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Public R&D, Education Spending, and Economic Growth in Finland: Evidence from a Cointegration Analysis

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Abstract:

The Finnish Government Programme identifies investment in innovation and education as central policy objectives for promoting productivity and economic growth. Using Johansen's cointegration methodology (VECM) and annual Finnish data from 1970 to 2024, this thesis estimates the long-term relationships between public R&D, education spending, and GDP, in the context of a small open economy near the technological frontier. The results indicate a positive association between public R&D and GDP, as well as a complementary relationship between public and private R&D. By contrast, no statistically significant long-term relationship is found between education spending and GDP.

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1 Introduction

A key objective of macroeconomic research is to identify the determinants of long-term economic growth in order to guide efficient public policy and investment decisions. In recent decades, attention has particularly been devoted to the role of innovation and human capital, giving rise to the following debates: Does public R&D spending crowd out private R&D, or generate positive externalities and complement it? Does the contribution of human capital diminish as countries approach the technological frontier?

In Finland, innovation and human capital policy have become increasingly central to the country's economic growth strategy. The government of Petteri Orpo has set a target to raise R&D expenditure to 4% of GDP, up from 3.22% in 2024 (Valtioneuvosto 2024). Alongside R&D, education spending has been identified as a driver of long-term productivity growth in the Finnish Government Programme, although it has been subject to cuts as part of measures to stabilize public finances. Historically, both R&D and education expenditure as a share of GDP increased steadily until the early 2000s, followed by a period of stagnation. With the renewed policy efforts of the 2020s, however, R&D and education spending developments have diverged with the former beginning to increase again and the latter declining further. These trends highlight the importance of understanding the relationships between R&D, education and economic growth.

This thesis estimates the long-term effects of public R&D and education spending on GDP in Finland. In addition, the thesis examines how the effects of R&D interact with technology diffusion through imports in a small open economy, and whether public R&D stimulates private R&D investment. Accordingly, I address two main research questions: (1) How have public R&D and education spending affected Finnish GDP in the long term, and (2) What is the relationship between public and private R&D spending?

This thesis is grounded in endogenous growth theory, in which long-term output growth is driven by technological progress and human capital accumulation rather than by exogenous factors. Within this framework, public policy plays a central role in shaping productivity through investment in innovation and education. Public R&D spending directed toward fundamental research generates positive externalities for the broader economy, while support for private innovation alleviates firms' exposure to risk and cash constraints. Education spending increases the human capital stock, thereby enhancing the capacity of the labor force to adopt new technologies.

The effects of public R&D and education spending on GDP remain subject to debate in empirical literature. While some prior studies have found a positive association between public R&D and GDP, evidence on the interaction between public and private R&D remains limited. Moreover, these relationships have not been extensively examined in Finland or in other small open economies. Existing research on education spending and GDP in Finland relies on long time series encompassing substantial institutional changes. This thesis contributes to the literature by focusing on more recent data and by incorporating technology diffusion through imports.

The empirical analysis is based on annual data from Statistics Finland and the World Bank. The R&D-related research questions are examined over the period 1975-2024, while education-related analysis covers 1970-2022. All variables are expressed in real terms and in logarithms, allowing the results to be interpreted as elasticities. The analysis uses a cointegration framework and a Vector Error Correction Model (VECM) to capture the long-term equilibrium relationships of the variables, while allowing for short-term feedback effects.

The results indicate a positive association between public R&D and GDP and suggest complementarity between public and private R&D. A 100% increase in public R&D is associated with a 4% higher GDP. The findings are consistent with previous evidence from the Netherlands and the United States. By contrast, no statistically significant long- or short-term relationship is found between education spending and GDP. This deviation from prior Finnish evidence may reflect diminishing marginal returns to education spending, although alternative explanations regarding model specification cannot be ruled out.

The thesis is structured as follows. Section 2 reviews the relevant theoretical and empirical literature. Section 3 describes the data. Section 4 presents the methodology. Section 5 reports and discusses the empirical results. Finally, Section 6 concludes.

2 Related Literature

This section reviews the theoretical and empirical literature on the relationship between public R&D, education spending and economic growth. It begins with a discussion of endogenous growth theory, highlighting the mechanisms through which public R&D and education spending affect the GDP. The literature suggests that public R&D generates positive externalities through advances in fundamental research and may complement private R&D by mitigating risk and fixed-cost barriers to innovation. Education spending, in turn, increases the human capital stock, resulting in higher productivity and raising long-run output.

The section then reviews empirical literature studying the effects of public R&D and education spending on GDP, with particular attention to methodology, data, and variable specification. A common feature of this literature is that public R&D, education and GDP are often jointly determined in a dynamic system, highlighting the necessity to account for endogeneity.

2.1 Endogenous Growth Theory

The Solow model (1957) describes the contribution of technical change to aggregate output growth. With diminishing marginal returns to inputs, labor and capital, long term steady state output growth originates strictly from exogenous technical change: $F = (K, L, A)$.

