Bulletin of Geography. Socio-economic Series, No. 57 (2022): 45-63
http://doi.org/10.12775/bgss-2022-0022

BULLETIN OF GEOGRAPHY. SOCIO–ECONOMIC SERIES

ISSN 1732–4254 quarterly

journal homepages:
https://apcz.umk.pl/BGSS/index
https://www.bulletinofgeography.umk.pl/

Extended Threshold Error Correction Model of economic growth in Israel

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How to cite:
Osińska, M., Gałecki, M., Boehlke, J., Fałdziński, M., Khan, A.M. & Shachmurove, Y. (2022). Extended Threshold Error Correction Model of economic growth in Israel. *Bulletin of Geography. Socio-economic Series*, 57(57): 45-63. DOI: http://doi.org/10.12775/bgss-2022-0022

Abstract. The paper utilizes a comprehensive approach to threshold cointegration to analyse the Israeli per capita Gross Domestic Product (GDP) growth dynamics. The time-series data for the years 1980–2019 are taken. The study uses a two-regime threshold error correction model (TECM) to test short- and long-term growth factors. The results reveal that Research and Development (R&D) expenses measured as a percentage of GDP are the primary driving force in the long and short term. The threshold value of 3.25% of GDP exhibits a substantial difference between the two regimes corresponding to the development phases of the Israeli economy. The results are validated using various tests for threshold models. The general conclusion is that the applied hierarchical procedure for TECM model construction is robust and universal for modelling economic growth. The results allow the formulation of policy implications.

Article details:
Received: 22 April 2022
Revised: 05 May 2022
Accepted: 12 May 2022

Key words:
structural break,
threshold error correction model,
economic growth,
research and development,
Israel

Contents:

1. Introduction

The paper analyses the growth dynamics of the Israeli *per capita* Gross Domestic Product (GDP) for 1980–2019 from the growth acceleration factors' perspective. We believe that growth acceleration results from internal economic shocks caused by a national economic policy. The policy creates institutional drivers of change and development in the economic system rather than barriers to development.

Balcerowicz and Rzońca (2015) distinguish between two types of growth mechanisms: the first, based on innovation, is potentially sustainable and universal; the second comprises of specific growth mechanisms in policy formed by certain institutional systems, creating a stimulus economic policy. Rodrik (2007) defines an acceleration of economic growth as a *per capita* GDP growth of at least two percentage points maintained for at least eight years, which generally requires implementing a specific reform package. Experience shows that rapid economic growth is associated with a narrow range of political reforms combining institutional solutions. However, maintaining the high economic growth rate requires a broader scope of institutional changes. Rodrik (2007) emphasizes that institutional changes introduced in some countries are difficult to implement in others due to incompatible environments (tradition, structure of society and economy, and many others). He concludes that effective growth strategies should be based on bi-directional changes. The first direction concerns the short-term strategy aiming at accelerated growth.

In contrast, the second direction should include medium and long-term strategies to sustain growth. The necessity to combine economic growth policy with institutional changes conducive to development, known as inclusion institutions, is highlighted by Acemoglu and Robinson (2013), which is now a widely accepted view in economics. Inclusive institutions contain a universal state-based pension; universal access to justice; non-discriminatory recruitment of civil services; inheritance protection for widows; greater equality of political rights for women, etc.

The innovative nature of the reforms fits the foundations of the Israeli economy (Dyduch & Olszewska, 2018; Katz, 2018). Therefore, the study aims to identify and model economic growth factors specific to Israel, focusing on R&D. The choice of Israel is motivated by the fact that it is the second-largest start-up ecosystem globally and a leader in innovative, cutting-edge technologies. In Israel, 135 out of every 10,000 resident workers are scientists or engineers. Moreover, nine out of every 1,000 resident workers are engaged in R&D, nearly double the USA and Japanese rates (1).

The study uses a two-regime threshold error correction model (TECM) to test short- and long-term growth factors. The applied tests correspond to the Enders and Siklos test (2001) and its modifications. The other tests, like the Tsay test (1998) and Hansen and Seo (2002), are applied to justify the results. Finally, the estimated model is presented and discussed.

The related research questions are the following.

1. RQ1: Can the TECM approach uncover driving forces of economic growth in Israel in the long and short run?
2. RQ2: Are the results robust against a linear error correction model and a stationary threshold autoregression model?
3. RQ3: Which factors drove the economic growth in Israel in the analysed period?

The empirical literature on identifying the accelerated growth periods is broad. Two streams can be distinguished. The first one refers to the general classification of the economies. Pritchett (2000), based on stylized facts observed in the years 1960–1992, generalized and classified growth in all economies according to their *per capita* GDP trends accompanied by individual structural breaks. He distinguishes the following groups of economies representing different growth patterns: (1) steep hills – countries with annual growth rates of greater than 3% before and after a structural break (Japan, Cyprus, Ireland); (2) hills – countries with growth rates of greater than 1.5% before and after a structural break (the United States, most of the OECD countries, including Israel), (3) plateaus – countries with growth rates of greater than 1.5% before and above zero and less than 1.5% afterward (Brazil, Sweden); (4) mountains – countries with growth rates greater than 1.5% before and less than zero afterward (Algeria, Gabon, Nigeria, Saudi Arabia, Cote d'Ivoire, Guyana, Jamaica, Zambia and Latin America), (5) plains

– countries with growth rates less than 1.5% both before and after their structural break (Sub-Saharan Africa) and (6) accelerators – countries with growth rates less than 1.5% before their structural break and greater than 1.5% afterward (Indonesia after 1966, Mauritius after 1970, India).

Based on Pritchett's observations, Jerzmanowski (2006) estimates a set of Markov-switching regressions to characterize four distinct growth regimes and transitions between them for 89 countries throughout 1962–1994 using annual data on output per worker. The results show that countries switch among regimes of stable growth, miracle catch-up, stagnation and crisis, with the transition probabilities determined by the quality of institutions. The paper emphasizes shifts in growth performance and reveals that identical average growth rates can conceal distinct growth paths, which is entirely in line with Rodrick's considerations. On the one hand, better institutions appear to improve long-run growth by making episodes of fast growth more persistent. On the other hand, weak institutions do not prevent growth take-offs but hinder their sustainability.

The second stream is related to the factors of economic growth. In the modern Israeli economy, R&D expenditure is essential. Teitel (1987) investigates the relationship between economic growth, *per capita* income, population, R&D expenditure, and stock of scientists and engineers by using quadratic and logarithmic forms of econometric models. He gathers a sample of developing and industrialized countries of the world. The study shows a positive relationship between R&D expenditure (explained variable) and *per capita* income and population (explanatory variables) in all 29 countries, including 11 developing and industrialized countries. Similarly, Bebczuk (2002) finds a positive relationship between R&D expenditures and GDP *per capita* by analysing 88 countries from the 1980s to the 1990s.

Considering the example of Israel, Chorev and Anderson (2006) look at critical factors leading to successes in Israeli high-tech new ventures as a catalysation for economic growth. The factors in the Chorev and Anderson (2006) study are categorized into three groups: the first group consists of crucial elements, such as the idea, the strategy, the core team's commitment and expertise, and marketing; the second group consists of supporting features, such as management, customer relationships, and research and development; and the last group consists of broader parts, including the economy, politics and the general business environment. Israel has well-developed institutions essential for growth, such as an increasing population (mainly due to immigration) and human capital development. Other growth factors include massive capital injection, significant R&D and agricultural development investments, and the transition from agriculture to the current state-of-the-art technologies. Military research and development stimulate innovations. Cohen et al. (1996) analysed the short- and long-term impacts of defense expenditure on the macro-economy. They conclude that while the data cannot confirm a direct effect of military R&D, there exist long-term signals for indirect linkages, known as the "peace dividend", that can be observed.

