	20	12
N – Administrative and support service activities	18	7
Q – Human health and social work activities	16	2
H – Transportation and storage	13	5
O – Public administration and defence; compulsory social security	12	5
A – Agriculture, forestry and fishing	10	5
S – Other service activities	10	6
Other industries	19	8
Total	**672**	**225**

Source: own work.

Generally, the share of companies from the top 5 industries amounted to ca. 79% of the total entities analysed. Moreover, manufacturing companies accounted for 34.5% of the initial sample. The shares of companies from the C, G, J, M and F industries in the total number of entities analysed did not significantly (based on the *t*-tests) differ between the initial and final samples. Therefore, it seems that sectoral differentiation did not play a significant role in this research.

3.3. Book-to-market values

Entities constituting the final sample were chosen based on the B/M values. Companies with the 20% highest values of this variable were selected, in line with Piotroski's (2000) approach. The number of companies and entities with the highest B/M values is presented in Figure 1.

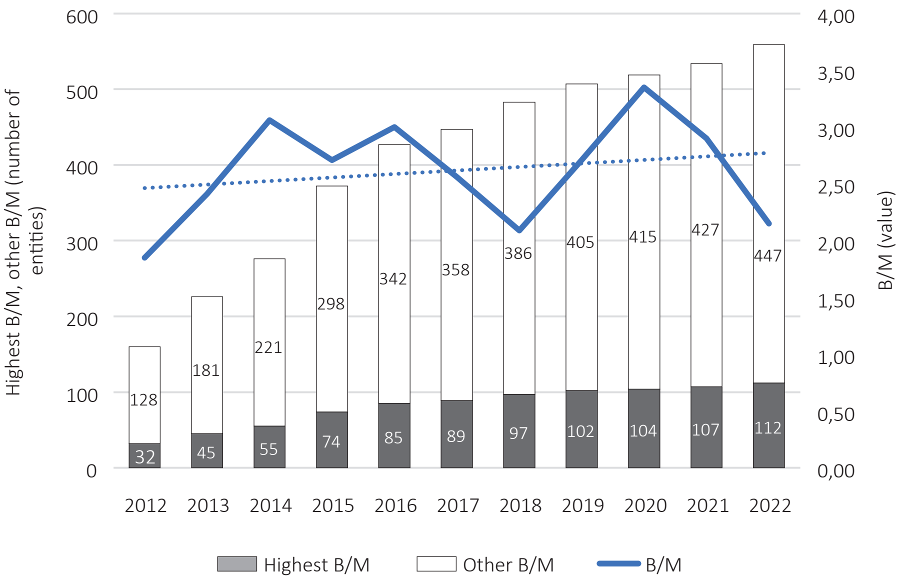

Figure 1. Number of entities with the highest B/M

Source: own work.

As can be indicated on the basis of Figure 1, the number of entities included in the research grew substantially year on year over the period analysed. The value of B/M that differentiated high and other B/M companies was between 1.85 and 3.35. Changes in this value might be explained to some extent by the post-crisis recovery, the period of shortening of the monetary policy and increasing globalisation, as well as the COVID pandemic. Please note that there are a total of 225 companies in the final sample and 902 items of firm-observation data, e.g. based in the Figure 1. These numbers differ, as some of the companies were considered undervalued several times in different years.

4. Verification of the effectiveness of *F*-Score-like model

4.1. Distribution of models scoring

The maximum scoring of models analysed is different. The distribution of the number of entities with each scoring is also significantly differentiated between *F*-Score, PiotroskiTrfm and *FS*-Score. Histograms for these models are presented in Figures 2–4.

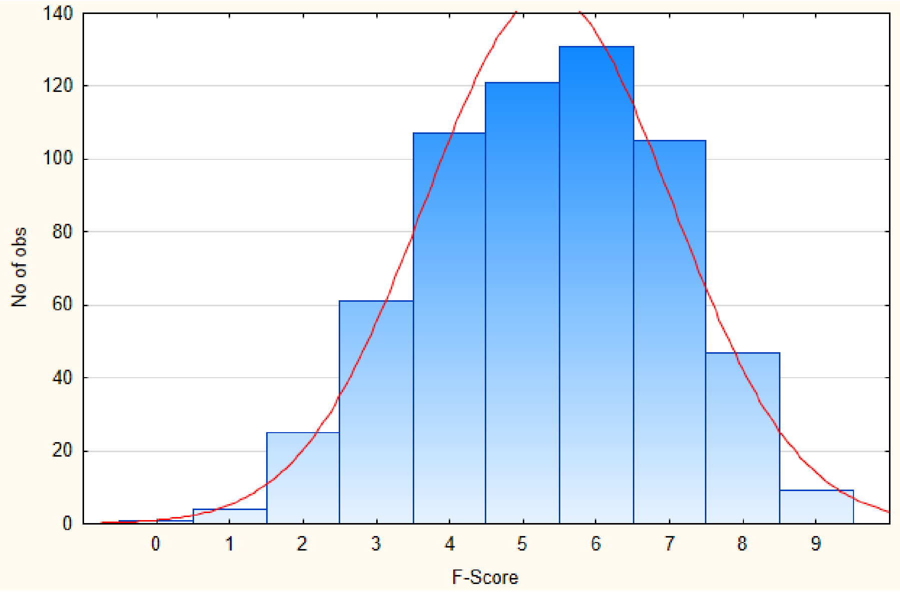

Figure 2. *F*-Score histogram

Source: own work using Statistica.

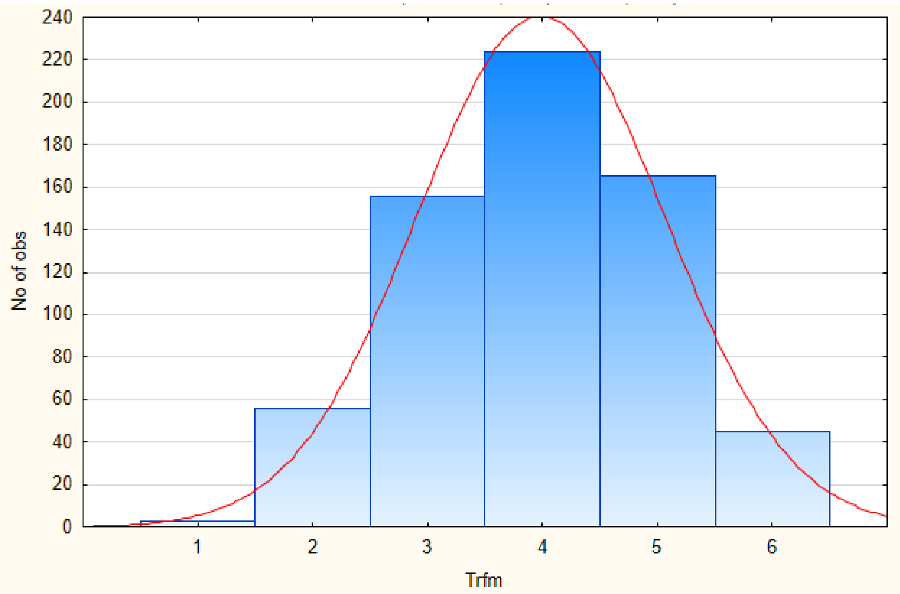

Figure 3. PiotroskiTrfm histogram

Source: own work using Statistica.

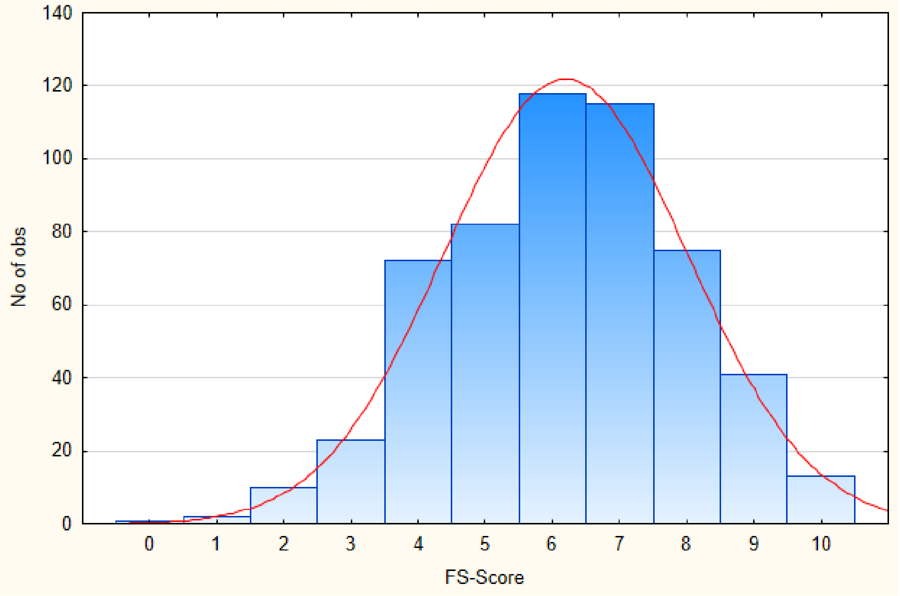

Figure 4. *FS*-Score histogram

Source: own work using Statistica.

As can be found based on Figures 2–4, the less frequent values were generally the lowest and the highest, similar to the Gauss distribution. The shares of companies with the two highest possible points under *F*-Score and *FS*-Score and with 6 points for PiotroskiTrfm (entities that were chosen to the investment portfolios) were 9.2%, 9.8%, 6.9%, respectively. For the companies with the lowest scoring (0–1 points), it was 0.8%, 0.5%, 0.5%, respectively. Based on these values, it seems that PiotroskiTrfm is significantly more restrictive in the choice of company. However, *F*-Score and *FS*-Score might benefit from greater portfolio diversification.

4.2. Descriptive statistics

Descriptive statistics for individual variables were further analysed. They concerned exogenous variables (ratios constituting *F*-Score, PiotroskiTrfm, and *FS*-Score) as well as returns. The results of such analysis are presented in Table 6 and Table 7.

No fewer than 25% of companies generated negative values—this applies to all variables except CFO and FCFTA. Most of the high B/M companies (over ¾) generated positive operating cash flows. For ROA, medians and means were positive—these are generally signs of positive average performance

Table 6. Descriptive statistics for exogenous variables included in the research

Variable	Mean (%)	1st quartile (%)	Median (%)	3rd quartile (%)	Standard deviation (%)	Percentage of positive signs (%)
ROA	1.09	–1.12	1.73	4.47	7.77	69.44
ΔROA	–0.40	–3.25	–0.23	2.23	8.44	46.46
CFO	5.08	0.25	4.71	9.66	7.18	76.59
ΔACCRUAL	–0.37	–5.47	–0.40	4.78	11.52	47.41
ΔLEVER	0.29	–2.70	0.31	3.32	6.44	54.00
ΔLIQUID	–4.56	–22.85	–1.05	23.19	148.08	48.13
ΔMARGIN	0.34	–2.82	–0.02	3.22	11.27	49.80
ΔTURN	–3.62	–10.67	–0.29	4.89	22.97	47.93
FCFTA	10.14	2.36	10.14	17.21	12.13	83.40
ΔFCFTA	–1.36	–8.44	–0.76	6.11	14.95	46.77
ACCRUAL	–8.03	–15.11	–8.34	–0.55	13.26	23.12

Source: own work.