Barro's (1990) endogenous growth model rationalizes Solow's (1957) exogenous technical change. Productivity growth occurs as a consequence of rational policy decisions affecting the human capital stock incorporated into the capital stock, allowing the model to drop the exogenous term: $F = (K, L)$. For Barro (1990), increases in human capital are the main driver of long term output growth. Diminishing returns of physical capital are therefore maintained from Solow (1957), where as human capital may endow constant or increasing returns.

Howitt & Aghion (1998) diverge from Barro (1990) and state that also the physical capital matters in the long run. They note that technology advancing innovation is primarily undertaken by the capital intensive R&D industry. Within this framework, physical capital and human capital determine the steady state GDP together, with unilateral movements exhibiting decreasing marginal returns and bilateral increases exhibiting constant or increasing returns.

Acemoglu et al. (2006) suggest that countries further from the global technology frontier are adoption-intensive, investing in human capital to enable workers to adopt existing technologies. When approaching the technology frontier, countries transition from adoption towards innovation of original technologies in order to remain on the convergence path towards the frontier. For this end, countries' investment increasingly engages in R&D, and physical capital ceases to be indifferent for steady state growth (Howitt & Aghion 1998).

According to Hölzl & Janger (2014), in 2006, Finland was among the EU countries closest to the technological frontier. This implies that over time Finland has transitioned from an adoption-intensive to an innovation-intensive economy. Consequently, endogenous growth theory provides a well-suited framework for identifying the determinants of long-term GDP in Finland.

2.1.1 Public R&D and the GDP: Externalities and Complementarity

Public R&D activity differs highly from its private counterpart. Broadly, it can be divided into fundamental research and support for private R&D. The latter includes direct subsidies to private R&D initiatives, interest-free and conditionally reimbursable loans, and venture capital, as well as indirect measures such as tax credits, deductions, and accelerated depreciation of R&D related capital assets.

Private R&D is driven by profit incentives and tends to emphasize scalable products with rapidly realizable returns to investment. In contrast, fundamental research generates knowledge with limited immediate commercial applicability. Its produce is often non-excludable or partially excludable, thereby resembling a public good that firms can exploit. Therefore, its contribution to GDP materializes indirectly over a long time horizon, emerging gradually as new technologies diffuse and are applied in production, thus shifting the technological frontier of entire industries. This constitutes the first transmission mechanism of public R&D into GDP: positive knowledge externalities. (Griliches 1979, Acemoglu et al. 2006).

The second transmission mechanism operates through the complementary role of public support for private R&D. Private R&D is inherently high-risk, with many innovations failing to generate returns. Firms mostly rely on internal funding due to the risk and limited profit appropriability of external investors. The fixed costs of R&D can be prohibitive for cash-constrained small and medium-sized firms. Large firms are better able to diversify risk across a wide R&D portfolio. (Czarnitzki & Hottenrott 2011, Zhang 2015).

Moreover, because of limited profit appropriability from innovation caused by imitation of competitors, private R&D spending tends to lie below its socially optimal level (Becker 2015). A subsidy to complement firms' own R&D spending can therefore stimulate investment towards the social optimum, conditional that the funding is effectively targeted (Becker & Pain 2008, Shin et al. 2019). E.g., Czarnitzki & Hottenrott (2011) show that private R&D activity increases following the introduction of such subsidies.

2.1.2 Education Spending and the GDP: Human Capital

Education spending affects long-term GDP primarily through its impact on the aggregate human capital stock of the economy (Barro 2001). In standard growth models, output per capita depends on productivity per labor unit, which in turn is influenced by the human capital stock. Public investment in education therefore plays a central role in shaping labor productivity and driving GDP growth.

The transmission of education spending on GDP varies across theoretical frameworks. In a Barro-style model (1990), the marginal returns to education spending are constant, indicating a homogeneous slope between investment and growth. In contrast, models emphasizing distance to the technological frontier suggest that the marginal returns to education spending are increasing in the country's distance to this frontier, as they can grow rapidly with adaption and imitation of existing technologies (Acemoglu et al. 2006).

2.1.3 Public Spending and Growth: Focus on R&D and Education

In addition to R&D and education, public spending encompasses a wide range of policy domains, many of which may influence long-term GDP, including healthcare, infrastructure, and legal institutions. They contribute to the economy by supporting a healthy labor force, enabling efficient economic activity and trade, and ensuring the enforcement of property rights.

Institutional factors are widely recognized as key determinants of cross-country differences in long-term GDP growth (Acemoglu et al. 2008). However, the empirical strategy of this thesis abstracts from institutional variation and focuses on the channels suggested by endogenous growth theory. In this framework, productivity is driven by technological progress and human capital accumulation, primarily affected by R&D and education spending in public finances.