This paper contributes to the existing literature identifying determinants of accelerated economic growth observed as the innovative and R&D-based economy; it also verifies whether a threshold error correction model (TECM) can identify periods of intense growth with specific threshold variables. The threshold cointegration concept extends the linear cointegration case (Engle and Granger, 1987) by allowing adjustment after the deviation exceeds some critical threshold. Furthermore, it captures asymmetries in the short-run adjustment, in which positive or negative deviations are corrected in different manners. Enders and Siklos (2001) introduced that the long-run equilibrium phenomenon can be measured in different ways, i.e., SETAR and Momentum TAR. Other formulating thresholds are also possible (Kapetanios et al. 2006; Bruzda, 2007). Following Boehlke et al. (2018), we used the procedure of identifying thresholds by allowing individual economic variables to be thresholds in both long- and short-term equations. We call it the extended Enders and Siklos test (Gałecki & Osińska, 2022).

The remainder of the paper is organized as follows. In Section 2, the Israeli economy is briefly characterized. The econometric modelling and testing procedures used for empirical analysis of economic growth in Israel are specified in Section 3. Section 4 presents the selected empirical models. Finally, Section 5 concludes.

2. Economic growth in Israel

The economic history of modern Israel reflects a struggle for this tiny Middle Eastern country to survive and develop. The past 70 years show remarkable Israeli success in economic growth and development. Many authors, like Cohen et al. (1996), Maman (2002) and Mayer et al. (2005), have questioned the sources of such high economic growth. Even before its independence, Israel had the institutions and systems necessary for the orderly running of a country (Williamson, 1985). These institutions include the Labor Union, which represents both the workers and largest employers; the Jewish National Fund, which is responsible for acquiring land; the Jewish Agency, which is responsible for helping its immigrants; financial institutions; the judicial system; political parties; and military units. All these significant institutions were in place before the creation of the state.

As a small nation, Israel has limited natural resources. Thus, human capital is its most valuable economic resource that can be further developed to support sustained economic growth (Peled, 2001). Moreover, the Israeli workforce comprises a relatively high share of hi-tech workers, engineers and scientists. This highly skilled workforce is less costly than the equivalent workforce in other industrialized countries. There are, however, some aspects related to the labour force and human capital. First, one can observe two massive phases of population increases caused by immigration. The first phase of immigration, in 1950, was regulated by *The Israeli Law of Return*, which imposed no barriers to immigration of Jews or those descended from at least one Jewish grandparent. All other immigrants were subject to temporary status for a few years before being able to request citizenship. The second crucial observed phase of immigration occurred over the decade of the 1990s from the former Soviet Union. Researchers attribute this phase of immigration to the economic depression in the Soviet Union, which caused Soviet GDP to fall between 37% and 50% for the years 1989–98 (Rosefielde & Hedlund, 2009). In the short time between 1948 and 2016 Israel absorbed more than 3.1 million immigrants (Fig. 1). Many new immigrants were highly educated and strongly motivated to succeed in their newfound land (Shachmurove, 2019). Eckstein et al. (2020) argue that, since the end of 2003, Israel has shown consistent growth in employment rates. They show that, of the average annual growth of 3.5% during the past decade, the increase in work hours (2.6% per year) contributed about 75% of the growth,

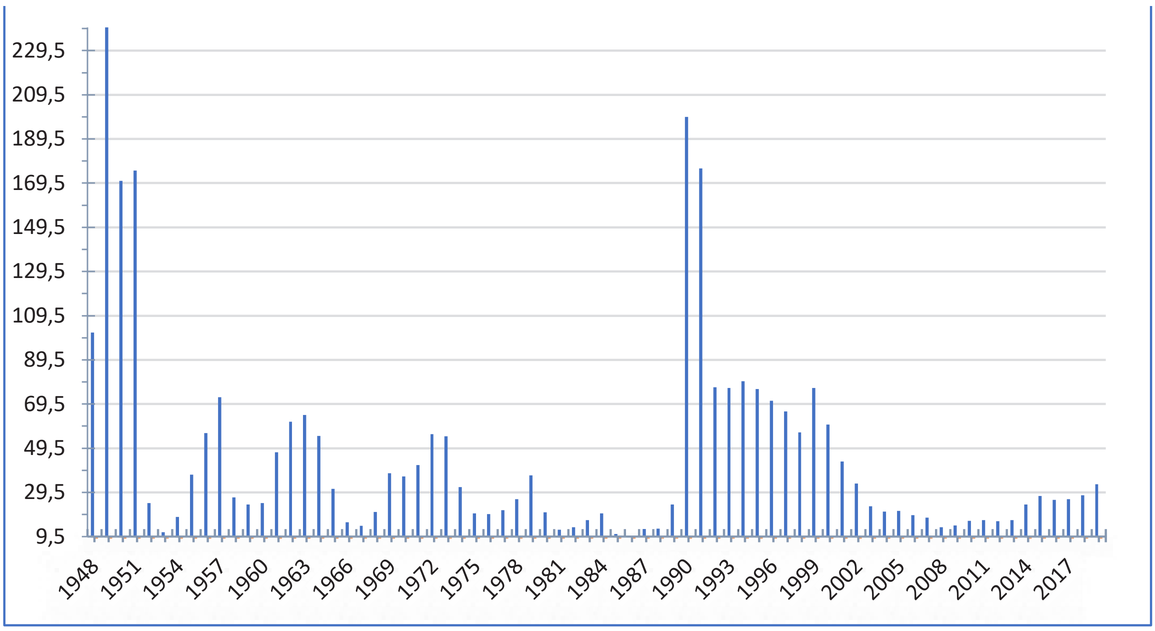

Fig. 1. Immigration to Israel in 1948–2019 (in thousands)
Source: Israeli Statistical Office, https://www.cbs.gov.il/en/mediarelease/pages/2020/immigration-to-israel-2019.aspx

while the increase in productivity (only 0.9% per year on average) was responsible for only about 25% of growth. Therefore, they indicate that productivity growth is the policy target in the following years.

There is, however, the opposite face of migration, i.e., emigration from Israel. After the 1980s, a massive exodus from Israel occurred; however, starting in 2003, this general trend of emigration from Israel decreased. It should be mentioned that an enormous spike in emigration was observed during the escalation of the Israeli–Palestinian conflict in 2001–02. Despite this isolated spike in emigration, by 2017, emigration had dropped to its lowest level in decades (Rosenberg, 2019). In summary, Israeli net immigration remains negative, with the 8,400 Israeli citizens and residents who returned to Israel in 2017 leaving a net outflow of 5,800 from Israel for that year (Rosenberg, 2019).

An important aspect of the Israeli population is its national structure: 74.2% are registered as Jews among nine million people and 20.9% as Arabs. The remaining 4.9% of the population are non-Arab Christians or have no religion. The demographic make-up of Israel is essential when considering the Israeli education system. It has recently been observed that Israel ranks poorly in the Program for International Student Assessment (PISA) organized by the Organization for Economic Co-operation and Development (OECD) and held since 2000; it measures 15-year-old school pupils' scholastic performance in mathematics, science and reading. A study by Gruber (2017) analyses performances of Israeli pupils in mathematics in 2012. The study finds evidence of a relationship between national origin and test performance. In general, pupils with Hebrew nationality performed better than others. A more significant factor in the study refers to personal and class characteristics. The study suggested massive inequality within Israeli society, both between groups and within groups. In summary, one must consider two things: an unparalleled ratio of highly educated and experienced staff employed in the innovative sectors of the economy out of every 10,000 workers in Israel, 135 are scientists and engineers, vs 85 in the US (Hi-Technion, 2000), as well as a significant inequality between Jewish and Arab children, whose chosen disciplines, consequently, hinder prospects for finding suitable job positions.