Table 7. Descriptive statistics for raw and market-adjusted returns

Returns	Mean (%)	10th percentile (%)	25th percentile (%)	Median (%)	75th percentile (%)	90th percentile (%)	Percent-age of positive signs (%)
RR	15.62	–41.57	–21.74	–1.12	28.41	71.88	45.36
MAR	12.40	–48.56	–26.56	–1.73	25.13	76.39	47.54

Source: own work.

of analysed entities. However, ΔROA and ΔFCFTA were mostly negative—on average, ROA and FCFTA declined over time. On the other hand, ACCRUAL was negative for ca. 77% of observations, which is a sign of high conversion of profits into operating cash flows. Such changes are also supported by the ΔACCRUAL variable—its values were negative in most cases, which is a positive sign in Piotroski's (2000) view.

Most of the entities (ca. 54%) increased their indebtedness and both the mean and median for ΔLEVER were positive. Moreover, the absolute value of the 3rd quartile was significantly higher than for the 1st quartile – the scale of debt increase was on average higher for 25% of entities than its decline for the opposite ones. In terms of liquidity, most observations generated a negative change. What is more, there were many entities with a significant drop in liquidity, as the mean for ΔLIQUID is noticeably lower than the median for this variable. The differentiation of changes in liquidity was highest among all the variables that were analysed.

The changes in operating effectiveness, measured by ΔMARGIN and ΔTURN, were mainly negative. Regarding ΔMARGIN, there were similar shares of entities that increased and declined the value of this variable in a given year (± 0.4 p.p.). However, the mean was positive—the scale of the improved gross margin on sales among the entities analysed was higher than the decreasing margin. On the other hand, for ΔTURN, the mean was significantly negative—most of the entities generated a noticeable drop in sales productivity.

Piotroski (2000) stated that high B/M entities are poorly performing on average. The results obtained partially support these findings—profitability ratios were mostly positive. However, they were also declining on average. An average drop in liquidity, increase in debt level, and inconclusive results regarding operating effectiveness were also noted.

The share prices of most of the entities analysed decreased, especially after the inclusion of the market rate of return (from WIG) as a benchmark. However, the means for RR and MAR were at the level of 12%–16%—positive returns generated by the minority of companies were on average higher than negative changes in the share price of other entities (in absolute values). Particularly, there were 10% of companies that achieved raw returns (market-adjusted ones) exceeding 71.8% (76.3%), while for 10% of the companies with the weakest performance, raw returns were lower than 41.5% (48.5%).

A correlation analysis was made for an initial insight into the relationship of the variables analysed to the returns and scoring of the models. It is presented in Table 8. Correlations between exogenous variables are shown in the Appendix.

Most of the correlations between exogenous variables and returns were insignificant. In the case of significant ones, the negative association between ROA and RR is surprising. On the other hand, the expected negative interdependence between ΔLIQUID and MAR was observed. The correlations between FCFTA, ΔFCFTA, ACCRUAL, and *F*-Score as well as PiotroskiTrfm are also with expected signs. It is not an obvious conclusion, as these variables appear only in *FS*-Score out of the three models analysed. A similar situation concerned the CFO and *FS*-Score.

Generally, there are no particularly strong correlations between exogenous variables and returns. Regarding ΔLIQUID, the results obtained support the findings of Nast (2017), but they are opposite to Piotroski's (2000). For ROA, the results are opposite to both authors' conclusions – asset profitability has proven to be negatively associated with future returns from the example of the Polish stock market. It seems that these results might be treated as preli-

Table 8. Correlations between exogenous variables, returns, and scoring of models analysed*

Variable	RR	MAR	*F*-Score	Trfm	*FS*-Score
ROA	–0.0876	–0.0628	–0.0060	**0.2604**	0.0021
ΔROA	–0.0698	–0.0244	–0.0272	0.0167	–0.0220
CFO	–0.0669	–0.0721	**0.1026**	**0.1895**	**0.0855**
ΔACCRUAL	–0.0807	–0.0336	–0.0393	0.0410	–0.0807
ΔLEVER	–0.0009	–0.0109	–0.0102	0.0081	0.0749
ΔLIQUID	–0.0786	**–0.0984**	0.0284	0.0263	–0.0249
ΔMARGIN	–0.0047	–0.0109	–0.0717	–0.0151	–0.0603
ΔTURN	–0.0669	–0.0433	0.0147	**0.1123**	0.0324
FCFTA	0.0267	0.0252	**0.2738**	**0.2595**	**0.4993**
ΔFCFTA	0.0341	0.0289	**0.1595**	0.0214	**0.4554**
ACCRUAL	–0.0773	–0.0614	**–0.2725**	**–0.1031**	**–0.4894**
EQ_OFFER	0.0560	0.0686	**0.1361**	**0.2410**	**0.0928**
NEQUISS	0.0535	0.0674	**0.1514**	**0.2561**	**0.1043**

* Bold values are significant at $p < 0.05$.

Source: own work.

minary evidence of the models' ineffectiveness. However, the analysis of returns by scoring was conducted in the following part. It should provide more credible results.

4.3. Returns by scoring

Assuming that the scoring approach adopted in *F*-Score, *FS*-Score and PiotroskiTrfm is effective, the returns of high-score companies should outperform the rates of return of low-score entities and the total (final) sample. Descriptive statistics for entities with each scoring were calculated. Tables 9–14 present raw and market-adjusted returns with this regard.

There was a minor share of entities with low scores (11–18 times lower than the number of high-score companies for individual models) among the companies analysed. Median market-adjusted returns were non-positive for entities with 0–1, 3, 5–6, and 8 scoring according to *F*-Score. Regarding raw returns, there was also a negative median for entities with scores of 2 and 7. A significantly different situation concerned the means—they were positive for the companies with 2–9 scoring for both raw and market-adjusted returns. The differences between returns from high-score entities and low-score companies were in favour of the first group for all statistics analysed. However, compared to the total (final) sample, high-score entities were less effective,

Table 9. Raw returns by scoring: *F*-Score

Scoring	Mean (%)	10th perc.	25th perc.	Median (%)	75th perc.	90th perc.	% positive	*n*
All entities	13.9	–36.7	–20.8	–1.3	27.8	69.3	46.6	611
0	–74.6	–74.6	–74.6	–74.6	–74.6	–74.6	0.0	1
1	–7.9	–45.9	–28.2	–9.7	10.6	31.7	25.0	4
2	5.9	–56.2	–45.7	0.0	33.1	83.7	48.0	25
3	10.3	–38.9	–26.2	0.0	34.0	56.5	49.2	61
4	18.9	–24.9	–15.2	4.0	33.2	83.2	55.1	107
5	21.9	–42.3	–20.5	–3.3	27.1	84.4	47.1	121
6	10.3	–36.7	–23.9	–5.8	19.4	57.7	39.7	131
7	11.7	–28.4	–19.4	–1.9	18.8	89.0	43.8	105
8	8.6	–29.8	–18.2	–0.3	24.7	45.2	46.8	47
9	19.7	–22.9	–15.2	14.3	24.5	52.1	66.7	9
Low score	–21.2	–67.8	–57.7	–18.4	–1.1	27.0	20.0	5
High score	10.4	–29.9	–17.8	0.3	25.2	45.8	50.0	56
High-all	–3.6	6.8	2.9	1.5	–2.6	–23.6	3.4	–
High-low	31.6	38.0	39.8	18.6	26.3	18.8	30.0	–

Notes: Perc. – percentile, % positive – percentage of positive signs, *n* – number of entities, high-all – the difference between high-score companies and total final sample, high-low – the difference between high-score and low-score companies.

Source: own work.

Table 10. Market-adjusted returns by scoring: *F*-Score

Scoring	Mean (%)	10th perc.	25th perc.	Median (%)	75th perc.	90th perc.	% positive	*n*
All entities	11.5	–44.4	–23.7	–1.5	25.1	77.6	47.6	611
0	–82.8	–82.8	–82.8	–82.8	–82.8	–82.8	0.0	1
1	–15.3	–48.8	–20.1	–3.5	1.4	8.9	25.0	4
2	11.9	–50.4	–29.6	7.6	28.4	80.6	52.0	25
3	8.3	–42.0	–21.8	–5.7	26.4	52.5	45.9	61
4	14.4	–37.8	–14.2	2.8	26.8	70.1	54.2	107
5	18.7	–51.0	–27.3	–2.4	27.7	84.0	46.3	121
6	5.8	–44.9	–25.4	–6.4	11.4	48.1	38.9	131
7	11.5	–39.8	–20.6	5.4	33.7	73.5	54.3	105
8	6.8	–36.9	–20.5	–4.9	27.3	60.7	44.7	47
9	28.3	–13.9	–0.6	15.1	30.5	67.7	66.7	9
Low score	–28.8	–76.9	–67.9	–4.2	–2.8	7.2	20.0	5
High score	10.2	–35.8	–18.2	–1.2	28.2	61.2	48.2	56
High-all	–1.2	8.6	5.5	0.3	3.0	–16.4	0.6	–
High-low	39.0	41.1	49.7	3.0	31.0	54.0	28.2	–

Source: own work.

Table 11. Raw returns by scoring: PiotroskiTrfm

Scoring	Mean (%)	10th perc.	25th perc.	Median (%)	75th perc.	90th perc.	% positive	*n*
All entities	18.4	–38.6	–20.5	–0.5	30.4	76.9	46.7	649
0	–	–	–	–	–	–	–	0
1	–11.2	–16.4	–14.1	–10.2	–7.9	–6.5	0.0	3
2	34.7	–42.4	–21.2	–4.8	43.0	147.7	42.9	56
3	14.3	–42.6	–24.6	–7.1	27.1	72.9	44.9	156
4	20.3	–37.3	–19.9	0.0	33.4	89.1	49.6	224
5	16.8	–32.2	–20.4	–1.3	29.0	59.8	44.2	165
6	11.4	–25.1	–15.3	3.4	20.6	64.0	55.6	45
Low score	–11.2	–16.4	–14.1	–10.2	–7.9	–6.5	0.0	3
High score	11.4	–25.1	–15.3	3.4	20.6	64.0	55.6	45
High-all	–7.0	13.5	5.2	3.9	–9.8	–12.9	8.9	–
High-low	22.6	–8.7	–1.3	13.7	28.5	70.5	55.6	–

Source: own work.