2.2 Empirical Literature

The estimated effect of public R&D spending on GDP is variant in empirical literature. Studies applying panel regressions generally report negligible GDP effects, whereas studies using cointegration methods, which distinguish the long- and short-term dynamics, find positive estimates. On the contrary, education spending is widely considered as a driver of GDP growth in both panel regressions and cointegration models.

2.2.1 Public R&D and GDP

To my knowledge, no previous studies estimate the impact of public R&D on Finnish GDP in the long term. My thesis aims to fill this gap in literature and provide notion for future public R&D policy. The relevant literature analyzing empirically the effect of public R&D on GDP is summarized in Table 1.

In a recent Dutch study, Soete et al. (2020) find that public R&D had a positive long term effect on GDP and a complementary effect on private R&D. They detect multiple dynamic relationships between public and private R&D, GDP and foreign R&D stocks, highlighting the necessity of a dynamic multi-equation model for correct identification. Notably public R&D is associated with an increase in long term GDP. Furthermore, public R&D is weakly exogenous in the equation describing the dynamics between public and private R&D, and private R&D respectively relates to an elevation in the GDP. Therefore, public R&D grows with the GDP both directly and indirectly through the complementary effect in private R&D.

Table 1: The Effect of Public R&D Spending on GDP Growth

Authors	Countries	Period	Methodology	Effect Variable	Result
Bassanini et al. (2001)	14–17 OECD Countries	1981–1998	Panel Regression	Spending (% of GDP)	Negative
Goel et al. (2008)	USA	1953–2000	ARDL	Spending (% of GDP)	Positive
Soete et al. (2020)	Netherlands	1968–2014	VECM	Spending (Stock)	Positive
Szarowska et al. (2017)	20 EU Countries	1995–2013	GMM	Spending (% of GDP)	Positive

Additionally, Goel et al.'s (2008) findings from the USA show that public R&D increases with the GDP in the long-term and speak against public R&D crowding out private R&D. Applying an Auto Regressive Delayed Lags (ARDL) model, Goel et al. (2008) estimate that out of the aggregate of US R&D expenditure, public R&D composes the GDP enhancing fraction in the long-term, where as private R&D has a negative coefficient. While the VECM of

Soete et al. (2020) explicitly assesses all feedback mechanisms across the variables, the ARDL model evaluates only one potential co-integrating relationship. Subsequently, the potential complementary relationships are left unpronounced. In the empirical section, I therefore choose to follow Soete's (2020) VECM approach.

In a panel regression of 17 OECD countries, Bassanini & Scarpetta (2001) estimate that public R&D has a negative effect on GDP, crowding out private R&D in the capital markets. They note that their regression neglects the plausible co-integrating relationships of the variables in the long term equilibrium, most notably that of public and private R&D, and therefore the positive externalities that public R&D might emit are potentially embedded in the coefficient of private R&D, which is found to be largely positive. As stated in Soete et al. (2020), the complementary effect [positive externalities for Bassanini & Scarpetta (2001)] of public R&D on private R&D is essentially missing unless a dynamic multi-equation is applied.

Additionally, Bassanini & Scarpetta (2001) raises the issue of trade openness in estimating the GDP effect of public R&D spending. Their coefficient of total R&D spending on GDP diminishes, despite still being significantly positive, when an index of trade openness is included to the regression. This demonstrates how trade spreads technology and ideas over nation borders. High level of trade openness might cause spillovers of foreign technology and human capital, thereby biasly inflating the presumed attribution of domestic R&D expenses in GDP growth (Bustos et al. 2007). Failure to control for trade openness might thus inflate the marginal GDP increase attributed to R&D spending. This becomes especially pronounced with smaller trade dependent nations, such as Finland.

Neither the VECM model of Soete et al. (2020), nor Goel et al.'s (2008) ARDL model control for trade openness. However, with the USA situated on top of the global technology and research frontier, the necessity to control for trade openness might be alleviated. Soete et al. (2020) constructs foreign R&D capital stocks to consider similar effects. They assume that countries generally concentrate their R&D efforts into similar objectives, whereby simultaneously performed R&D across multiple countries has a smaller marginal produce than circumcised efforts undertaken by an individual country. However, if these efforts are assumed to be heterogeneous across countries, the trade openness index might prove a more suitable control variable. Therefore, to study the effect of public R&D on Finnish GDP, I include an index of trade openness into the VECM.

Finally, Szarowská (2017) estimates a GDP enhancing long term effect of public R&D from a panel of EU countries. The paper builds on the Generalized Method of Moments (GMM) model, a suitable method, as it particularly facilitates calibrating with endogenous macro variables. However, the model falls short in distinguishing long term structural effects and short term business cycle effects. Szarowská (2017) lists this differentiation as a direction for future research, noting further the general heterogeneity issue in panel estimations.