In addition to human resources, Israel has benefitted from the Diaspora's capital transfers, Germany's reparations, and foreign aid from other countries, most notably from the USA, in recent years (2). Another essential factor helping the Israeli economic performance is new oil and gas drilling technologies. These discoveries are expected to change the country's international status, making it a significant exporter of oil and gas (Shachmurove, 2019).

Considering the pioneering society with its innovative education system and educated immigrants, the next significant growth factor is investment in Research and Development. Peled (2001) focuses on the crucial role of defence and military developments. He states that defence-related R&D had significant impacts on the Israeli industrial sector, its higher education system in science and engineering, its research community, and its workforce composition. Peled (2001) highlights the unique situation of the country. Israel's particular defence needs, the small size of the Israeli economy and its technically skilled workforce may have crucial effects on the external benefits gained from public investment in military R&D. Peled (2001) mentions that, in other studies on this subject, Lichtenberg (1995) finds that government contractors' profitability, mainly in the defence sector, is 68–82% higher than that of other producers. It may explain many enterprises' economic decisions and innovative military technologies because the military sector offers more significant incentives. Furthermore, this study has no evidence to support the hypothesis that defence R&D stimulates civilian R&D, thereby positively indirectly affecting productivity growth. However, it has been recognized that the defence sector provides both the resources and the opportunities to develop new technologies for military applications that also have complete civilian applications (Peled, 2001).

Figure 2 shows the positive trend of R&D expenditure as a percentage of GDP from 1996 until 2018. The Israeli R&D profile shows that R&D expenditure almost doubled from 2.59% in 1996 to 4.95% in 2018.

Figure 3 shows the trend of R&D expenditure (% of GDP) in the top ten countries from 1996 to 2018. The R&D profile indicates that Israel is the

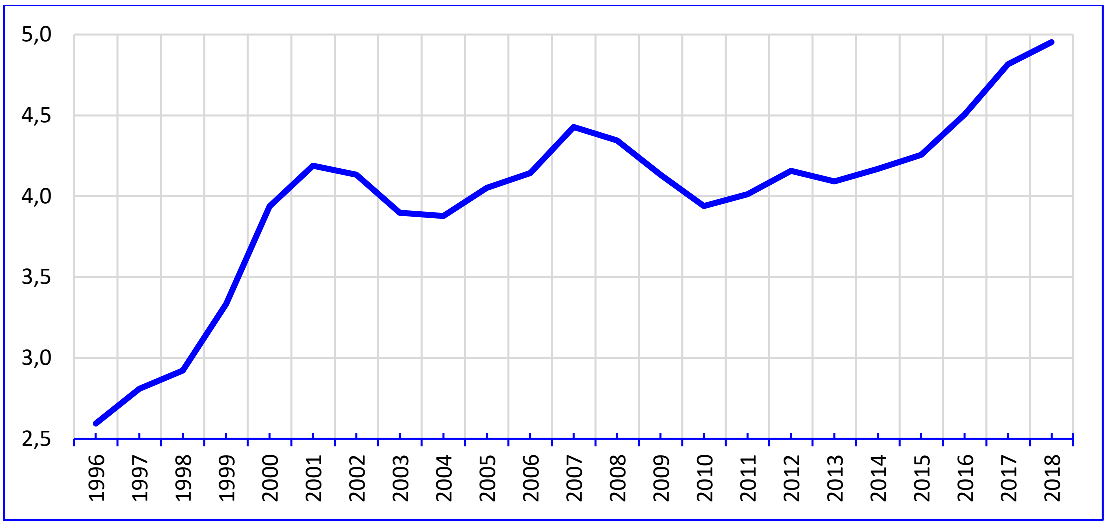

Fig. 2. Research and Development (R&D) Expenditures in Israel (% of GDP)
Source: World Development Indicators, https://data.worldbank.org/indicator/GB.XPD.RSDV.GD.ZS (accessed 20.03.2020)

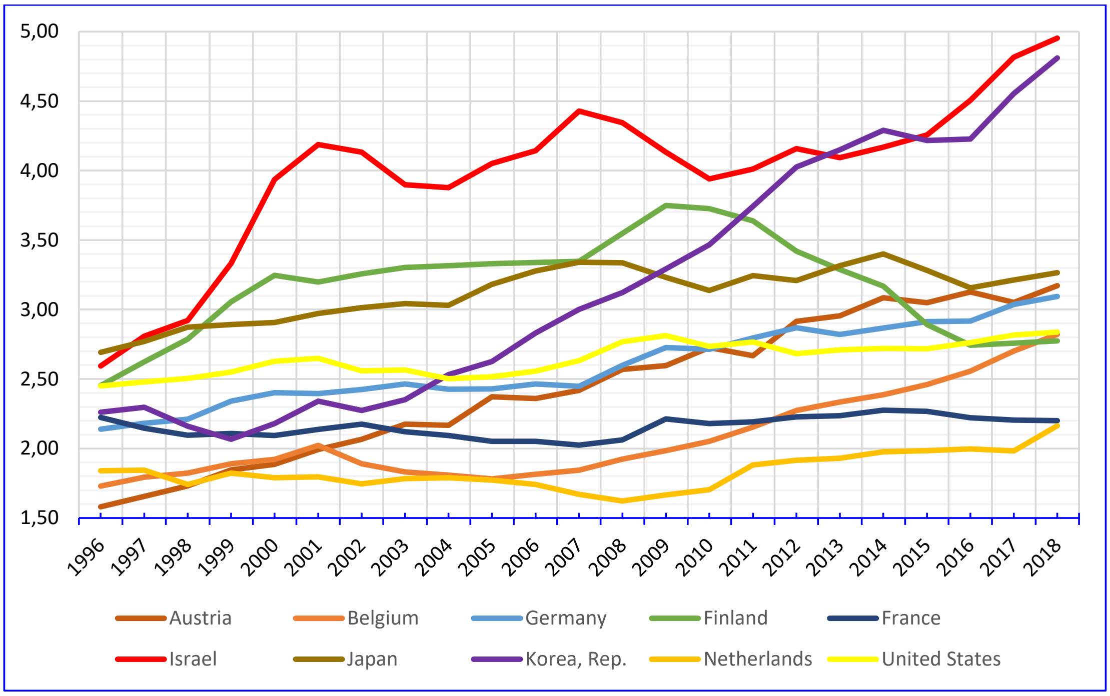

Fig. 3. Research and Development Expenditure (% of GDP) in top ten countries from 1996 to 2018
Source: World Development Indicators

top-ranked country globally for R&D expenditure, with South Korea ranking second.

Israel currently has the greatest concentration of high-tech start-up companies (i.e., Gordis, 2017; Shalom, 2017; Jorisch, 2018; Senor & Singer, 2011; Rodman, 2017). Israeli private companies are concentrated in the following sectors: Basic Industries, Capital Goods, Consumer Durables, Consumer Non-Durables, Consumer Services, Finance, Health Care, Public Utilities and the High-Technology sector.

The graph in Fig. 4 illustrates Israel's progress in increasing GDP over a relatively short period. Figure 5 presents the Israeli GDP in constant 2010 US$ and its growth rate. The figure shreds evidence that Israel has never had a recession, as usually defined.

An essential feature of the Israeli economy is that the 2000–2002 Information Technology (IT) bubble, also known as the "Dot-Com bubble," affected the Israeli economy more than the financial crisis of 2007–08. The drop in GDP growth was twice as significant in 2000–2002 as in the 2007–2008 global financial crisis.

Economic fluctuations in Israel have generally been associated with waves of immigration: a massive immigration flow requires an adjustment period until it is productively absorbed. The investments for its absorption in employment and housing stimulate economic activity. Fluctuations in output were particularly marked by periods of inflation in the 1980s and periods of unemployment starting at the beginning of the twenty-first century. Figure 5 shows the *per capita* GDP in constant 2010 USD.