Table 12. Market-adjusted returns by scoring: PiotroskiTrfm

Scoring	Mean (%)	10th perc.	25th perc.	Median (%)	75th perc.	90th perc.	% positive	*n*
All entities	15.7	–44.5	–23.6	–0.8	26.4	80.6	48.5	649
0	–	–	–	–	–	–	–	0
1	–1.4	–19.4	–9.3	7.6	10.9	12.9	66.7	3
2	32.3	–54.3	–25.6	0.2	32.1	165.6	50.0	56
3	11.5	–45.0	–26.7	–5.9	24.4	78.6	44.2	156
4	19.1	–40.8	–20.3	0.8	29.7	86.0	51.8	224
5	12.6	–42.9	–20.8	–1.5	22.4	47.7	47.3	165
6	5.5	–47.5	–19.6	–1.1	19.3	53.3	48.9	45
Low score	–1.4	–19.4	–9.3	7.6	10.9	12.9	66.7	3
High score	5.5	–47.5	–19.6	–1.1	19.3	53.3	48.9	45
High-all	–10.2	–3.0	4.0	–0.3	–7.1	–27.3	0.4	–
High-low	6.9	–28.1	–10.3	–8.7	8.4	40.3	–17.8	–

Source: own work.

Table 13. Raw returns by scoring: *FS*-Score

Scoring	Mean (%)	10th perc.	25th perc.	Median (%)	75th perc.	90th perc.	% positive	*n*
All entities	11.6	–34.6	–20.6	–1.7	26.9	64.6	46.4	552
0	–74.6	–74.6	–74.6	–74.6	–74.6	–74.6	0.0	1
1	82.2	53.0	64.0	82.2	100.4	111.4	100.0	2
2	–21.3	–58.7	–55.2	–22.5	2.8	14.2	30.0	10
3	6.1	–45.7	–28.8	0.6	40.5	57.6	52.2	23
4	7.0	–37.5	–23.4	–0.1	20.7	50.4	45.8	72
5	26.4	–31.2	–16.6	6.2	45.8	90.4	56.1	82
6	20.2	–34.3	–19.6	–4.9	25.8	103.4	45.8	118
7	–0.2	–34.9	–24.2	–6.3	11.8	43.1	37.4	115
8	7.3	–30.6	–17.6	–4.9	13.8	56.9	41.3	75
9	18.3	–30.0	–14.6	14.3	35.0	91.9	61.0	41
9	4.1	–22.0	–15.5	0.5	16.8	39.7	53.8	13
Low score	29.9	–50.5	–14.4	45.7	82.2	104.1	66.7	3
High score	14.9	–29.5	–15.1	10.5	32.3	78.8	59.3	54
High-all	3.3	5.0	5.5	12.1	5.4	14.2	12.9	–
High-low	31.6	38.0	39.8	18.6	26.3	18.8	30.0	–

Source: own work.

Table 14. Market-adjusted returns by scoring: *FS*-Score

Scoring	Mean (%)	10th perc.	25th perc.	Median (%)	75th perc.	90th perc.	% positive	*n*
All entities	8.5	–44.4	–23.9	–1.9	23.3	65.1	47.5	552
0	–82.8	–82.8	–82.8	–82.8	–82.8	–82.8	0.0	1
1	64.7	24.1	39.3	64.7	90.2	105.4	100.0	2
2	–25.2	–68.3	–54.6	–20.1	–0.3	9.2	30.0	10
3	1.5	–54.1	–28.9	2.8	27.7	56.0	52.2	23
4	2.7	–50.4	–23.5	–1.4	17.7	39.7	47.2	72
5	17.4	–46.7	–20.9	2.8	28.2	79.2	52.4	82
6	18.9	–39.5	–22.1	–3.4	28.7	90.4	44.1	118
7	–0.7	–46.8	–24.2	–5.3	17.7	37.3	44.3	115
8	4.9	–38.7	–25.7	–4.9	19.8	66.4	44.0	75
9	16.1	–37.6	–13.9	4.0	36.6	71.6	58.5	41
9	4.7	–29.8	–19.6	4.6	30.5	36.1	61.5	13
Low score	15.6	–63.5	–34.5	13.9	64.7	95.3	66.7	3
High score	13.4	–33.7	–16.6	4.2	34.7	62.8	59.3	54
High-all	4.9	10.7	7.2	6.1	11.5	–2.3	11.8	–
High-low	–2.2	29.8	17.8	–9.7	–30.0	–32.4	–7.4	–

Source: own work.

taking into account means and 90th percentiles (for raw returns, it was observable also for the 75th percentile).

In the case of PiotroskiTrfm, median raw returns were negative or at 0 for entities with 0–5 scoring. On the other hand, the positive median in market-adjusted returns concerned companies with scores of 1–2 and 4, while for entities with a score of 6, the median was negative. Mean returns (both raw and market-adjusted) were positive for high-score companies, but they were outperformed by the results for the total sample. On the other hand, low-score entities performed worst.

Regarding *FS*-Score, medians differed significantly between entities with different scoring. They were positive for high-score entities. However, medians for low-score companies were also positive and even higher than in the case of high-score entities. A similar situation concerned means: the low-score entities generated higher values than high-score companies (however, the difference regarding market-adjusted returns was noticeably lower than for raw returns). On the other hand, high-score entities outperformed the total sample.

Based on the above results, it seems that the scoring approach did not lead to the generation of better returns than for a total portfolio of high B/M companies; this applies to *F*-Score and PiotroskiTrfm. Regarding *FS*-Score, though high-scored entities outperformed the total sample, they were worse than low-score companies. To test mean differences between high and low, as well as high and all, statistical tests were conducted. The results of these are presented in Table 15.

Table 15. Results of the *t*-test for mean differences

Groups	Statistic	*F*-Score		PiotroskiTrfm		*FS*-Score	
		RR	MAR	RR	MAR	RR	MAR
High-all	*t*-statistic	–0.3769	–0.1322	–0.5236	–0.7696	0.3852	0.5768
	p-value	0.7064	0.8949	0.6008	0.4418	0.7022	0.5643
High-low	*t*-statistic	1.4038	1.6271	0.8075	0.2499	–0.5459	–0.0812
	p-value	0.1656	0.1090	0.4236	0.8038	0.5873	0.9356

Source: own work.

No statistically significant results were obtained. In the case of high-low for *F*-Score and PiotroskiTrfm, it could be explained by a very low number of low-score companies (5 and 3, respectively). Therefore, despite the quite high absolute differences between the means for these groups, they were found to be statistically insignificant. Generally, the above results partially confirmed the effectiveness of the models analysed. However, high-score entities performed worse than either low-score companies (it applies to *FS*-Score) or the total sample (*F*-Score, PiotroskiTrfm).

4.4. Building investment portfolios

Since the purpose of the paper is connected with the empirical analysis of investment strategies' performance, separate portfolios consisting of shares of entities with high and low scores were built. The assumption was of equal shares of each entity in the portfolios, i.e. simple diversification. The returns generated from these portfolios are shown in Table 16.

Table 16. Mean returns from investment portfolios built

Model	***F*-Score**			**PiotroskiTrfm**			***FS*-Score**		
Scoring	**High (8–9)**			**High (6)**			**High (9–10)**		
Item	**RR (%)**	**MAR (%)**	***n***	**RR (%)**	**MAR (%)**	***n***	**RR (%)**	**MAR (%)**	***n***
2013	–	–	0	14.54	4.28	1	28.39	18.14	3
2014	6.13	–9.88	2	–7.25	–23.26	4	–	–	0
2015	19.64	16.58	4	5.72	2.66	3	31.99	28.93	5
2016	12.48	28.04	5	25.62	41.17	4	–1.73	13.82	7
2017	38.72	2.38	6	76.06	39.72	5	16.69	–19.66	6
2018	–18.83	–9.97	4	–30.28	–21.42	4	–29.57	–20.71	3
2019	–10.83	–19.03	8	–13.61	–21.81	5	–18.03	–26.23	4
2020	51.62	69.45	9	23.44	41.27	5	21.70	39.53	11
2021	1.21	–30.65	6	13.52	–13.82	9	55.09	23.23	8
2022	–9.59	10.25	12	–4.35	15.49	5	–6.99	12.86	7
2013–2022	*7.12*	*2.66*	*56*	*7.20*	*3.42*	*45*	*7.01*	*4.69*	*54*
Scoring	**Low (0–1)**			**Low (0–1)**			**Low (0–1)**		
Item	**RR (%)**	**MAR (%)**	***n***	**RR (%)**	**MAR (%)**	***n***	**RR (%)**	**MAR (%)**	***n***
2013	–57.68	–67.94	1	–	–	0	–	–	0
2014	–	–	0	–	–	0	–	–	0
2015	–1.12	–4.18	1	–	–	0	118.67	115.61	1
2016	–18.37	–2.81	1	–	–	0	–	–	0
2017	–	–	0	–	–	0	–	–	0
2018	–	–	0	–	–	0	–	–	0
2019	–74.61	–82.81	1	–17.93	–26.13	1	–74.61	–82.81	1
2020	–	–	0	–10.22	7.60	1	–	–	0
2021	45.74	13.88	1	–	–	0	45.74	13.88	1
2022	–	–	0	–5.56	14.28	1	–	–	0
2013–2022	*–18.69*	*–24.72*	*5*	*–3.56*	*–0.96*	*3*	*–2.10*	*–8.27*	*3*

Note: 2013–2022 – geometric mean return for 2013–2022 (including years with no entities chosen by the models).

Source: own work.

A high *F*-Score portfolio led to the generation of positive returns in 5 (for market-adjusted returns) or 6 (regarding raw returns) out of the 10 years analysed, similar to *FS*-Score. Regarding PiotroskiTrfm, it was 6 years for both RR and MAR. There were no high-score entities identified in 2013 based on *F*-Score nor in 2014 according to *FS*-Score.

The average annual raw return for high-score portfolios was between 7.0% and 7.2% for all the models analysed. However, market-adjusted returns differed significantly, but on average was highest for *FS*-Score. Generally, all high-score portfolios generated positive market-adjusted returns.

Low-score portfolios comprised only a few companies – up to 5 in total. Hence, years with no entities selected for the low-score portfolio were quite frequent (5 out of 10 according to *F*-Score and 7 according to *FS*-Score and PiotroskiTrfm). Such portfolios generated significantly negative returns on average (both raw and market-adjusted). However, they were noticeably lower for *F*-Score than for the other two models.

Based on the high-score portfolio construction, all models were found to be effective – they generated positive raw and market-adjusted returns. This supports the findings resulting from the backtesting by Piotroski (2000), Gray (2015), and Nast (2017). Piotroski (2000) and Oyebode (2016) stated that it is worth taking short positions in low-scored entities, which was also empirically confirmed, as the low-score portfolios generated negative returns. However, high-score companies did not outperform the benchmarks (either low-score portfolio or total sample of high B/M companies). This is not consistent with the statistical tests performed by Piotroski (2000). Generally, both the main hypothesis and the supporting one might be considered only partially confirmed.