2.2.2 Education Spending and GDP

The effect of education spending on GDP has been extensively studied in both cross-sectional multi-country analyses (Barro 1990, Bassanini & Scarpetta 2001, Acemoglu et al. 2006, Contreras et al. 2025), and in single-country studies (Kokkinen 2012, Lupu et al. 2023, Mabrouki 2023), with recent work predominantly utilizing the ARDL and VECM models to detect the dynamic relationships. While the results are principally positive, some of the studies are inconclusive, mainly because the time series are unstationary at level and first lag.

Table 2 contains a summary of the single-country literature regarding education spending and GDP. Previous long term estimates of the effect of education spending on Finnish long term GDP are provided by Kokkinen (2012) and Pohjola (2017). In his dissertation, Kokkinen (2012) deduces Finnish human capital accumulation from public education expenditure and estimates a dynamic long term relationship between GDP and education spending. His VECM finds two-dimensional granger causality, where economic growth facilitates expanding the capacity of the education system, which in turn increases the GDP through labor productivity. Additionally, from the average of 2.1% yearly GDP growth between 1861-2015, Pohjola (2017) accounts 0.6 percentage points to education spending, demonstrating a pronounced positive long term effect.

My thesis aims to complement these Finnish studies by commenting on the contemporary relationship of education spending and GDP. Pohjola (2017) solely regards the aggregate effect of his research period 1860–2015. The most recent time series in Kokkinen (2012) runs from 1946 to 2000, during which large socio-economic changes and education reforms have taken place. Naturally, 1970–2022 contains similar institutional shifts, but arguably of smaller magnitude than those undertaken particularly in the immediate post-war Finland struggling to raise from poverty.

Table 2: The Effect of Public Education Spending on GDP Growth: Single-Country Studies

Authors	Countries	Period	Methodology	Effect Variable	Result
Annabi et al. (2011)	Canada	1995–2002	CGE	School Years	Inconclusive
Kiran et al. (2014)	18 Latin American Countries	1970–2009	ARDL with Structural Break	Spending (% of GDP)	Positive or Inconclusive
Kokkinen (2012)	Finland	1910–2000	VECM	Human Capital	Positive
Lupu et al. (2023)	11 Eastern European Countries	1990–2020	ARDL with Structural Break	Spending (% of GDP)	Positive or Inconclusive
Mallick et al. (2015)	India	1951–2012	VECM	Spending	Positive
Pohjola (2017)	Finland	1860–2015	Growth Accounting	Human Capital	Positive

Mallick & Dash (2015) adopt Johansen's Cointegration and Granger causality tests, and estimate positive unidirectional long term causality from education expenditure to GDP in India employing data from 1951 to 2012. The rigorousness of their VECM model allowing multi-equation co-integration and their extensive data availability reinforce the result.

Lupu et al. (2023) estimate positive effects of public education expenditure on GDP with the ARDL model in several Eastern European countries. The study is inconclusive for some nations, likely due to an insufficient time frame (30 years) for establishing a long term relationship. From a sample of Latin American countries, Kiran (2014) reports similarly mixed outcomes of education spending on long-term GDP using the ARDL model.

Lupu et al. (2023) and Kiran (2014) apply a structural break into the ARDL model to divide the research period in fractions with a dummy variable based on shifts in the political regime affecting education and economic growth, the shift to the post-Soviet education system in Eastern Europe and wide modernization of education systems in Latin American. Institutional shifts of this magnitude, that would affect the transmission of human capital to GDP are not assumed to have occurred in Finland during the research period of this thesis, 1970–2022.

The results of Lupu et al. (2023) and Kiran (2014) nevertheless demonstrate the variation in the transmission of education spending on GDP. This is conventionally viewed to arise either from differing institutional characteristics of countries, affecting their potential ability to convert human capital into stable growth, or from diminishing marginal return to human capital, as the initial levels of human capital accumulation vary across countries (Johnson 1970, Barro 1990, Acemoglu et al. 2014). This captures the paradoxical difficulty of long-term cointegration analysis. Long periods of data are required so the long term effects may play out. If institutional changes are omitted, however, education or other variables might absorb unintended institutional effects when estimating over long a time sample. Similarly, assuming diminishing returns of human capital, in shorter data periods, the differences in magnitude of the coefficients might rather depict the stage at which human capital accumulation lays during the research period, than inhibit capabilities in canalizing human capital to GDP growth. This highlights the necessity for long periods of data and institutional stability within the research period.

Cross-sectional studies regarding education spending and GDP are summarized in Table 3.

Again, cross-sectional estimations should be reviewed cautiously because of the plausibly erroneous institutional homogeneity assumption (Soete et al. 2020). Barro (2001) measures the impact of the quantity and quality of education on GDP growth by a cross-sectional panel regression of OECD countries with school attainment and test scores as independent variables. He finds positive results for both of these potential determinants of growth, apart from the negative coefficient of female school attainment. Thereby, he deducts that highly educated females are an insufficiently utilized resource in the economy globally.