In general, one observed an upward increase from $20,000 in 1990 to almost $35,000 in 2017. The level of GDP *per capita* ranks Israel as 20th in the world. According to Pritchett's classification

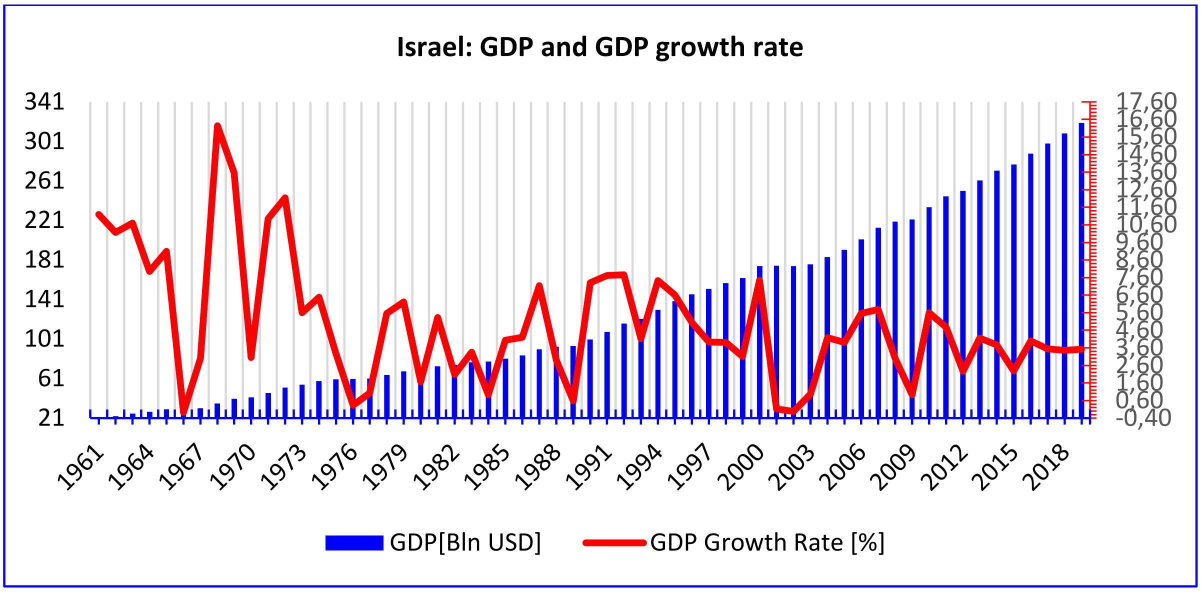

Fig. 4. Research and Development Expenditure (% of GDP) in top ten countries from 1996 to 2018
Source: World Development Indicators

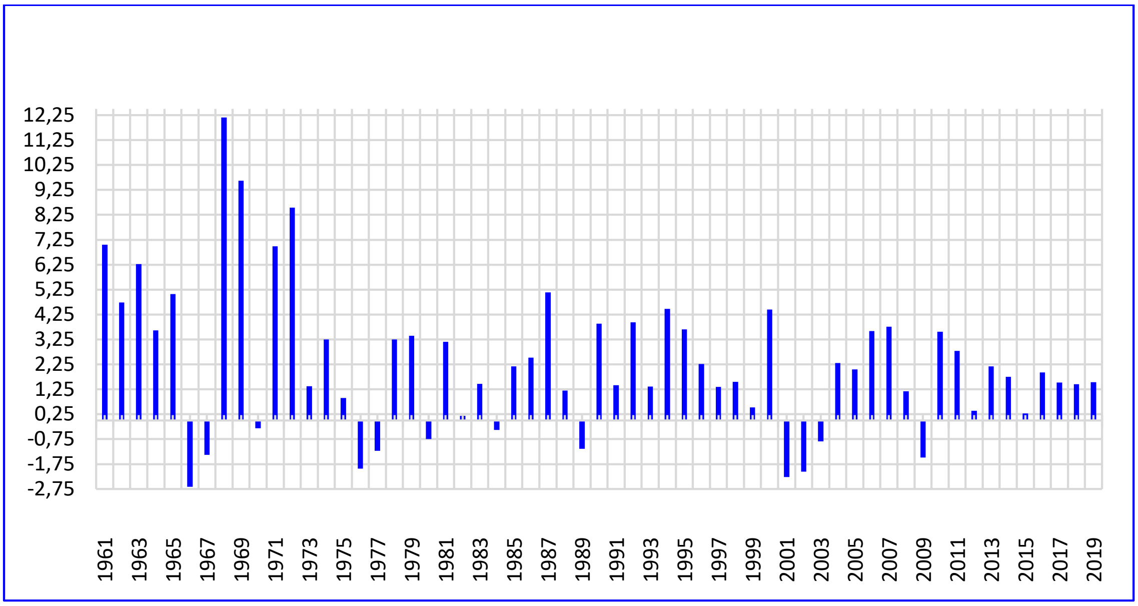

Fig. 5. GDP per capita Growth for Israel in 1961–2019 (Constant 2010 US$)
Source: http://www.cbs.gov.il/ts/ (accessed on 18.03.2021)

(Pritchett, 2000), using *per capita* GDP, Israel represents a hill with a growth rate of 2.31%>1.5% before the structural break in 2001–2002 and 1.91%>1.5% afterward on average.

3. Researching materials and methods

The study uses a threshold error correction model (TECM) approach, with a central assumption that a long-run path exists describing the direction of economic development. This dynamic is perceived as nonlinear and concentrated around a specific threshold variable, a subject of testing and estimation.

The use of the TECM model is influenced by Balke & Fomby (1997) and Enders & Siklos (2001). The model suggests a linear growth path of the economy in the long run. However, short-run adjustments can differ across regimes, mainly exhibiting noticeable asymmetries. The first aspect of the TECM methodology used is proposed by Enders and Siklos (2001). In this approach, it is assumed that a linear cointegrating equation exists under the conditions defined in Engle and Granger (1987), i.e.:

$$Y_t = \alpha_0 + \sum_{i=1}^{k} \alpha_i X_{it} + u_t \tag{1}$$

where

$$\hat{u}_t = Y_t - \hat{Y}_t = ECM_t$$

The estimated testing regression is as follows

$$\Delta\hat{u}_t = I_t \rho_1 \hat{u}_{t-1} + (1-I_t)\rho_2 \hat{u}_{t-1} + \sum_{i=1}^{p} \beta_i \Delta\hat{u}_{t-i} + \varepsilon_t \tag{2}$$

where

$$I_t = \begin{cases} 1 & \text{for} \quad \hat{u}_{t-1} \geq \gamma \\ 0 & \text{for} \quad \hat{u}_{t-1} < \gamma \end{cases}$$

or

$$I_t \begin{cases} 1 & \text{for} \quad \Delta\hat{u}_{t-1} \geq \gamma \\ 0 & \text{for} \quad \Delta\hat{u}_{t-1} < \gamma \end{cases}$$

and γ=0.

The threshold in (2) is defined in terms of the error correction mechanism (ECM)

$\hat{u}_{t-1}$ or $\Delta\hat{u}_{t-1}$

The set of two null hypotheses tested are:

$$H_{10}: \rho_1 = \rho_2 = 0 \tag{3}$$

$$H_{20}: \rho_1 - \rho_2 = 0 \tag{4}$$

H10 assumes no threshold cointegration. If it is true, then the Engle–Granger linear cointegration is confirmed (Engle & Granger, 1987). Linear cointegration can be further confirmed if H20 is true, since it assumes symmetry of adjustment in both regimes defined in model (2), because both parameters ρ_1 and ρ_2 are equal. The alternatives are opposite to both nulls, although many cases are possible under different alternative combinations. Enders and Siklos (2001) suggest a threshold type of cointegration in the long-run equilibrium. Consequently, the short-run adjustment is asymmetric, for positive and negative changes alike. Balke and Fomby (1997) provided a brief explanation of possible cases resulting from the test.