Conclusions

High B/M investing is a foundation of investment strategies based on *F*-Score and similar models. So far, both high B/M investing and the effectiveness of the *F*-Score model have been empirically confirmed by examples from different markets worldwide. However, regarding the Polish stock market, the only analyses conducted so far focused on relatively small samples and timeframes. This research provides an empirical insight into *F*-Score-based strategy based on the example of a comprehensive sample of Polish listed companies. Other similar models inspired by *F*-Score (i.e. *FS*-Score and PiotroskiTrfm) were also taken into account.

To verify the usefulness of the models analysed, returns by scoring were analysed. Generally, the returns for the entities with higher scoring were positive. However, mean returns for high-score entities were lower than the rates of return for the low-score portfolio (*FS*-Score) or for a total sample of high B/M companies (*F*-Score, PiotroskiTrfm). Nevertheless, statistical tests did not confirm the significance of mean differences.

Investment portfolios consisting of high- and low-score entities were built (separately), with an assumption of simple diversification. The results showed that using the models analysed here to build a high-score portfolio generated positive raw and market-adjusted returns. The low-score-based portfolio generated negative yields. It is also worth noting that low-score portfolios consisted of only a few shares. Therefore, they are not diversified in any way, especially as there were only single shares chosen for the portfolio in individual years.

Overall, the above findings are partially in line with the conclusions produced by Piotroski (2000) and most of the other authors whose results are presented in Table 3, namely, Gray (2015) and Nast (2017), regarding the effectiveness of *F*-Score, *FS*-Score, and PiotroskiTrfm, respectively. Moreover, the findings of Kusowska (2021) and Pilch (2021) regarding the effectiveness of the *F*-Score-based strategy on the Polish stock market were also empirically confirmed. On the other hand, the advantage of high-score companies over the total sample of high B/M entities postulated by Piotroski (2000) was not supported.

The implications of the research mainly concern value investors. The results pointed out the effectiveness of *FS*-Score and *F*-Score-based strategies, but also their weaknesses. Therefore, it seems that it might be sensible not only to invest in line with the models analysed, but also to invest in a total portfolio of high B/M companies. The advantage of this approach is also a greater portfolio diversification than with using *F*-Score-like models.

Among the limitations of the study might be the assumption regarding the simple diversification applied, which was also pointed out by Mehta et. al (2019). Transaction costs were also not included in the research. Another issue relates to the way of verifying the models' effectiveness, i.e. backtesting—it is commonly used but, as it fully focuses on historical financial data, without the inclusion of forward-looking measures. Moreover, the research focused on a relatively short period (mostly resulting from the data availability). On the other hand, it includes periods of both favourable economic situations and economic slumps, and this should be considered an advantage.

The directions for future research are strongly associated with the limitations indicated. They mostly refer to the building of investment portfolios with different shares for individual entities. Moreover, the inclusion of transaction costs might be useful. Investment portfolios consisting of a larger sample of high B/M companies, without reliance on *F*-Score-type scoring, should also be analysed using the example of the Polish stock market.

Appendix

Table A1. Correlations between exogenous variables

Variable	ROA	ROA	CFO	ΔACCRUAL	ΔLEVER	ΔLIQUID	ΔMARGIN
ROA	1.0000	**0.4127**	**0.3882**	**0.2527**	**–0.2502**	0.0646	**0.1295**
ROA		1.0000	0.0307	**0.5971**	**–0.2786**	0.0474	**0.2904**
CFO			1.0000	**–0.3882**	–0.0448	0.0239	0.0106
ΔACCRUAL				1.0000	**–0.1829**	**0.1092**	**0.1794**
ΔLEVER					1.0000	**–0.2953**	–0.0625
ΔLIQUID						1.0000	0.0457
ΔMARGIN							1.0000
Variable	**ΔTURN**	**FCFTA**	**ΔFCFTA**	**ACCRUAL**	**EQ_OFFER**	**NEQUISS**	
ROA	0.0687	**0.2687**	**–0.1784**	**0.3119**	0.0511	0.0725	
ROA	**0.2886**	0.0531	–0.0608	**0.1857**	0.0466	0.0445	
CFO	0.0195	0.3309	–0.1048	**–0.1024**	–0.0051	0.0122	
ΔACCRUAL	**0.0975**	0.0187	–0.0098	**0.1274**	0.0684	0.0750	
ΔLEVER	**0.1946**	**0.0883**	**0.1764**	**–0.2315**	–0.0110	–0.0190	
ΔLIQUID	–0.0813	–0.0568	**–0.1212**	**0.0933**	0.0102	0.0088	
ΔMARGIN	–0.0761	0.0825	–0.0029	–0.0067	0.0301	0.0282	
ΔTURN	1.0000	0.0296	0.0575	0.0105	0.0331	0.0313	
FCFTA		1.0000	**0.5614**	**–0.8313**	0.0267	0.0444	
ΔFCFTA			1.0000	**–0.6567**	0.0251	0.0233	
ACCRUAL				1.0000	0.0031	–0.0019	
EQ_OFFER					1.0000	**0.9803**	
NEQUISS						1.0000	

Source: own work.

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A causal and nonlinear relationship between trade credit policy and firm value: Evidence from an emerging market

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Abstract

This study examines whether there is a causal and nonlinear relationship between trade credit policy and firm value. In line with this purpose, the 2005Q1–2018Q4 period data is examined for 103 companies operating in the manufacturing industry in an emerging market, Borsa Istanbul, and the relationships revealed. The nonlinear relationship between trade credit and firm value has been proved with the two-step System GMM (Generalized Moment of Methods) and causality with Dumitrescu-Hurlin (2012) heterogeneous panel causality tests. According to the findings, a nonlinear (inverted U-shaped) relationship has been found between trade credit policy and firm value. Moreover, the values of firms that have moved away from optimum trade credit levels are also negatively affected. One of the original aspects of this study is that the bidirectional causal relationship between trade credit policy and firm value has been revealed.

Keywords

- trade credit policy
- firm value
- emerging market
- system GMM
- nonlinearity
- panel causality

JEL codes: G30, G32, L25

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Introduction

Firms extend and use trade credit simultaneously, making trade credit decisions an integral part of business decisions. Trade credit is created because of the exchange of goods by the two firms in business intercourse, establishing a lending-borrowing relationship. Due to this unique characteristic of trade credit, researchers have extensively investigated the reasons behind the firms' decisions to extend and use trade credit from both the supply-side and demand-side perspectives (Seifert et al., 2013). Policies related to both corporate finance and operations are all influential in trade credit decisions. The relations between the firms and their customers, suppliers and creditors as well as external factors such as legal systems, culture, and the economic situation determine the position of firms in extending and using trade credit (Kieschnick et al., 2013; Nam & Uchida, 2019). Moreover, even though trade credit-related decisions as part of working capital management decisions are considered to be short-term in nature, the persistence of working capital allocations is also documented in the literature questioning the value effects of working capital decisions, which include trade credit policies (Chauhan, 2019).

McGuinness et al. (2018) showed that trade credit investment, proxied by the accounts receivables to total assets ratio, in 13 European countries is 30% on average, ranging from 13% in Latvia to 49% in Greece.[2] Furthermore, it is demonstrated that trade credit investment, as measured by the ratio of accounts receivable to total assets, is 19% on average in 9 developed countries, ranging from 12% in Canada to 26% in France[3] (Karakoç, 2022). Based on the Turkish Central Bank Balance Sheets for the 2009–2021 period, the short-term accounts receivables to total assets ratio is approximately 23% and the ratio of accounts receivables to current assets is 37% in the manufacturing industry (CBRT, 2023). According to these findings, it is worth noting how significant trade credit investment is for both developing and developed countries.

These figures prove that trade credit extensions are an integral part of doing business in both developed and developing markets, especially in manufacturing firms listed on Borsa Istanbul, which has crucial implications for managers and financial investors. This also makes it an important issue for academic research. As more data has become available, trade credit research has primarily concentrated on investigating trade credit theories that attempt

[2] McGuinness et al. (2018) reported that other countries have accounts receivable to total assets ratio of 34% in Belgium, 16% in Finland, 29% in France, 20% in Germany, 19% in Hungary, 28% in Ireland, 37% in Italy 37%, 27% in Poland, 36% in Portugal, 30% in Spain, and 22% in the UK.

[3] Karakoç (2022) indicates that the other countries' trade credit investments are as follows: 15% in Australia, 21% in Germany, 25% in Italy, 23% in Japan, 21% in Korea, 18% in the UK, and 14% in the US.

to explain the motives for extending and using trade credit (Duliniec & Świda, 2021; Mian & Smith, 1992; Petersen & Rajan, 1997; Seifert et al., 2013). On the other hand, taking into account the tradeoff between benefits and costs of trade credit, another line of research has focused on the question of whether an optimal level of trade credit exists for firms. It is argued that optimal trade credit policy exists at the point where the marginal benefits and costs of trade credit financing are equal (Emery, 1984).

As explained above, there is extensive literature seeking answers to the question of why trade credit is extended or received. However, studies on the relationship between trade credit and its financial outcomes, such as its impact on firm performance or firm value, are scarce, especially in emerging markets (Hill et al., 2012; Kieschnick et al., 2013; Martínez-Sola et al., 2013) and inconclusive (Box et al., 2018; Chauhan, 2019). In such markets, and particularly in the manufacturing sector, where financial systems are not entirely developed and may be susceptible to economic crises, the use of trade credit becomes even more valuable. Hence, this study aims to contribute to the trade credit literature by investigating the relationship between trade credit and firm value using data for manufacturing firms in an emerging market, namely Borsa Istanbul, for the 2005Q1–2018Q4 period.

The contribution of this study is threefold. Firstly, it contributes to the existing literature by extending the limited number of studies on the relationship between trade credit and firm value, which are even scarcer in emerging markets, as Nam and Uchida (2019) emphasized. Secondly, the study extends the literature by providing evidence of the nonlinear (quadratic) relationship between trade credit and firm value, following studies by Aktas et al. (2015) and Martínez-Sola et al. (2013). The third contribution of this study is in its investigating the causal relationship between trade credit and firm value, which is not tested previously in terms of Borsa Istanbul manufacturing firms, even though Box et al. (2018) investigated the causal relationship between trade credit policies and profitability. Moreover, Chauhan (2019) argues that the current literature overemphasizes the value creation role of working capital and suggests that a cross-sectional analysis would be inadequate to address this aspect. In this respect, this study aims to fill the existing gap.

The remainder of the study is structured as follows: Section 1 develops the hypotheses of the study explaining the conceptual framework; Section 2 presents the data, variables, methodology, and models employed; Section 3 reports the findings of the study; last Section concludes by discussing the implications of the results and policy suggestions.