Table 3: The Effect of Public Education Spending on GDP Growth: Cross-Country Studies

Authors	Countries	Period	Methodology	Effect Variable	Result
Acemoglu et al. (2006)	OECD	1965–1995	Cross-Sectional Regression	School Years	Positive
Barro et al. (2001)	100 Countries	1960–1995	Panel Regression	School Atteinment (Primary & Secondary)	Inconclusive (Primary), Positive (Secondary)
Bassanini et al. (2001)	21 OECD Countries	1971–1998	Panel Regression	School Years	Positive
Contreras et al. (2025)	107 Countries	1970–2019	CS-ARDL	Spending (% of GDP)	Positive
Mabrouki et al. (2023)	Scandinavian Countries	1990–2019	CS–ARDL	Spending (% of GDP)	Negative

Mabrouki (2023) applies the cross-sectional ARDL approach for Scandinavian countries and finds a negative effect from education expenditure to GDP. Hís findings suggest that education expenditure is excessive and above the productive margin in Scandinavian countries.

Ultimately, Contreras et al. (2025) conduct a cross-sectional study with a large sample of OECD countries and estimate a significant positive effect of public education expenditure on GDP. Employing a cross-sectional ARDL model, they distinguish between short-term demand effects and long-term structural impact, both of which are found to be positive, in line with earlier cross-sectional studies of Acemoglu et al. (2006) and Bassanini & Scarpetta (2001).

3 Data

Table 4 describes the data utilized in this thesis. Employed datasets are provided online by Statistic Finland and World Bank, with a few missing years of education spending filled manually from Statistics Finland's publication "Kansantalouden tilinpito 1981". GDP, R&D variables, investment, imports and education spending were inflated to real figures with the consumer price index, 2010 as base year. Estimation was performed with all variables expressed in natural logs. Imports were transformed to an index to reflect the openness of the economy. All data manipulation and statistical analysis was conducted in R.