In the next stage of the model methodology, we applied a new testing procedure using the entire set of variables in the long and short runs. The procedure is used in Boehlke et al. (2018) and Boehlke et al. (2020). This procedure differs from the original Enders and Siklos' methodology because it extends the set of possible thresholds, allowing individual lagged variables to be tested as thresholds. It is referred to as the extended Enders and Siklos test (exE-S). It determines their impacts by identifying different regimes, here understood as periods of economic growth within the observed sample. The testing equation is given as follows:

$$\Delta Y_t = I_t \rho_1 \hat{u}_{t-1} + (1-I_t)\rho_2 \hat{u}_{t-1} + \sum_{s=1}^{p_{II}} I_t \beta_{s1} \Delta Y_{t-s} + \sum_{s=1}^{p_I} (1-I_t)\beta_{s2} \Delta Y_{t-s} + \sum_{i=0}^{k} I_t \alpha_i \Delta X_{it} + \sum_{i=0}^{k} (1-I_t)\alpha_i \Delta X_{it} + \sum_{j=1}^{q_{II}} \sum_{i=1}^{k} I_t \gamma_{j1} \Delta X_{it-j} + \sum_{j=1}^{q_I} \sum_{i=1}^{k} (1-I_t)\gamma_{j2} \Delta X_{it-j} + \varepsilon_t \tag{5}$$

where $Z_t = (Y_t, X_{1t}, X_{2t}, \dots, X_{kt})'$ is a vector of possible threshold variables other than $\hat{u}_{t-1}$ or $\Delta\hat{u}_{t-1}$ assumed by Enders and Siklos. The threshold value of a threshold variable is a subject of estimation, i.e. $I_t = \begin{cases} 1 & \text{for} \quad Z_{t-i} \geq \hat{\gamma} \\ 0 & \text{for} \quad Z_{t-i} < \hat{\gamma} \end{cases}$ **or**

$$I_t = \begin{cases} 1 & \text{for} \quad \Delta Z_{t-i} \geq \hat{\gamma} \\ 0 & \text{for} \quad \Delta Z_{t-i} < \hat{\gamma} \end{cases} \text{and} -\infty < \hat{\gamma} < \infty;$$

$$\hat{\gamma} = arg \min_{\gamma} AIC(\gamma).$$

In model (5), the short-term equations differ between regimes based on a vector of explanatory variables, the number of lags, and parameter estimates. The rationale for the approach is that one or more variables are responsible for regime changes. The advantage of such an approach is that, in the final TECM, different sets of variables can act in regimes while the long-run relationship is unchanged. Threshold variables can be observed in levels and first differences. One can identify the threshold variable assuming a theory-driven hypothesis or exploring the data. The testing procedure is described in detail in Gałecki and Osińska (2019). Furthermore, Gałecki and Osińska (2022) found that the power and size of the extended test are pretty satisfactory. The empirical TECM models are estimated using Balke and Fomby's (1997) approach, determining threshold variables for threshold cointegration.

The described testing procedure is a subject of validation. Two other tests for the threshold cointegration are applied. Following Tsay (1998), the first one refers to the variance–covariance matrix of the residuals, indicating whether a variable is generated by a linear or nonlinear process. It is assumed that Y_t is linear versus the alternative hypothesis that it follows the multivariate threshold model in the null hypothesis. Tsay used the following test statistic:

$$C(d) = [n - h - m_0 - (kp + vq + 1)]$$
$$\{\ln[det(S_0)] - \ln[\det(S_1)]\}$$

where the delay d means that the test depends on the threshold variable Z_{t-d}, det *(A)* indicates the determinant of the matrix *A*, and

$$S_0 = [\frac{1}{n - h - m_0}] \sum_{l=m_o+1}^{n-h} \hat{\eta}_{t(l)+d} \hat{\eta}'_{t(l)+d}$$

$$S_1 = [\frac{1}{n - h - m_0}] \sum_{l=m_o+1}^{n-h} \widehat{w}_{t(l)+d} \widehat{w}'_{t(l)+d}$$

where $\hat{w}_t$ is the vector of the least-squares residuals. If the null hypothesis that Y_t is generated by a linear data generating process (DGP) is true, under some regularity conditions, $C(d)$ is asymptotically distributed as a chi-squared random variable with $k(pk+qv+1)$ df.

Following Hansen and Seo (2002), the second test focuses on two model characteristics. It considers the differences between the parameter estimates for the error correction term and its variance–covariance matrix. The model assumes linearity under the null hypothesis, and the test statistics is defined as:

$$Sup\, LM = \sup_{\gamma_L \leq \gamma \leq \gamma_U} LM(\widetilde{\beta}, \gamma)$$

where,

$$LM(\beta,\gamma) = vec\left(\hat{A}_1(\beta,\gamma) - \hat{A}_2(\beta,\gamma)\right)'$$
$$(\hat{V}_1(\beta,\gamma) + \hat{V}_2(\beta,\gamma))^{-1} x\, vec\left(\hat{A}_1(\beta,\gamma) - \hat{A}_2(\beta,\gamma)\right)$$

$\hat{A}_1$ and $\hat{A}_2$ denote matrices of parameters estimates in regimes, $\hat{V}_1$ and $\hat{V}_2$ are auxiliary matrices, γ is the threshold value, and β is a cointegrating vector. The distribution of LM statistics is unknown. Hansen and Seo (2002) proposed using a bootstrap technique to calculate p-values as a percentage share of all LM values that exceed the value of the actual statistic.

The rejection of the TECM hypothesis results in two possible specifications. Either we confirm a linear error correction model (ECM), or we reject the cointegration and agree that asymmetry is present in the short run, which results in a stationary threshold autoregression (TAR) model (Tong, 1990).

4. Research results

This paper focuses on the GDP *per capita* growth rate to measure economic growth (Rupasingha et al., 2000; Sala-i-Martin, 2002). The explanatory variables adopted here derive from the neo-classical and institutional economics theory and empirical analysis. For an extension, see (Solow, 1956; Barro, 1991; Esterly & Levine, 2001; Elsner, 2012). They are divided into two groups: real indicators: FDIt, Ut, It, Net_EXPt, TFPt, R&Dt, NPt, Mt, TDt, MEt, and financial indicators: EXRt, PDt, Defl_GDPt, SRt, and LRt, observed in a time series between 1980 and 2019 inclusive; 40 observations (see Table 1 for a list of the variables). Variables not expressed in percentages are transformed into logs. The time series are checked for stationarity using the standard

Table 1. Variables used in the study (constant prices) and the ADF results

Variable name	Description	Order of integration - ADF test	Transformation
$GDPpc_t$	*Per capita* GDP	I(1)	Logs
EXR_t	Exchange rate	At least I(1)	Logs
FDI_t	Foreign Direct Investment	I(1)	Logs
U_t	Unemployment rate	I(1)	-
PD_t	The Public Debt	I(1)	Logs
$Defl\_GDP_t$	GDP deflator	At least I(1)	Logs
SAV_t	Savings	I(1)	Logs
I_t	Investments	I(1)	Logs
Net_EXP_t	Net Exports	I(1)	Logs
SR_t	Short-term interest rate	I(1)	-
LR_t	Long-term interest rate	I(1)	-
TFP_t	Total factor productivity	I(1)	-
$R\&D_t$	Investment in research and development	I(1)	Logs
NP_t	Number of patents	I(1)	Logs
ME_t	Military expenses	I(1)	Logs
M_t	Net Migrations	I(1)	Logs
TD_t	Expenditures for tertiary education	I(0)	Logs

Source: data downloaded from http://stats.oecd.org/ and Federal Reserve Bank of St. Louis, World Bank, International Monetary Fund, and Central Statistical Office in Israel

Table 2. Long-run equation for log GDP per capita

Regressor	Coeff	Std error	t-stat	p-value
Const	3.964	0.285	13.908	0.000
logR&D	0.097	0.041	2.365	0.023
logME	-0.382	0.028	-13.642	0.000
logSAV	0.181	0.068	2.661	0.013
logTD	-0.305	0.062	-4.919	0.000

Model diagnostics: R^2 = **0.9699**; AIC=**−141.34**; SC=**−132.90**; DW=**1.513**; Quandt stat QLR 2002 = **40.098 [0.000]**

Source: own work

ADF test by Dickey and Fuller (1979). They exhibit at least I (1) type non-stationarity. Furthermore, two tests for the structural breaks were applied.