1. Literature review and hypothesis development

For many years, researchers have argued as to the motives for firms using trade credit. Trade credit research has mainly focused on testing trade credit theories, which aim to explain the reasons of extending and using trade credit as more data becomes available (Duliniec & Świda, 2021; Mian & Smith, 1992; Petersen & Rajan, 1997; Seifert et al., 2013). Researchers who approach trade credit from operational and marketing perspectives argue that firms can use trade credit to discriminate between their customers as part of their pricing and sales policy through credit terms (Brennan et al., 1988; Pike et al., 2005), enable their customers to test the quality of their products before any payment is made (Deloof & Jegers, 1996; Emery & Nayar, 1998; Lee & Stowe, 1993; Long et al., 1993; Ng et al., 1999; Petersen & Rajan, 1997; Seifert et al., 2013; Wilner, 2000), and for the purposes of product market positioning (Seifert et al., 2013). The literature on relationship lending hypothesis as well as on supply chain finance (SCF) and financial supply chain management (FSCM) emphasizes the simultaneity of financial flows in relation to physical and informational flows in their approach to trade credit (L. Zhang et al., 2015; T. Zhang et al., 2019). Since information asymmetry and trust factors are important ingredients in the decision to extend credit (Wang et al., 2015), the already established business relationship between the firms and their customers reduces the information asymmetry and forms a basis for trust as argued by the relationship lending hypothesis (Long et al., 1993; Pike et al., 2005; Uchida et al., 2013). Consequently, firms with the ability to lend can act as creditors to their customers by postponing their payments for their purchases, improving financial performance, lowering transaction costs and enhancing inventory management efficiency, as well as reducing financial distress for the trade credit receiver, especially during times of crisis (Box et al., 2018; Ferris, 1981; Kestens et al., 2012; Nam & Uchida, 2019; T. Zhang et al., 2019).

Another line of research argues that firms that can raise capital more easily supply trade credit to their customers who have limited access to capital, especially during times of financial crisis. This means that trade credit received from suppliers serves as a source of short-term finance, enabling firms to keep their cash and pay later. This makes trade credit a substitute for short-term finance forming the basis for the substitution hypothesis between short-term debt and trade credit (Bastos & Pindado, 2013; Huang et al., 2011; Meltzer, 1960; Petersen & Rajan, 1997; Schwartz, 1974). In this regard, trade credit serves as an investment through accounts receivables for the firm offering it (Long et al., 1993).

Despite its benefits, trade credit extension comes with risks and costs. Customers may delay or even default on payments, which causes the firms extending credit to lose revenues and reduce expected cash inflows. To avoid any negative impact from bad debts firms extending credit establish departments that follow payments and accounts receivables, incurring monitoring costs. Moreover, this situation increases the cash conversion cycle, and the company has more cash invested in net working capital than required. Consequently, financing costs rise, as the firms extending trade credit end up financing their investments in accounts receivables by additional borrowing and loosening credit terms, leading to negative impacts on firm performance and liquidity (Cheng & Pike, 2003; Mian & Smith, 1992). Therefore, firms should aim to balance the benefits and costs of extending trade credit (Martínez-Sola et al., 2013). Scherr (1996) provides a framework for setting trade credit limits to eliminate these costs and credit risk, and by focusing on trade credit limits, concludes that understanding how trade credit limits can increase shareholder wealth is crucial for practitioners and managers. Since credit limits and credit terms enable firms to limit the costs of high trade credit, the benefits exceed the costs, leading to positive effects on firm profitability and firm value. The contradictory findings provided by the researchers lead to the argument that the relationship between trade credit and firm value can be conditional on the country, the industry, and economic situation as well as the net benefits received (Bastos & Pindado, 2013; Çelik et al., 2016; Enqvist et al., 2014; Hill et al., 2012; Kim & Atkins, 1978; Nam & Uchida, 2019; Zeidan & Shapir, 2017).

The limited number of studies focusing on the relationship between trade credit and firm value provide inconclusive evidence, especially on the Borsa Istanbul stock market. Hill et al. (2012), Aktas et al. (2015), Zeidan and Shapir (2017), Box et al. (2018), Dary and James (2019), Boisjoly et al. (2020), and R. Zhang (2020) argue that trade credit supplied to customers has information value, decreasing information asymmetry. They conclude that trade credit has a positive effect on firm value and shareholder wealth. On the other hand, Wang (2002), Deloof (2003), Filbeck et al. (2007), García-Teruel and Martínez-Solano (2007), and Kieschnick et al. (2013) provide evidence that aggressive liquidity management, which requires low levels of trade credit, enhances value, thereby arguing that trade credit and firm value are negatively related. Lewellen et al. (1980) and T. Zhang et al. (2019) further suggest no relationship between trade credit and shareholder wealth. In the meantime, although there are many methods to measure firm value, the Tobin Q ratio developed by Chung and Pruitt (1994) is commonly used, which strongly represents firm value. Therefore, Tobin Q was chosen as the dependent variable in this study.

The contradictory evidence provided leads to the argument that there should be an optimal level of trade credit investment, where the marginal benefits of investing in trade credit exceed the marginal costs leading to positive effects on value (Aktas et al., 2015; Baños-Caballero et al., 2014; Ben-Nasr, 2016; Ek & Guerin, 2011; Emery, 1984). As firms extend trade credit, the initial benefits are greater than the costs. Firms experience a value-enhancing effect of increased sales, improved customer relations, and reduced inventory costs without substantial increases in their monitoring and financing costs. However, as the level of trade credit grows, these costs also rise and more investment is required in trade credit, thus diminishing the positive effect on value. Once the optimal level is exceeded, the effect becomes negative, since the firm also becomes risky, with it being perceived negatively by investors. Furthermore, based on the insights from Jory et al. (2020) examines the nonlinear relationship between trade credit policy and firm value during the Economic Policy Uncertainty (EPU) periods and enunciate keeping account receivable at low levels during EPU periods creates an increase in firm value, whereas excessive avoidance in account receivables negatively affects firm value by losing customers to competitors. All in all, the inverted U-shaped relationship that is suggested requires further investigation. Hence, following Martínez-Sola et al. (2013), Baños-Caballero et al. (2014), Aktas et al. (2015), Ben-Nasr (2016), and Jory et al. (2020), the first hypothesis of the study is expressed as follows:

H_1: There exists an inverted U-shaped relationship between trade credit and firm value.

Chauhan (2019) questions the implicit assumption in working capital and trade credit research that investment in working capital and, more specifically, in trade credit, is short-term in nature. He argues that the change created in value by the changes in investment in working capital is overemphasized, since a portion of these investments are permanent. Hence, the effect of deviations from the optimal level of trade credit on firm value deserves further investigation. When Martínez-Sola et al. (2013) investigated the nonlinear relationship between trade credit policy and firm value, they were inspired by the approach proposed by Tong (2008) and confirmed that an optimum trade credit policy exists within a firm. According to their study, deviations from the optimal trade credit level pull the firm value below its potential level. This study aims to reveal the presence of the optimal trade credit level in the event of the verification of H_1. In light of the studies by Martínez-Sola et al. (2013), Kroes and Manikas (2014), hypothesis 2, which aims to investigate the impact of deviations from optimal level of trade credit policy on firm value, is expressed as follows:

H_2: Deviations from optimal level of trade credit have a negative impact on firm value.

Studies on trade credit implicitly assume that changes in trade credit policy lead to changes in value in the subsequent years. In other words, trade credit policy is accepted as a determinant of firm value. However, it can also be argued that firms with high value may have better access to financial markets and can raise funds at a lower cost; therefore, they may provide credit to their customers more easily, as argued by the financial constraints hypothesis. Kroes and Manikas (2014) test the direction of the relationship between cash flow and the changes in performance of firms. In their study they provide evidence that reductions in accounts receivables, specifically measured as Days of Sales Outstanding (DSO), are found to be significantly associated with changes in Tobin's Q. They found no evidence of reverse causality. Hence, the direction of the relationship between trade credit and firm value deserves further investigation. From this viewpoint, no study has been found that establishes causality between trade credit policy and firm value for the manufacturing industries on Borsa Istanbul, which is one of the emerging markets. The third hypothesis of the study is expressed as follows:

H_3: There is a bidirectional causal relationship between trade credit investment and firm value.

2. Sample and methodology

2.1. Sample and data collection

The sample of the present study comprises 103 manufacturing firms with no missing data on Borsa Istanbul (BIST) for the period from the first quarter of 2005 (2005Q1) to the fourth quarter of 2018 (2018Q4). BIST manufacturing firms have adopted International Financial Reporting Standards (IFRS) since 2005. Hence, the study period starts in 2005 in order to avoid the unambiguous effects of IFRS adoption on firm value. A balanced panel of quarterly cross-sectional data is used in the analysis and includes 5,768 observations.

There are two motivations for focusing on the manufacturing sector of Borsa Istanbul in this study. Firstly, manufacturing is the locomotive of the Istanbul Stock Exchange and is divided into 9 sub-sectors under the control of manufacturing (1 – Food, Beverage and Tobacco, 2 – Textile, Wearing Apparel and Leather, 3 – Wood Products Including Furniture, 4 – Paper and Paper Products Printing, 5 – Chemicals, Petroleum Rubber and Plastic Products, 6 – Non – Metallic Mineral Products, 7 – Basic Metal, 8 – Fabricated Metal Products Machinery Electrical Equipment and Transportation Vehicles, 9 – Other Manufacturing Industry). Secondly, trade credit investments occupy an important place in manufacturing balance sheets (see Table 1).

The companies listed on Borsa Istanbul (BIST) continuously since 1986 are included in the sample. The data were retrieved from the Finnet database (FINNET, 2019) and the Public Disclosure Platform (PDP, 2019).

2.2. Model specifications and variables

To investigate the nonlinear relationship between trade credit and firm value, and to test the first hypothesis, Model 1 was developed, as follows:

$$FV_{it} = \beta_0 + \beta_1(\mathrm{FV}_{it-1}) + \beta_2(TC_{it}) + \beta_3(TC)^2_{it} + \beta_4(GROWTH_{it}) + \beta_5(LEV_{it}) + \\ + \beta_6(SIZE_{it}) + \beta_7(Crisis\,Dummy_t) + \mu_i + \gamma_t + I_{it} + \varepsilon_{it} \quad (1)$$

In Model 1, the dependent variable and firm value are demonstrated by two alternative measures. The first measure is Tobin's Q, calculated as the ratio of the sum of the market value of equity and total liabilities to the book value of assets (Baños-Caballero et al., 2014; Chung & Pruitt, 1994; Martínez-Sola et al., 2013; Nam & Uchida, 2019; T. Zhang et al., 2019). The second measure is the MARKET (market-to-book ratio), which is commonly used in the literature to measure firm value (Jory et al., 2020; Martínez-Sola et al., 2013).