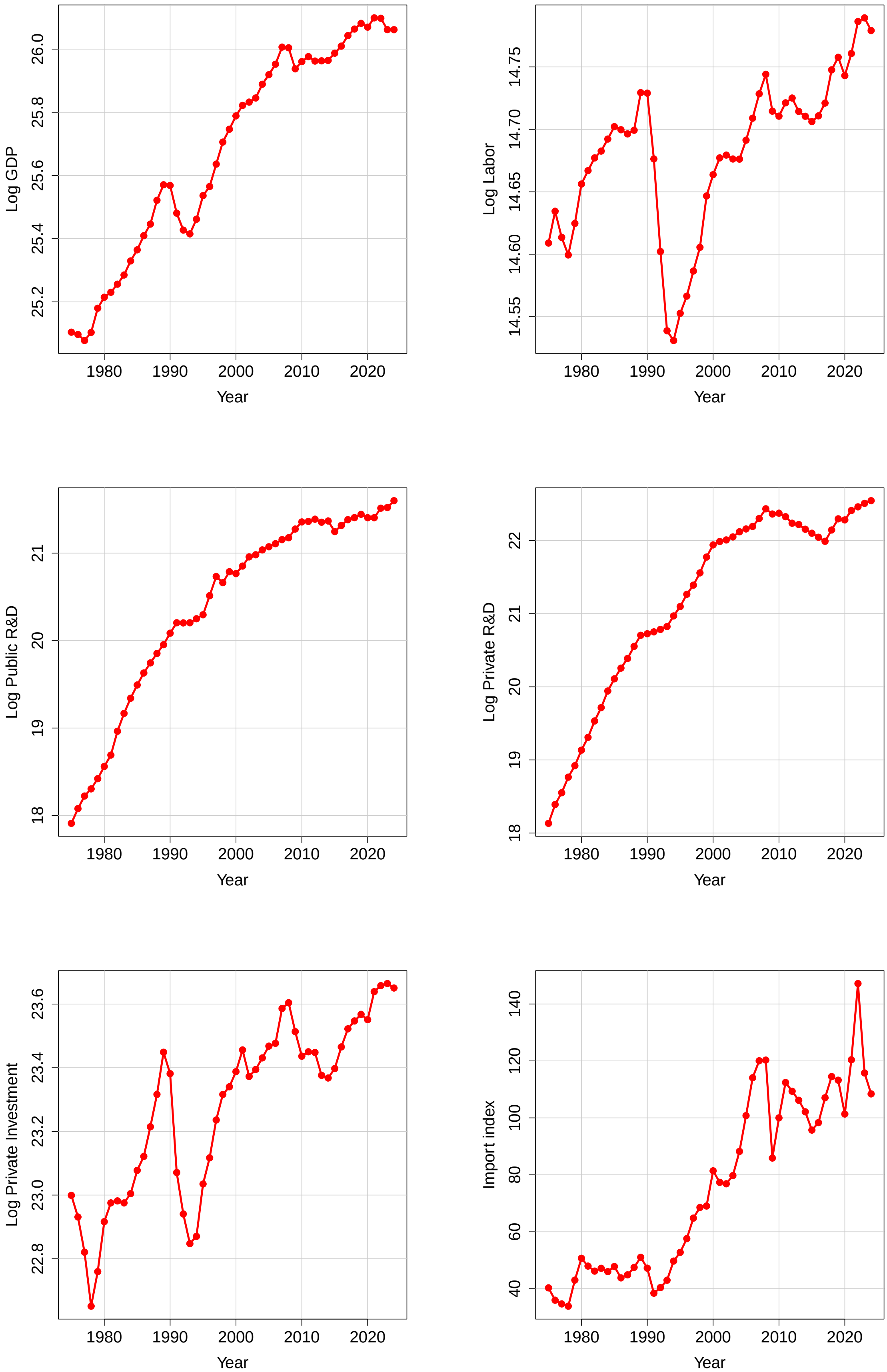
Table 4: Data

Variable	Source	Period	Max	Mean	SD	Min
GDP	Statistics Finland	1970–2024	216,100	142,700	49,819.69	60,920
Education Spending	UNESCO	1970–2018	7.496	5.887	0.803	4.482
Public R&D GFCF	Statistics Finland	1975–2024	1,885	1,141	575.53	262.9
Private R&D GFCF	Statistics Finland	1975–2024	5,594	2,803	1,717.05	328.6
Private Investment	Statistics Finland	1975–2024	18,940	13,290	3,400.91	6,874
Labor	Statistics Finland	1975–2024	2,647,875	2,359,501	156,961	2,045,000
Technology Import Index	Statistics Finland	1975–2024	147.18	75.78	31.31	33.86

3.1 R&D Spending in Finland: 1975-2024

Figure 3 illustrates the development of GDP per capita and public and private R&D gross fixed capital formation in Finland during the years 1975-2024. Additionally, the trends of labor, gross private investment and imports, indexed to the base year 2010, are presented, as they will enter the empirical estimation regarding R&D in Section 6.

Figure 1: Trends of GDP, R&D, Investment and Imports

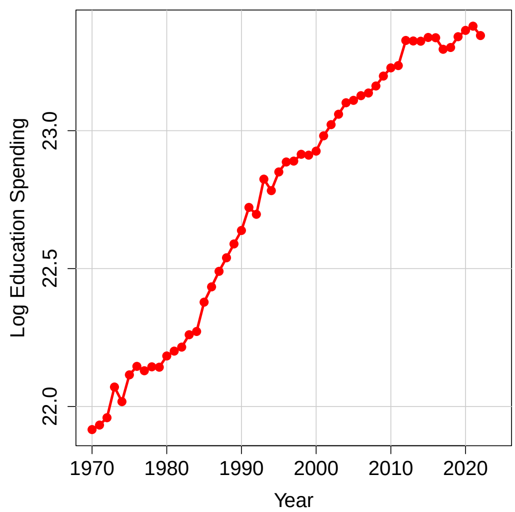


Technology Imports contain the merchandise denoted by Statistics Finland as "Investointi-tavarat", i.e. capital intensive machinery and equipment. In this thesis, they are used to approximate the part of imported productivity enhancing technological innovations in Finland. I include them into the empirical model as a potential substitute to the innovations developed in domestic R&D. Gross private investment respectively denotes the capital intensive machinery and equipment investment in the private sector. The fraction of this spending devoted to R&D is omitted from the private investment variable to explicitly distinguish between private investment and private R&D.

3.2 Education Spending in Finland: 1970-2022

Figure 4 depicts the development of education spending in Finland between 1970-2022, the years for which data are available.

Figure 2: Trend of Education Spending



Education spending has been growing since 1970 with the most rapid expansion throughout the 1980's, some deceleration in the 1990's and 2000's and a stagnation in the 2010's. The trend in education spending follows similar patterns with the GDP, from fast initial growth all the way to the contemporary slowdown.

4 Methodology

Macroeconomic time series, such as those used in this thesis, often exhibit autocorrelation and are typically non-stationary in levels. Economic theory further suggests that these variables are likely endogenous.

To address these data characteristics, I apply Johansen's procedure (1991), a standard approach for testing cointegration of non-stationary time series. Cointegration means that two or more non-stationary time series move together in the long-term, so that a linear combination of them is stationary, after the removal of short-term fluctuations. If identified correctly, this linear combination can then be interpreted as a long-term equilibrium.

Unlike traditional instrumental variable methods, Johansen's test treats all variables as endogenous (Soete et al. 2020). Economic interpretation is therefore derived by renormalization of the cointegration vectors and by imposing linear restrictions. This approach also facilitates testing weak exogeneity of variables to potentially identify causal directions in the long-term equilibrium (Soete et al. 2020).