Zivot & Andrews (1992) and Bai & Perron (1998, 2003) examine structural breaks in *per capita* GDP. GDP *per capita* exhibited structural breaks in 2001 according to the Zivot and Andrews test, and in 1987, 1993, 2000, 2009 according to Bai and Perron tests. The results of structural breaks testing are available from the authors on request.

In the next stage, we construct the long-run equation. In the long run, it has been assumed that technological progress and human capital development are the critical factors for increasing GDP *per capita* in Israel. We estimated the long-run equation, which satisfies theoretical assumptions and statistical tests. The results are presented in Table 2.

The estimation results show that R&D expenditures and savings stimulate *per capita* GDP in Israel in the long run. Two other variables, i.e., Military Expenditures (ME) and Expenses for Tertiary Education (TD), exhibit negative signs. TD in Israel decreased over time while *per capita* GDP increased; thus, negative parameter estimates signs for an indirect estimation seem natural. ME financed by the government and high profitability for private enterprises, particularly in innovative areas, caused a crowding-out effect in other private sector activities. Having the long-run relation estimated, Engle–Granger's linear cointegration was confirmed. Then we checked if a structural break

Table 3. Results of the exE-S, Tsay and Hansen and Seo testing for threshold cointegration for Israel

Threshold variable	exE-S test H10: $\rho_1 = \rho_2$=0) p-value	exE-S test H20: ($\rho_1 - \rho_2$=0) p-value	Tsay C(d)	p-value	Hansen and Seo test	p-value
ECM_{t-1}	0.0369	0.0000	21.9713	0.0012	0.8831	0.9981
ΔECM_{t-1}	0.2017	0.0000	24.6733	0.0018	6.5220	0.0040
$logNet\_EXP_{t-1}$	0.0000	0.0000	28.3856	0.0004	0.7881	0.9999
TFP_{t-1}	0.0744	0.0000	3.3924	0.8465	612.337	0.8522
$logR\&D_{t-2}$	**0.0001**	**0.0000**	**26.9112**	**0.0027**	2.3541	0.9998
U_{t-2}	0.0000	0.0000	15.0335	0.0200	0.8981	0.9978
ΔTFP_{t-2}	0.0000	0.0000	0.6245	0.9989	53.4972	0.0040
ΔSR_{t-2}	0.0000	0.0000	12.6331	0.0492	4.8811	0.0351
$logNP_{t-3}$	0.0000	0.0000	12.0225	0.0172	0.7411	0.3762
$logSAV_{t-4}$	0.2723	0.0000	27.4598	0.0003	2.8681	0.4951
$logPD_{t-5}$	0.0006	0.0000	38.4423	0.0000	0.8261	0.9970
SR_{t-5}	0.0556	0.0000	10.4621	0.0632	12.0261	0.9753
$logME_{t-5}$	0.0118	0.0000	31.0240	0.0001	16.6202	0.4652
$logTD_{t-5}$	0.0283	0.0000	9.7038	0.0841	18.4031	0.0011
$logGDPpc_{t-5}$	0.0000	0.0000	5.4208	0.6088	0.4122	0.9981
$\Delta logNet\_Exp_{t-5}$	0.1886	0.0000	25.9695	0.0002	0.2423	0.9962
$\Delta logDeflGDP_{t-5}$	0.0031	0.0000	6.98072	0.3226	33.8250	0.9980
$\Delta logI_{t-5}$	0.3654	0.0000	9.99674	0.2653	3.9042	0.9999
$\Delta logR\&D_{t-5}$	**0.0011**	**0.0000**	**29.3551**	**0.0006**	0.6044	0.9999
$\Delta logSAV_{t-5}$	0.0071	0.0000	29.6267	0.0001	7.8491	0.0021
$\Delta logTD_{t-5}$	0.0039	0.0023	28.864	0.0007	0.3790	0.9998
$\Delta logGDPpc_{t-5}$	0.0001	0.0000	14.1528	0.0147	0.1242	0.9989

Source: own work

was present in the residuals. The date of a structural break in the residuals using the standard Quandt (1960) test was significantly confirmed in 2002.

The next step is to test for thresholds, namely ECM_{t-1} and ΔECM_{t-1} in the Enders and Siklos (2001) test. The Enders and Siklos test results suggest a linear cointegration, since the null hypothesis for symmetric adjustment towards the long-run equation cannot be rejected. Therefore, further analysis of individual factors for economic growth as threshold variables is provided using the TECM test. The individual thresholds are considered in the form of levels and first differences. Such an approach indicates whether growth patterns are related to a certain level of a threshold variable or to its dynamics. It corresponds to Enders and Siklos' approach related to ECM_{t-1} and momentum ECM_{t-1}. The number of lags for a given threshold is a subject of estimation and model selection procedure. The TECM results are validated for robustness using the Hansen and Seo (2002) test, which combines the analysis of individual thresholds with the variance-covariance matrix. The TECM and Hansen and Seo test results are presented in Table 3.

Based on Enders and Siklos, Hansen, and Seo tests, the results strongly support linear cointegration for the Israeli economy. As it has been already mentioned, that is reasonable because Israel's economic growth exhibits the path of "hill", which means that before and after a structural break in 2002, its growth rate seems to be stable over time. However, the Tsay test confirmed the extended Enders and Siklos test results revealed two threshold variables related to research and development expenditures, i.e., $logR\&D_{t-2}$ in levels and $\Delta logR\&D_{t-5}$ in differences, supporting threshold cointegration. This conclusion based on the exE-S and Tsay testing results, as well as the TECM model estimation, confirmed that both ECM_{t-1} parameter estimates $\widehat{\rho_1}$ and in $\widehat{\rho_2}$ regimes I and II are negative and statistically significant. They are shown in Table 4.

One more issue arises when further inference is to be made, i.e., the question of exogeneity.

Both threshold variables were checked for strong exogeneity using an inverse Granger causality test (Engle, Hendry and Richard, 1983). The results are as follows: for $logR\&D_t$, the F (3, 28) test showed no causality from $\Delta logGDPpc_t$ up to three lags with the value 2.026 (p-value 0.1327), and for $\Delta logR\&D_t$ the respective result was F (3, 27) =3.5185 (p-value 0.0284). These imply that in levels $logR\&D_t$ is strongly exogenous to $\Delta logGDPpc_t$, while in differences, $\Delta logR\&D_t$ is not. Thus, the two-regime TEC models for two thresholds have been estimated. The model based on the $logR\&D_{t-2}$ threshold outperformed the model assuming $\Delta logR\&D_{t-5}$ as a threshold in both exogeneity and diagnostic tests. It is presented in Table 4.