The independent variable of the study was trade credit (TC). Since the study investigated the nonlinear relationship between trade credit and firm value, the trade credit variable was squared and included in the analysis as an independent variable. Trade credit level was also displayed using two alternative measures. It was measured as the ratio of accounts receivables to total sales (AR/NS), following Petersen and Rajan (1997), Niskanen and Niskanen (2006), and Martínez-Sola et al. (2013), and as the ratio of accounts receivables to current assets (AR/CA). Additionally, to test for the quadratic relationship, these ratios were squared and included in the analysis as AR/NS-squared $(AR/NS)^2$ and AR/CA-squared $(AR/CA)^2$. A negative relationship was expected between the trade credit proxies AR/NS and AR/CA and firm value at high trade credit levels. A positive relationship was expected at low levels of trade credit. The sign of the AR/NS and AR/CA variables was expected to be positive, whereas the $(AR/NS)^2$ and $(AR/CA)^2$ variables were expected to be negative in the model if hypothesis 1 is supported.

The control variables used in Model 1 are growth in sales (GROWTH), firm size (SIZE), leverage (LEV), and crisis dummy (CRISIS). (GROWTH) variable is demonstrated by the annual growth in sales and is calculated as the ratio of the difference between current-year sales and previous-year sales to previous-year sales (Martínez-Sola et al., 2013; Niskanen & Niskanen, 2006; Paul et al., 2018). The second control variable, firm size (SIZE), is demonstrated by the natural logarithm of net sales (Martínez-Sola et al., 2013; Mian & Smith, 1992; Petersen & Rajan, 1997). The third control variable, leverage (LEV), is measured as the total debt to total equity ratio. The crisis dummy has been added to the model as a control variable for the years 2008 and 2009 to control the effect of crisis periods on financial markets and trade credit policy (Bastos & Pindado, 2013; Enqvist et al., 2014; Nam & Uchida, 2019). μ_{it} is unobservable heterogeneity, γ_t refers to the time effects and are year dummy variables, I_{it} refers to the industry dummy, while ε_{it} is the residuals.

To test the hypothesis 2, initially, Model 2 was improved and estimated based on the literature on determinants of trade credit and is shown below:

$$TC_{it} = \beta_0 + \beta_1(GROWTH_{it}) + \beta_2(SIZE_{it}) + \beta_3\left(\frac{STD}{TS}\right)_{it} + \beta_4\left(\frac{FE}{TD}\right)_{it} + \\ + \beta_5\left(\frac{EBITDA}{TS}\right)_{it} + \beta_6\left(\frac{TA}{TS}\right)_{it} + \beta_7\left(\frac{NIA}{TS}\right) + \mu_i + \gamma_t + I_{it} + \varepsilon_{it} \qquad (2)$$

In Model 2, trade credit (TC) variables AR/NS and AR/CA were estimated based on the literature on trade credit determinants. GROWTH and SIZE variables were calculated as in Model 1. Additionally, the determinants used in the estimation were short-term debt to total sales (STD/TS), based on Long et al. (1993), Deloof and Jegers (1996), García-Teruel and Martínez-Solano (2010), and financial expenses to total debt (FE/TD), earnings before interest, taxes, depreciation, and amortization to total sales (EBITDA/TS), total asset turnover (TA/TO) and net income plus depreciation and amortization to sales (NIA/TS) based on Petersen and Rajan (1997), Niskanen and Niskanen (2006), García-Teruel and Martínez-Solano (2010). μ_{it} is the unobservable heterogeneity, γ_t refers to the time effects and are year dummy variables, I_{it} refers to the industry dummy, ε_{it} is the residuals. As shown above, Model 2 is initially estimated using a multiple linear fixed-effects regression method. The residuals that emerge as a result of the estimation are then obtained as "predict residual series" and the absolute values of the residuals are revealed as the DEVIATION variable and placed in Model 3. The reason for choosing such a method is to obtain econometric estimation residuals that will reveal whether there is an optimal level of commercial credit if the existence of the nonlinear relationship between commercial credit policy and firm value stated in Model 1 is proven, and whether deviations from this optimal commercial credit policy negatively affect firm value.

At this stage, to determine whether deviations from the optimal level of trade credit have a negative effect on firm value, Model 3 was developed, inspired by Chauhan (2019), Kroes & Manikas (2014), and Martínez-Sola et al. (2013). The developed model is as follows:

$$FV_{it} = \beta_0 + \beta_1(FV_{it-1}) + \beta_2(DEVIATION_{it}) + \beta_3(GROWTH_{it}) + \\ + \beta_4(LEV_{it}) + \beta_5(SIZE_{it}) + \beta_6(Crisis\,Dummy_t) + \mu_i + \gamma_t + I_{it} + \varepsilon_{it} \qquad (3)$$

(GROWTH), (LEV) and (SIZE) variables in Model 3 are calculated as in Model 1. Because of the analysis, according to hypothesis 2, the coefficient of the (DEVIATION) variable is expected to be negative ($\beta_2 < 0$). Therefore, the aim is to prove a negative relationship between deviations from optimal level of trade credit level and firm values of the companies.

2.3. Methodology

The series used for econometric forecasting must be stationary, that is, it must contain no unit roots. Although the problem of superior regression is common in econometric estimates made for non-stationary series, these estimates reveal inconsistent results (Granger, 2003; Phillips, 1986). In this study, the stationarity tests of the series are carried out using the CIPS (Cross-sectionally Augmented IPS) panel unit root test developed by Pesaran (2007). This test is a cross-section-based and developed version of Im et al.'s (2003) unit root test (IPS) and calculates individual CADF test statistics. The CADF test statistic is revealed by the following regression:

$$\Delta Y_{it} = \alpha_i + \rho_i Y_{it-1} + d_0 \overline{Y}_{t-1} + \sum_{j=0}^{p} d_{j+1} \Delta \overline{Y}_{t-j} + \sum_{k=1}^{p} c_k \Delta Y_{i,t-k} + \varepsilon_{it} \tag{4}$$

where the α_i is the deterministic term of the model, p is the lag length, $\overline{Y}_t$ and is the mean of all N observations with respect to time t. Based on the above regression, CADF t statistics are obtained by calculating individual ADF test statistics. Moreover, the CIPS test statistics for the panel are derived by taking the average of the CADF test statistics of each cross-section, which is calculated as follows:

$$CIPS = \frac{1}{N} \sum_{i=1}^{N} CADF_i \tag{5}$$

The critical values by which the CIPS test statistics are evaluated were suggested by Pesaran (2007).

Traditional econometric estimation methods such as panel OLS models, panel fixed effect models, and panel random effect models cannot yield effective results in trade credit policy decisions (Djebali & Zaghdoudi, 2020). In this study, dynamic panel data models were used to obtain more effective results and eliminate this problem. The dynamic panel data model is a generalized method of moments (GMM) estimation model first developed by Arellano and Bond (1991). In the next step, the first difference model was transformed by using the instrument variable matrix outlined by Arellano and Bover (1995) and Blundell and Bond (1998). The GMM approach uses lagged values of instrument variables in various differential equations and initial differences in level equations. Compared to the "Difference GMM" method developed by Arellano and Bond (1991), the estimators obtained from the one- and two-step System-GMM proposed by Arellano and Bover (1995) and Blundell and Bond (1998) are better predictors (Roodman, 2009). Therefore, in this study, the two-stage system GMM method was preferred in estimating the relationship between trade credit policy and firm value. On the other hand, other reasons for the preference of this method are simultaneity bias, omitted variables, and especially the problem of endogeneity. In addition, this method tests the validity of instrumental variables and takes the autocorrelation problem into account, as developed by Sargan (1958) and Arellano and Bond (1991), respectively.

If any relationship is found between any two variables, the question whether there is also a causal relationship between these two variables should be of interest. That is why the Dumitrescu and Hurlin (2012) panel causality test was used in order to detect the relationship between trade credit, control variables and firm value. The method used in the study is a similar but more developed version of the Granger causality test, and it was used for heterogeneous panel data. The model developed based on the panel VAR model is as follows:

$$Y_{it} = \alpha_i + \sum_{k=1}^{K} \gamma_i^{(k)} Y_{it-k} + \sum_{k=1}^{K} \beta_i^{(k)} X_{it-k} + \varepsilon_{it} \tag{6}$$

Here, lag length (k) is constant for each cross-section and when the panel data is balanced, the autoregressive parameter $\gamma_i^{(k)}$ and slope parameter $\beta_i^{(k)}$ vary according to the cross-section. The test statistics obtained through this method are shown below:

$$W_{N,T}^{HNC} = \frac{1}{N}\sum_{i=1}^{N} W_{i,T}$$

$$Z_{N,T}^{HNC} = \sqrt{\frac{N}{2K}}\,(W_{N,T}^{HNC} - K) \rightarrow N(0,1) \tag{7}$$

Here, the Wald statistic is represented by $W_{i,T}$, and by averaging the Wald statistics of each cross-section, and $W_{N,T}^{HNC}$ was found. Accordingly, there is no Granger relationship between the variables of all units considering the null hypothesis. However, there is a relationship between two variables in at least one unit regarding the alternative hypothesis. The model itself is heterogeneous, and while the alternative hypothesis provides heterogeneous results, the null hypothesis still provides a homogeneous result.

3. Empirical results and discussion

3.1. Descriptive statistics and correlation matrix

Account receivables investment is crucial for companies in Europe. McGuinness et al. (2018) conducted a study in 13 European countries (Belgium 34%, Finland 16%, France 29%, Germany 20%, Greece 49%, Hungary 19%, Ireland 28%, Italy 37%, Latvia 13%, Poland 27%, Portugal 36%, Spain 30%, UK 22%) which revealed that the average total account receivable asset share is 30%. As in European companies, account receivables are crucial for Borsa Istanbul manufacturing firms. Within the framework of the sample of the research, it is understood from Table 1 that the accounts receivables of these companies account for 55% of sales and 41% of current assets. Here in Turkey, sales of account receivables have an important place in current assets. On the other hand, the Tobin Q average of the companies is 1.46, the average firm value/book value is 2.05, and the selected companies create value in the financial market. Furthermore, it can be seen that there is an average 14% expansion in the sales of the selected companies, and the leverage ratio is 1.52, and the companies benefit from the leverage effect.