The section proceeds as follows. First, I present the unit root tests applied to each time series. VAR representation and the tests for detecting optimal lag length are introduced. Then, I present Johansen's test, which is used to identify the cointegration rank. Cointegration rank denotes the number of cointegrated long term relationships between variables. Next, I describe the Vector Error Correction Model, which estimates the cointegration vectors consistent with the cointegration rank chosen by Johansen's test. Finally, I elucidate how renormalization and linear restrictions are applied to identify the cointegration space.

4.1 Unit Root and Lag Length Tests

Johansen's procedure requires variables integrated of order one, $I(1)$ (Lütkepohl 2005). To test the order of integration, this thesis employs the Augmented Dickey-Fuller (ADF) and

Phillips-Perron (PP) tests. They both evaluate the null hypothesis of a unit root against the alternative hypothesis of stationarity, $H_0 : \gamma = 0$, against $H_1 : \gamma < 0$ in the regression:

$$\Delta Y_t = \alpha_0 + \alpha_1 t + \gamma Y_{t-1} + \sum_{i=1}^{p} \beta_i \Delta Y_{t-i} + \epsilon_t, \tag{1}$$

for each time series variable Y_t, with a deterministic time trend t, first-difference operator Δ, lag length p and a white noise error term ϵ_t (Dickey & Fuller 1981, Phillips & Perron 1988). Deterministic time trend is included into the test in levels to account for stationary around a trend.

Following confirmation that no variable is stationary in levels, $I(0)$, the ADF and PP are repeated in first differences to verify stationarity in $I(1)$. In this regression, the time trend is excluded:

$$\Delta^2 Y_t = \alpha_0 + \gamma \Delta Y_{t-1} + \sum_{i=1}^{p} \beta_i \Delta^2 Y_{t-i} + \epsilon_t, \tag{2}$$

for each time series variable Y_t, with a first-difference operator Δ, lag length p, a white noise error term $\epsilon_t \sim \text{i.i.d.}(0, \sigma^2)$ and the same null and alternative hypotheses as above (Dickey & Fuller 1981, Phillips & Perron 1988).

Besides preserving degrees of freedom, lag length selection for Johansen's test should aim to minimize residual autocorrelation (Soete et al. 2020). The Akaike Information Criterion (AIC) and Final Prediction Error (FPE) are therefore favored, as they provide a more flexible lag structure in comparison to Bayesian Information Criteria (BIC), which penalizes model complexity. These criteria are estimated from the vector autoregressive (VAR) model:

$$X_t = A_1 X_{t-1} + \cdots + A_p X_{t-p} + \epsilon_t, \tag{3}$$

where $X_t = [X_{1t}, ...X_{kt}]$ is a $k \times 1$ vector of endogenous time series variables, A_i are $k \times k$ coefficient matrices, p denotes lag order, and $\epsilon_t \sim \text{i.i.d.}(0, \sigma^2)$ is a white noise error term.

Unit root test results are presented in Panel A1 of Appendix A, while lag length test results are reviewed in Panel A2.

4.2 Trace Test

The core of Johansen's procedure is the trace test for cointegration Johansen (1991). The test is based on a Vector Error Correction Model (VECM), which is obtained by rewriting the level VAR model in first differences. Consider the VAR(p) model from Equation (3). Subtracting X_{t-1} from both sides yields:

$$\Delta X_t = (A_1 - I)X_{t-1} + A_2 X_{t-2} + \cdots + A_p X_{t-p} + \epsilon_t \tag{4}$$

$$\Delta X_t = (A_1 - I)X_{t-1} + A_2(X_{t-1} - \Delta X_{t-1}) + \cdots + A_p(X_{t-1} - \sum_{j=1}^{p-1} \Delta X_{t-j}) + \epsilon_t. \tag{5}$$

Collecting the level and difference terms separately yields:

$$\Delta X_t = (\sum_{i=1}^{p} A_i - I)X_{t-1} - \sum_{i=2}^{p} A_i \sum_{j=1}^{i-1} \Delta X_{t-j} + \epsilon_t. \tag{6}$$

Define $\Gamma_i = -\sum_{j=i+1}^{p} A_j$, $i = 1, \cdots, p-1$, as coefficient matrices describing the short-term dynamics, and $\Pi = \sum_{i=1}^{p} A_i - I$ as the coefficient matrix of the long term equilibrium. The rank of Π determines the number of cointegrating relationships. The VECM representation can then be written as:

$$\Delta X_t = \Pi X_{t-1} + \sum_{i=1}^{p-1} \Gamma_i \Delta X_{t-i} + \epsilon_t. \tag{7}$$

The objective of the trace test is to determine the rank $r = \text{rank}(\Pi)$. The null hypothesis of the trace test is defined as $H_0 : r \leq r_0$ against the alternative hypothesis $H_1 : r > r_0$, for $r_0 = 0, 1, \cdots, k-1$. The test is performed repeatedly, increasing r_0 until the null hypothesis cannot be rejected. Test statistics are compared with the critical values tabulated in Johansen (1988).