The differences between regimes are interesting. Regime I (below the threshold value of 1.181 corresponds to the 3.25 R&D expenses as % of GDP) contains ten short-term factors. It exhibits a slower adjustment to the long-run path than regime II because the adjustment coefficient equals -0.025. Regime II (over the threshold) contains eight regressors and the speed of the adjustment is twice as fast as in regime I, with the coefficient estimate of -0.051. In regime I, a positive impact of investments, expenses for tertiary education and public debt can be noticed, corresponding to building the economic resources. The negative impact of migrations and savings, corresponding to negative net migration, is also visible. The increase in TFP does not imply positive *per capita* growth. In regime II, one observes a positive impact of net exports and domestic and foreign investment (I and FDI, respectively). The negative effects of long-term interest rates and expenses for tertiary education are also visible. The long-term interest rate shows fluctuations in financial markets similar to the exchange rate. The increase in tertiary education

Table 4. Estimated TECM model for ΔlogGDPpc in Israel for the period 1980–2019

Dependent variable	Threshold variable		Value of the threshold	
	$logR\&D_{t-2}$		1.181 [exp(1.181) = 3.25]	
$\Delta logGDPpc_t$	No of obs. I = 17		No. of obs. II = 20	
	I regime		*II regime*	
Regressor	Coeff	p-value	Coeff	p-value
Const	0.021	0.000	0.011	0.000
t			0.0003	0.000
ΔLR_t			-0.089	0.001
ΔTFP_{t-1}	-0.118	0.007		
$\Delta logNet\_Exp_t$			0.014	0.001
$\Delta logEXR_t$	-0.014	0.001	0.009	0.000
$\Delta logI_t$	0.044	0.000	0.012	0.001
$\Delta logI_{t-1}$	0.027	0.002		
$\Delta logFDI_t$			0.001	0.005
$\Delta Defl\_GDP_{t-1}$	0.030	0.000		
$\Delta logM_{t-1}$	-0.003	0.023		
$\Delta logTD_t$	0.030	0.001	-0.013	0.082
$\Delta logSAV_{t-1}$	-0.020	0.002		
$\Delta logPD_t$	0.068	0.001		
ECM_{t-1}	-0.025	0.087	-0.051	0.000
AIC		-413.207		
BIC		-395.08		
ARCH LM(4) p-value		0.909		0.389
Ljung- Box p-value	Q(1)	0.097		0.243
	Q(2)	0.249		0.283
	Q(3)	0.277		0.242
	Q(4)	--		0.243

Source: own work

does not contribute to growth in a well-educated society, absorbing and utilizing innovations.

The division into regimes corresponds to the level of R&D$_{t-2}$ equal to 3.25% of GDP. Figure 6 shows two error correction terms, i.e., ρ_1 (below the threshold) and ρ_2 (above the threshold). Regimes correspond to the phases of the economic development of the Israeli economy. The first one starts in 1982 and lasts until 1999, while the second starts in 2000, lasting until 2019, and includes one observation in 1981. In the mid-80s, the decision to promote and invest in innovative sectors of the Israeli economy based on high technologies was made. It was based on the legislation called the Law for the Encouragement of Industrial Research and Development ("the R&D Law" later known as the "Innovation Law") (Dyduch & Olszewska, 2018). In 2000–01 the dot-com bubble burst caused a new phase of economic development (Lach et al. 2008).

The above analysis provides more in-depth insights into earlier findings made by Cohen et al. (1996). It shows that higher R&D expenditures imply a higher *per capita* growth rate in the long run.

As the Hansen and Seo test did not support TECM, but it confirmed a threshold-type asymmetry, another model, which is a stationary TAR specification, was very likely taking the results of testing for a threshold variable. Two estimated TAR models are presented in Table 5.

The estimated TAR models confirmed asymmetry in the short-run dynamics of the Israeli economy according to two threshold variables, i.e., lagged-by-five-years tertiary education expenditures (logTDt-5) and lagged-by-five-years change of global savings (ΔlogSavt-5). Both threshold variables are strongly exogenous with respect to the explained one, with p values 0.4020 and 0.3977, respectively. The models differ in both variables present in regimes and parameters signs. The BIC and AIC values support model I. Both TAR models confirmed that changes in investment stimulate economic growth in the short run. In the model I, negative signs are for changes in ME and R&D. From model II, one can notice that changes in military expenditures, expenses for tertiary education, and long-term interest rates do not accelerate economic growth in the short run. This means that, conditional on a threshold variable, the individual results differ. These models cannot directly compete with the TECM structure, which covers both short- and long-run dynamics of the growth expressed in *per capita* GDP. However, having good statistical properties allows interpreting the impact of particular growth factors within regimes. Compared to TECM, the information criteria of TAR models (BIC and AIC) are higher, favouring the TECM approach.

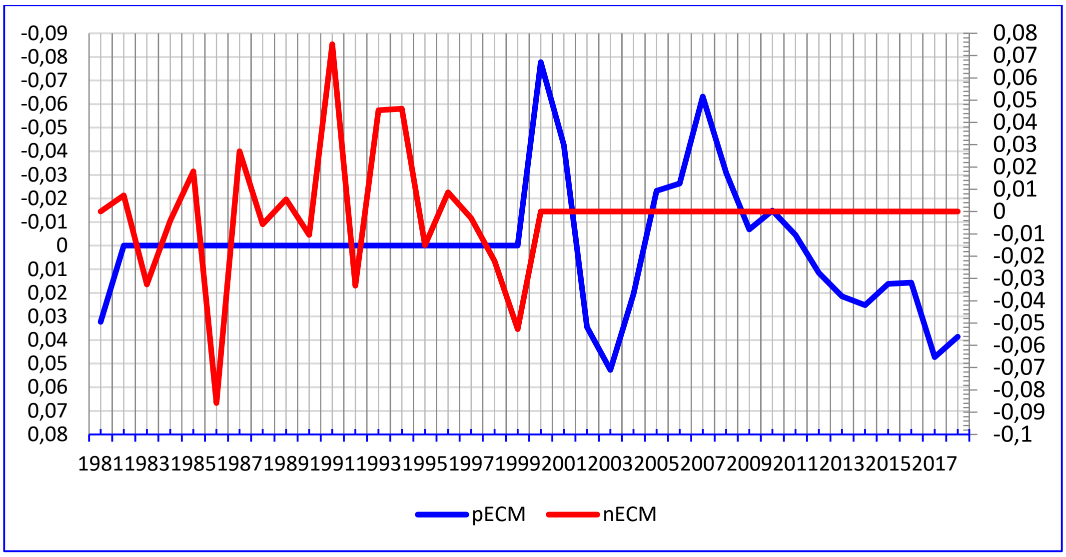

Fig. 6. GDP *per capita* regimes' division according to logR&D$_{t-2}$

Table 5. Estimated stationary TAR models for ΔlogGDPpc in Israel for the period 1980–2019

Dependent variable	Threshold variable		Value of the threshold	
	Model I			
	$logTD_{t-5}$		1.867 [exp(1.867) = 6.468]	
$\Delta logGDPpc_t$	No of obs. I = 23		No. of obs. II = 11	
	I regime		*II regime*	
Regressor	Coeff	p-value	Coeff	p-value
Const	0.004	0.001	0.029	0.000
T			-0.001	0.003
$\Delta logR\&D_t$			-0.017	0.053
$\Delta logME_t$	-0.004	0.054		
$\Delta logTD_t$	0.022	0.001		
$\Delta logI_t$			0.037	0.007
$\Delta logGDPpc_{t-1}$	0.743	0.000		
AIC		-367.101		
BIC		-360.968		
Inverse Granger Non-causality p-value	F(3,27)	0.074		
ARCH LM(4) p-value		0.306		0.350
Ljung- Box p-value	Q(1)	0.127		0.927
	Q(2)	0.196		0.601
	Q(3)	0.247		
	Q(4)	0.287		
	Model II			
	$\Delta logSav_{t-5}$		-0.015 [exp(-0.015) = 0.985]	
$\Delta logGDPpc_t$	No of obs. I = 13		No. of obs. II = 21	
	I regime		*II regime*	
Regressor	Coeff	p-value	Coeff	p-value
const	0.014	0.000	0.014	0.000
ΔLR_t			-0.139	0.001
ΔTFP_t	0.075	0.045		
$\Delta logR\&D_t$			0.013	0.012
$\Delta logME_t$	-0.013	0.017	-0.007	0.085
$\Delta logTD_t$	0.050	0.001		
$\Delta logI_t$	0.020	0.044		
$\Delta Defl\_GDP_t$	0.043	0.001	0.065	0.000
$\Delta logSav_t$	-0.012	0.021	-0.016	0.011
AIC		-349.817		
BIC		-339.595		
Inverse Granger Non-causality p-value	F(3,28)	0.384		
ARCH LM(4) p-value		0.234		0.397
Ljung- Box p-value	Q(1)	0.315		0.925
	Q(2)	0.603		0.995
	Q(3)			0.683
	Q(4)			0.815