Table 1. Descriptive statistics

Variable	Observations	Mean	Standard deviation	Median	10th percentile	90th percentile
Tobin's *Q*	5768	1.4679	1.2514	1.1600	0.3500	0.7700
Market	5768	2.0535	2.2568	1.4200	0.3000	0.6300
AR/NS	5768	0.5471	0.5582	0.3800	0.0100	0.1300
AR/CA	5768	0.4125	0.1853	0.4100	0.0200	0.1800
Growth	5768	0.1426	0.3087	0.1200	–0.5300	–0.1500
Lev	5768	1.5249	2.0175	0.8700	0.0600	0.2400
Size	5768	18.806	1.7979	18.750	14.000	16.780

Note: This table shows the values of descriptive statistics of the variables used in the analysis. Data is quarterly and ranges from 2005Q1 to 2018Q4. Tobin's *Q* – Tobin's *Q* ratio, Market – firm value/book value, AR/NS – the ratio of account receivables to total sales, AR/CA – the ratio of account receivables to total current assets, Growth – the growth in sales of each firm, Lev – the ratio of total debt to total equity, Size – the natural logarithm of total net sales.

Source: based on data provided by Finnet database (FINNET, 2019) and Public Disclosure Platform (PDP, 2019).

A high correlation between independent variables in multiple linear regression analysis leads to the problem of multicollinearity. Therefore, a high correlation between independent variables is undesirable in the analysis. The correlation matrix of the variables used in Model 1 is presented in Table 2.

As shown in this table, the analyses are carried out with the existing data set without any adjustment, since there is no high correlation between independent variables.

Table 2. Correlation matrix

Variable	Tobin's *Q*	Market	AR/NS	AR/CA	Growth	Lev	Size
Tobin's *Q*	1.000						
Market	0.633***	1.000					
AR/NS	–0.034*	0.034*	1.000				
AR/CA	–0.016	–0.008	0.410***	1.000			
Growth	0.089***	0.083***	–0.055***	0.030	1.000		
Lev	0.022	0.507***	0.127***	0.067***	0.056	1.000	
Size	–0.094***	–0.112***	–0.391***	–0.045**	0.141***	–0.068***	1.000

Note: Significance at 1%, 5%, and 10% is indicated by the symbols ***, ** and *, respectively.

Source: based on data provided by the Finnet database (FINNET, 2019) and Public Disclosure Platform (PDP, 2019).

3.2. Panel unit root test results

The stationary of the series was tested using the Pesaran (2007) CIPS (cross-sectionally augmented IPS) test, which considers the cross-sectional dependency in the series to be used in the analysis of the study. Since the CIPS statistic calculated according to the results presented in Table 3 was greater than

Table 3. Panel CIPS unit root test

	Tobin's *Q*	Market	AR/NS	AR/CA	Growth	Lev	Size
Lag=1	–2.440***	–2.663***	–4.532***	–3.680***	–3.168***	–2.692***	–2.090***
Lag=2	–2.325***	–2.556***	–4.241***	–3.358***	–3.283***	–2.596***	–2.325***
Lag=3	–2.288***	–2.579***	–3.145***	–3.233***	–3.612***	–2.168***	–2.337***
Lag=4	–2.268***	–2.554***	–3.270***	–3.359***	–2.955***	–2.215***	–2.228***
Lag=5	–2.345***	–2.577***	–3.507***	–3.363***	–3.114***	–2.289***	–2.178**

Note: The values in the table represent the CIPS test statistics. Significance at 1%, 5%, and 10% is indicated by the symbols ***, ** and *, respectively. Since no trends are detected in the variables, the constant model is preferred during unit root analyses Critical values for the test are based on the company and time section for each panel, from the 4th chapter, pp. 275–279, of Pesaran (2007) study for 1% –2.30; –2.16 for 5% and –2.08 for 10%.

Source: based on data provided by the Finnet database (FINNET, 2019) and Public Disclosure Platform (PDP, 2019).

the absolute value of the critical value, H_0 was rejected. It was decided that there is no unit root in the series forming the panel.

According to Table 3, it was concluded that all series are up to 5 lag lengths *I*(0), stationary at level. Since all of the series were stationary, the study hypotheses were tested and estimated with two-step system GMM developed by Arellano and Bover (1995), and Blundell and Bond (1998), as well as Dumitrescu and Hurlin's (2012) heterogeneous panel causality models.

3.3. Baseline of the estimation results

As can be understood from Table 4, the findings support the quadratic relationship (concave) between account receivables and market values, i.e. hypothesis 1. In other words, trade credit investment increases firm value up to a certain point (turning point), but after a certain point, increases in trade credit negatively affect firm value. Increases in low trade credit positively affect firm value due to the incentive to take advantage of trade credit advantages to increase market share, and the desire to establish new customer relations. In contrast, increases in high trade credit investment negatively affect firm value due to the cost and financial risks brought about by trade credit. These results support the hypotheses put forward by Martínez-Sola et al. (2013) based on Spanish firms, and this study's hypothesis 1 is also valid for Borsa Istanbul manufacturing firms.

Based on the results in Table 4, it was proved that trade credit investment positively affects firm value up to a certain point but negatively after this limit is reached. From this point of view, it should be determined to what extent the companies included in the sample should invest in account receivables and help them develop financial policies in this regard. Inspired by the study of Martínez-Sola et al. (2013), in this study it was calculated that the account receivables level of the firms should not exceed 54.13% of the current assets and the account receivables level should not exceed 47.15% of the current assets (turning point) in terms of market value (vertex calculated by taking the first derivative).

GROWTH, one of the control variables, has a statistically significant and negative coefficient of 1% in the model where both dependent variables are used. This result is compatible with Jensen's (1986, 1988) agency and governance theories. It is understood from this result that changes in sales negatively affect firm value on Borsa Istanbul. Moreover, the conclusion is that the opinions suggesting that it may increase the value of the firms utilizing growth opportunities are not valid in Borsa Istanbul Manufacturing firms, as proposed by Claessens et al. (2002), Porta et al. (2002), Durnev and Kim (2005), Maury and Pajuste (2005) and Tong (2008). The LEV variable was significant

Table 4. Nonlinear relationship between trade credit and firm value

Variables	Tobin's *Q*		Market	
AR/NS	0.155*** (–0.004)		0.322*** (–0.01)	
$(AR/NS)^2$	–0.020*** (–0.001)		–0.044*** (–0.003)	
AR/CA		1.282*** (–0.062)		1.740*** (–0.241)
$(AR/CA)^2$		–1.184*** (–0.068)		–1.845*** (–0.280)
Growth	–0.130*** (–0.006)	–0.142*** (–0.006)	–0.202*** (–0.017)	–0.205*** (–0.013)
Lev	–0.004 (–0.002)	–0.003 (–0.002)	0.187*** (–0.006)	0.203*** (–0.005)
Size	0.041*** (–0.001)	0.019*** (–0.001)	0.076*** (–0.004)	0.034*** (–0.002)
Crisis dummy (2008–2009)	–0.112*** (–0.003)	–0.121*** (–0.003)	–0.240*** (–0.009)	–0.264*** (–0.009)
AR(–1)	–2.3565 [*p* = 0.0184]	–2.3559 [*p* = 0.0185]	–3.6843 [*p* = 0.0002]	–3.6898 [*p* = 0.0002]
AR(–2)	0.17081 [*p* = 0.8644]	0.13881 [*p* = 0.8896]	–0.07652 [*p* = 0.9390]	–0.10447 [*p* = 0.9168]
Sargan Test	93.94 [*p* > 0.10]	97.10 [*p* > 0.10]	92.52 [*p* > 0.10]	99.74 [*p* > 0.10]
Year dummy	YES	YES	YES	YES
Industry dummy	YES	YES	YES	YES

Note: Four lags and a two-step system GMM estimator were used to conduct all estimations. All the variables are endogenous, and the instruments are lagged independent variables. Market value of equity plus book value of total debt to total assets, which is the dependent variable *Q* (Tobin's *Q*), are presented in columns 1 and 2. The percentage of market capitalization of the company to equity book value, demonstrated in columns 3 and 4, is used as the dependent variable in the proxy firm evaluation process. Accounts receivable are measured by AR/CA and AR/NS. Growth, the Lev, and Size are the control variables. All regressions include industry and time dummies. Statistically insignificant sector dummies are excluded, and it is calculated by not using a constant term. Under the null hypothesis of no serial correlation, AR(–1) is a test statistic for first-order autocorrelations, while AR(–2) is second-order in residuals, distributed as standard normal *N*(0, 1). Under the null hypothesis of instrument validity, the Sargan test is used to over-identify the constraints, distributed as chi-squares. Significance at 1%, 5%, and 10% is indicated by the symbols ***, ** and *, respectively.

Source: own work.

in two of the four regression models used. The fact that the LEV coefficient is statistically positive and significant at 1% when the dependent variable is MARKET shows that it is consistent with the tax argument of Modigliani and Miller (1963) and the free cash flow argument of Jensen (1986).

The SIZE variable has a statistically significant and positive coefficient at 1% in both dependent variables. This result supports the idea put forward by Berger and Ofek (1995) that net sales may positively affect firm value. Finally, the crisis dummy variable, which examines the effects of the 2008–2009 global crisis, is statistically significant and negative at the 1% level. Thus, the global crisis in Turkey had a negative effect on firm value. This evidence is in line with the ideas expressed by Bastos & Pindado (2013), Enqvist et al. (2014), and Nam & Uchida (2019).

In Table 5, the results regarding hypothesis 2 are tested with Model 3. In other words, the relationship between the deviations from optimal level of trade credit level and firm value is presented. Accordingly, a negative association was found between DEVIATION and firm value at the 1% statistical significance level. The Deviation AR/NS and DEVIATION AR/CA results are shown in columns 1 and 2 in Table 5 with both dependent variables.

Arguing that these results are moving away from the firm's targeted trade credit levels and the decrease in market value, Martínez-Sola et al. (2013) also supports the opinion and this study's H_2 is also valid for Borsa Istanbul manufacturing firms. While the control variables LEV are insignificant for Tobin's *Q*, they positively affect MARKET at a statistical significance level of 1%. The SIZE independent variable coefficients were estalished as being positive at the 1% statistical significance level. However, a negative relationship was found between the GROWTH independent variable and the firm value at a statistical significance level of 1%. These results are consistent with the results put forward for Model 1.

Revealing the relationship between trade credit policy and firm value raises the question of whether there is causality between them. In this context, Table 6 shows the results of the Dumitrescu and Hurlin (2012) Heterogeneous Panel Causality Test. When the results are examined, a statistically bidirectional causal relationship at a 1% significance level is determined between AR/NS and AR/CA referring to trade credit and Tobin's *Q* and MARKET referring to firm value. Within the framework of the findings obtained, hypothesis 3 is supported. This causal evidence is consistent with Kroes and Manikas' (2014) approach. The causal relationship is not limited only to the relationship between trade credit and firm value. The causal relationships between control variables Growth, the Lev and Size and firm value are also examined, and statistically significant bidirectional causal relationships are determined. The fluctuations in the companies' sales and total net sales cause the abovementioned relationships in firm value. Moreover, changes in the debt/equity structure of companies may have caused the firm value previously mentioned.

Table 5. Deviations from optimal level of trade credit and firm value

Variables	Tobin's *Q*		Market	
AR/NS	0.074*** (0.005)		0.206*** (0.011)	
$(AR/NS)^2$	0.002*** (0.001)		0.005*** (0.002)	
AR/CA		1.059*** (–0.122)		2.154*** (0.268)
$(AR/CA)^2$		–0.597*** (0.138)		–1.598*** (0.311)
DEVIATION AR/NS	–0.129*** (0.009)		–0.336*** (0.018)	
DEVIATION AR/CA		–0.500*** (0.043)		–0.931*** (0.053)
Growth	–0.076*** (0.005)	–0.100*** (0.006)	–0.190*** (0.011)	–0.221*** (0.010)
Lev	0.000 (0.002)	0.001 (0.001)	0.228*** (0.004)	0.239*** (0.004)
Size	0.025*** (0.002)	0.003 (0.002)	0.041*** (0.004)	–0.005*** (0.003)
Crisis dummy (2008–2009)	–0.144*** (0.005)	–0.163*** (0.005)	–0.231*** (0.007)	–0.262*** (0.007)
AR(–1)	–2.0491 [*p* = 0.0405]	–2.0521 [*p* = 0.0402]	–3.4885 [*p* = 0.0005]	–3.4789 [*p* = 0.0005]
AR(–2)	0. 27759 [*p* = 0. 7813]	0.24773 [*p* = 0.8043]	0.5042 [*p* = 0.6141]	0.38774 [*p* = 0.6982]
Sargan test	94.5309 [*p* > 0.10]	94.6322 [*p* > 0.10]	92.0565 [*p* > 0.10]	95.1865 [*p* > 0.10]
Year dummy	YES	YES	YES	YES
Industry dummy	YES	YES	YES	YES

Note: Four lags and a two-step system GMM estimator are used to conduct all estimations. All the variables are endogenous, and the instruments are lagged independent variables. Market value of equity plus book value of total debt to total assets, which is the dependent variable is *Q* (Tobin's *Q*), are in columns 1, 2, 3 and 4. The percentage of market capitalization of the company to equity book value, demonstrated in columns 1, 2, 3 and 4, is used as the dependent variable in the proxy firm evaluation process. Deviation is measured by Deviation AR/CA and AR/NS. Growth, the Lev, and Size are the control variables. All regressions include industry and time dummies. Sector insignificant is excluded, and it is calculated by not using a constant term. Under the null hypothesis of no serial correlation, AR(–1) is a test statistic for first-order autocorrelations, while AR(–2) is second-order in residuals, distributed as standard normal N (0,1). Under the null hypothesis of instrument validity, the Sargan test is used to over-identify the constraints, distributed as chi-squares. Numbers in brackets are standard errors. Significance at 1%, 5%, and 10% is indicated by the symbols ***, ** and *, respectively.

Source: own work.

Table 6. Dumitrescu-Hurlin (2012) heterogeneous panel causality test

Null hypothesis:			Walt Statistics	Zbar Statistics	*p*-value
Dependent variable: Tobin's *Q*					
AR/NS	⇏	Tobin's *Q*	1.63912	4.01067	0.0001***
Tobin's *Q*	⇏	AR/NS	1.46678	2.85700	0.0043***
$(AR/NS)^2$	⇏	Tobin's *Q*	1.34091	2.01441	0.0440**
Tobin's *Q*	⇏	$(AR/NS)^2$	1.41357	2.50081	0.0124***
AR/CA	⇏	Tobin's *Q*	1.83542	5.32476	0.0000***
Tobin's *Q*	⇏	AR/CA	1.56642	3.52400	0.0004***
$(AR/CA)^2$	⇏	Tobin's *Q*	1.82303	5.24187	0.0000***
Tobin's *Q*	⇏	$(AR/CA)^2$	1.46982	2.87735	0.0040***
Dependent variable: Market					
AR/NS	⇏	Market	1.50918	3.14085	0.0017***
Market	⇏	AR/NS	1.77017	4.88795	0.0000***
$(AR/NS)^2$	⇏	Market	2.81571	3.40786	0.0007***
Market	⇏	$(AR/NS)^2$	3.48056	6.50898	0.0000***
AR/CA	⇏	Market	1.56792	3.53405	0.0004***
Market	⇏	AR/CA	2.09444	7.05873	0.0000***
$(AR/CA)^2$	⇏	Market	1.57463	3.57895	0.0003***
Market	⇏	$(AR/CA)^2$	2.08676	7.00735	0.0000***

Note: Significance at 1%, 5%, and 10% is indicated by the symbols ***, ** and *, respectively.

Source: own work.

Conclusions

Trade credits are crucial, as they constitute a significant part of the company's balance sheets and are included in the working capital elements. Trade credits have been a large and growing source of finance in all sectors of the world since the Second World War, especially in the United States economy (Nadiri, 1969). There is growth in Turkey as well; this funding source has reached a considerable level. One of the many factors contributing to this importance is that the development of financial and capital markets is limited or not developed in large volumes. In cases where market conditions cannot adequately meet companies' financial needs, companies meet these needs among themselves through trade credit financing. Consequently, there are indications that constraints in financial markets can affect companies' decisions regarding trade credit, and such decisions may, in turn, influence the firm's value (Lewellen et al., 1980). For this reason, this study focuses on the relationship between trade credit policy and firm value, with quarterly data of 103 selected firms in an emerging market such as Borsa Istanbul manufacturing industries in Turkey for 2005Q1–2018Q4.

Firms that try to increase their market value by taking advantage of trade credit face financial risks after a certain point. Therefore, this study claims that there is a nonlinear (quadratic) relationship between trade credit investments and firm value. In addition, Martínez-Sola et al. (2013) suggested a nonlinear relationship between trade credit investments and firm value in their study on SME's in Spain. Thus, the present study reveals that the results obtained from study by Martínez-Sola et al. (2013) are valid for manufacturing companies operating on Borsa Istanbul. One of the striking results of this study is that there is a cost-benefit balance in trade credit. Account receivables investments increase firm value with certain motivations and benefits. However, after a certain stage, investors force the firms to reduce trade credit due to liquidity constraints, decreased profits, financial risk, and opportunity cost. Although the finance manager demands an expansion in trade credit due to operational, financial and commercial benefits, the trade credit will be stopped by the investors when the firm value is at its maximum level. Therefore, it is concluded that there is an inverted U-shaped relationship between trade credit and firm value.

Another interesting finding of the study is that the financial crisis had a negative effect on firm value by including the years 2008–2009 as a crisis dummy in the model. The adverse effects on the market values of firms in times of crisis enable trade credit to expand. For example, a firm invests at low levels of trade credits. In that case, it may take advantage of trade credits to eliminate the negative impact of the financial crisis on the firm's value and prevent a decline in firm value. Moreover, it can be said that Modigliani and Miller's optimal capital structure, Modigliani and Miller (1963)'s argument tax and Jensen's (1986) free-cash-flow are valid in BIST manufacturing firms. Finally, one of the original aspects of the present study is that the bidirectional causal relationship between trade credit policy and firm value was revealed. While investment in account receivables causes changes in firm value, firm value changes also generate changes in account receivables investments. In reality, it is no surprise that this relationship exists. Significantly, the idea of increasing firm value by using falling market values as a lifeline during crisis periods shows that there is a causal relationship between them. This study reveals the existence of this relationship. On the other hand, the increase in sales, net sales of the company, and the use of leverage can be explained as the dynamics that determine the firm value of the companies. Due to these features, this study makes a significant contribution to the literature and is the first to express this view.

From the standpoint of policy recommendation, in this study, the turning point of the account receivables of 103 Borsa Istanbul manufacturing companies included in the sample is examined. From this perspective, for BIST manufacturing firms, this study has identified a sectoral average that will maximize both the firm and market values through trade credit policy. With the calculated turning point identified, it becomes possible for the aforementioned firms to develop policies within this framework. When compared to (Martínez-Sola et al., 2013), which is one of the most important studies conducted in the literature, account receivables investment is more crucial in terms of the account receivables investment of BIST manufacturing companies, with a more elastic structure and among working capital elements.

The most important constraint of this study is that it only deals with trade credit investment, financial crises, sales and fluctuations, optimal capital structure, and firm value relations. Undoubtedly, many internal and external factors affect firm value. These relationships can be evaluated together with macroeconomic indicators, trade loans, and net trade credit. Moreover, this study's analysis can be expanded with more recent econometric tests on different sub-sectors and countries.

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Appendix

Table A1. Variable definitions

No.	Proxy	Variable definitions	Unit and measurement
1	Q	The Ersatz for firm value is identified as Tobin's Q (Chung and Pruitt, 1994). The ratio of a company's book value to its market value. It is calculated as the ratio of total assets to the market value of equity plus the entire book value of debt.	ratio
2	Market	The market-to-book ratio is the proportion of equity's book value to market value.	ratio
3	AR/NS	Accounts receivable. Accounts Receivable as a percentage of Net Sales	ratio
4	AR/CA	Accounts receivable. Accounts receivable to Current Assets Ratio	ratio
5	Growth	Growth opportunities, or a rate of annual sales growth, calculated as $[(t_2 - t_1) / t_1]$	ratio
6	Size	The natural logarithm of net sales is used for calculating firm size.	natural log
7	Lev	Total debt divided by total assets pertains to leverage.	ratio
8	STD/TS	Short-term financing is measured as current liabilities to net sales to determine short-term leverage.	ratio
9	FE/TD	The ratio of financial costs to outside financing less trade creditors is the cost of external financing.	ratio
10	NIA/TS	Internal finance, or cash flow, is calculated as earnings after tax plus depreciation, and amortization divided by total sales.	ratio
11	TA/TO	The ratio of sales to assets minus accounts receivable is used to determine a company's asset turnover.	ratio
12	EBITDA/TS	Earnings before interest, taxes, depreciation, and amortization divided by total sales is referred to as the profit margin.	ratio
13	Crisis	The Crisis Dummy is equal to "1" in 2008 and 2009 and "0" otherwise.	dummy
14	Industry(I_{it})	Industry Dummy: Divided into 9 sub-sector(1 – Food, Beverage and Tobacco, 2 – Textile, Wearing Apparel and Leather, 3 – Wood Products Including Furniture, 4 – Paper and Paper Products Printing, 5 – Chemicals, Petrol Rubber and Plastic Products, 6 – Non-Metallic Mineral Products, 7 – Basic Metal, 8 – Fabricated Metal Products Machinery Electrical Equipment and Transportation Vehicles, 9 – Other Manufacturing Industry	dummy
15	(u_{it})	Unobservable heterogeneity	real number
16	(Y_t)	Refers to the time effects and are year dummy variables	real number
17	(u_{it})	Residuals	real number

Source: own elaboration and inspired by (Martínez-Sola et al., 2013).

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