Source: own work

5. Discussion

Based on the modelling results and considering the perspective of economic policymaking in Israel, three scenarios are possible. Firstly, based on the Enders and Siklos approach, the linear error correction model is preferred. The linearity hypothesis assumes that there is no driving force for growth acceleration, and the impact of the variables is symmetric around the long run. It enables a gradual growth rate over a certain period in the sample and assumes a similar path out of the sample. This case is not considered in the paper but cannot be excluded. The article focused on finding the incentive for growth acceleration. Thus, the second possible scenario is based on the threshold error correction model with two years lagged R&D as the threshold variable. It means that R&D expenses have the power to accelerate the growth rate around the steady-state represented by the long-run equation presented in Table 2. The policymaker can use the R&D expenses as an instrument of growth acceleration if the policy is focused on this goal. The last scenario refers to the stationary TAR models. They did not refer to the long run but indicated that two potential growth accelerators in the short run are noteworthy, i.e., increased savings or tertiary education expenditures. The impact of savings change is evident from the economic point of view. The result of tertiary education increases growth directly because an educated society is more innovative, so is prepared to induce economic growth. The time lag is essential here; the model shows five years' lag between increasing incentive (TD) and the effect (GDP p.c. growth).

The results obtained for Israel show that the presented approach based on TECM is a valid construction for checking different economic hypotheses. Applying the hierarchical procedure – starting from Enders and Siklos' approach through extended Enders and Siklos as well as Tsay and Hansen and Seo tests – ensures results robustness. The exE-S test allows both ECM and ΔECM, as well as the individual variables to be considered and the threshold variable. Having different model specifications, it is possible to indicate the best one and compare the impact of the same factors from many perspectives. The approach requires relatively long time series, which are not always available. It is noteworthy that the difference between parameter estimates $\widehat{\rho_1}$-$\widehat{\rho_2}$ is not too big in value, although significant. Such a case is typical in economic applications, but when the difference is lower than 0.1, and the number of observations is less than 100, the results of E-S and exE-S tests have insufficient power (Gałecki & Osińska, 2022). Therefore, additional tests are demanded.

The described procedure is based on rigorous statistical testing consisting of (1) data analysis; (2) testing for unit roots (ADF/PP tests); (3) testing for structural breaks (Zivot and Andrews, and Bai and Perron tests); (4) estimation of long-run relationships using OLS and testing for structural breaks in residuals using the Quandt test (Quandt, 1960); (5) testing for threshold error correction form vs linear cointegration (Linear ECM) or vs the threshold stationary model (TAR-X/SETAR-X) in a sequence of tests including the original Enders & Siklos approach (2001) and the exE-S approach (Boehlke et al., 2018; Gałecki & Osińska, 2022); (6) checking for the robustness of the results using the Tsay test and Hansen and Seo test. The model estimation uses the full information maximum likelihood (FIML) method with the Chan procedure (Chan, 1993) to estimate the threshold value. This multistage procedure is universal in modelling asymmetric reactions around the long run and other threshold variables. The results lead to selecting a reasonable model among different model specifications.

6. Conclusion

Israel's economy presents an extraordinary and exciting case for analysing growth and fluctuations. On the one hand, it has very well-developed institutions and systems, a highly literate society, strong R&D, and a high concentration of top innovative companies. In 1980–2019, Israel experienced a stable GDP *per capita* growth rate that exceeded 1.5% on average. The most severe collapse was related to the dot-com bubble at the beginning of the 21st century. Our research indicated that R&D investment has played a role as a driving force of the Israeli economy in the last four decades. Such conclusions are based on earlier literature (e.g., Cohen et al., 1996; Peled, 2001). We applied two tests for the threshold error correction structure of the growth rate, i.e., a classical test of Enders and Siklos (2001) and a modified TECM test proposed by Boehlke et al. (2018). Furthermore, we validated the results with the Hansen and Seo (2002) testing procedure.

The results indicate strong support for a linear cointegration relationship. That is likely because, as already mentioned, the Israeli economic growth exhibits a path of "hill", indicating that, before and after the structural break in 2002, its growth rate seems to be stable over time. However, the results of two tests, i.e., the TECM and Tsay, reveal two threshold variables: i.e., logR&Dt-2 in levels and ΔlogR&Dt-5 in differences supporting the threshold cointegration model. It should also be noted that, in the long-run equation, research and development expenses show a positive impact on economic growth. Conclusions from both the TECM and Tsay tests and the TECM model estimation results confirm that both ECM_{t-1} parameters in the first and the second regimes are negative and statistically significant. AIC and BIC selected the estimated two-regime model with logR&Dt-2 threshold variable as the best one. Granger's non-causality test result supports its choice.

There are interesting differences between Regime I and II. Regime I contains ten short-term factors. It exhibits a slower adjustment to the long-run path than regime II since the adjustment coefficient equals -0.025. Regime II has eight regressors, and the speed of the adjustment is twice as fast as in regime I, with the coefficient estimate of -0.051. In regime I, investments had positive impacts, and expenses for tertiary education and public debt are noticeable, corresponding to the economy's building. The adverse effects of migrations and savings, corresponding to negative net migration, is also visible. As the number of emigrants increases, they take their savings to their new countries. This negatively influences economic processes. Furthermore, the increase in TFP does not correspond to positive *per capita* growth.

In regime II, one observes the positive impact of net exports as well as domestic and foreign investments (I and FDI, respectively). The negative effects of long-term interest rates and expenses for tertiary education are also ascertained. Long-term interest rate shows fluctuations in the financial markets similarly to exchange rate. The increase in tertiary education does not contribute to growth in a well-educated society, adopting and utilizing innovations. This is possible due to the high ratio of people possessing an academic diploma (over 46% of people aged 25-64), which means that the society is highly educated and the marginal effect of education is not so important. The division into regimes corresponds to the level of R&Dt-2 equal to 3.25% of GDP, observed before 1999. Regimes correspond to the phases of the economic development of the Israeli economy and show great efforts toward keeping its highest innovativeness capabilities. For comparison, TAR models were estimated. It can be concluded that the results are sensitive conditionally on the threshold variable in the short run.

The general result is that the applied hierarchical procedure for TECM model construction is robust. It is based on rigorous statistical testing being universal for modelling asymmetric reactions in the long and short run.

7. Notes

1. https://www.technion.ac.il/en/technion-israel-institute-of-technology/
2. U.S. Foreign Aid to Israel; Updated November 16, 2020, Congressional Research Service https://crsreports.congress.gov RL33222, accessed 5.07.2021

Acknowledgement

Financial support from the National Science Centre in Poland (Grant no 2015/17/B/HS4/01000) is gratefully acknowledged.

The authors are grateful to Oded Galor for his inspiring discussion.

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