If all variables are stationary in levels, the rank equals the number of variables, $r = k$. If the rank is zero, $r = 0$, cointegration is absent. If the rank is nonzero but strictly less than the number of variables, $0 < r < k$, cointegration exists.

The results of the trace test are reported in Panels B1 and B2 of Appendix B.

4.3 VECM and the Identification of the Cointegration Space

The coefficients of long-term equilibrium, speed of adjustment and short-term response are estimated from the VECM using the R function "cajorls" from the "ur.ca" package. These results are provided in Table C1 of Appendix C. β-coefficients describe the long-term equilibrium, while α-coefficients denote the speed of adjustment from short-term deviations towards the long-term equilibrium. To interpret the results of this unrestricted VECM, some additional identification steps are required.

The cointegration space is uniquely identified by imposing $r \times k$ number of restrictions on the β-coefficients of the cointegration vectors. These restrictions consist of normalizing the cointegration vectors and imposing linear restrictions. Normalization means setting one coefficient in a cointegration vector to 1. Linear restriction sets the β-coefficient to 0. The steps to renormalization and the results of the linear restriction tests are reported in Appendix D.

Furthermore, linear restrictions are applied jointly to the β-coefficients across cointegration space to test the relevance of each variable in the long-term equilibrium. T-statistics are also calculated for the α coefficients, and corresponding p-values are extracted. A statistically significant t-statistic implies that a variable adjusts to shocks in other variables. A non-adjusting variable is weakly exogenous, driving the long-term equilibrium rather than adjusting to deviations.

Overall, each cointegration vector must carry at least one variable with a statistically significant and negative α-coefficient. Conversely, no force reinstates equilibrium from deviations, rendering the VECM unstable and all interpretations invalid.

5 Results

This section presents the empirical results of this thesis. First, the primary results for R&D are reviewed, followed by the results regarding education. I then report the results of some standard robustness checks of VECM estimation. Finally, the findings are evaluated in relation to my research questions, previous empirical literature and endogenous growth theory, and the limitations of this study and potential directions for future research are discussed.

5.1 Public R&D and GDP

Table 5 reports the normalized restricted VECM results for R&D. The Error Correction Terms, ECT_i contain the long-term equilibrium β-coefficients, while the corresponding speed of adjustment α-coefficients are provided in parentheses. The initial unrestricted VECM is presented in Appendix C, while Appendix D shows the steps to renormalization and the rationale of the imposed set of linear restrictions.

Table 5: Normalized Restricted VECM: R&D

	GDP	Public R&D	Private R&D	Investment	Labor	Imports	Trend
ECT1	1.000	-0.038	-0.012			-0.009	-0.01
	(-0.183)*	(-0.387)**	(-0.368)*			(0.001)	
ECT2		-1.434	1.000		0.098	-0.016	0.033
		(1.071)	(-8.523)*		(-1.182)	(-0.928)	
ECT3		-0.268		1.000	-2.223	0.004	
		(-0.263)		(-2.417)**	(0.312)	(0.249)	

Significance level of the t-test on an α- coefficient is denoted by *, **, and ***, at the 10%, 5%, and 1% significance levels respectively. A variable with a statistically insignificant speed of adjustment coefficient is interpreted weakly exogenous in the particular ECT.

Equation 8, representing ECT_1 normalized to GDP, indicates that R&D spending is positively associated with long-term GDP. Public R&D exhibits an approximately fourfold larger association than private R&D. Specifically, a 100% increase in public R&D is associated with an approximately 4% higher level of GDP in the long term, whereas a corresponding increase in private R&D is associated to a 1% increase in GDP.

$$GDP = \underset{**}{0.04\, RD_{\text{public}}} + \underset{*}{0.01\, RD_{\text{private}}} + 0.01\, Imports + 0.01\, Trend \tag{8}$$

Significance level of the β-coefficients:: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.10$.

The α-coefficients for GDP and R&D are statistically significant and negative, denoting that these variables stabilize the system by adjusting to deviations from the long-term equilibrium. This suggests that the dynamics of GDP and R&D are multidirectional. Therefore, the direction of causality cannot be established. Capital intensive technology imports have a statistically insignificant β-coefficient, which implies no evidence that technology-diffusing imports would contribute to long-term GDP.

Equation 9 displays ECT_2 normalized to private R&D, suggesting a positive association of public and private R&D. Public R&D is weakly exogenous and does not adjust to shocks in other variables. Labor and imports are also non-adjusting, and therefore, private R&D is the sole stabilizing variable in ECT_2. This implies that, in addition to the direct positive association between public R&D and GDP observed in Equation 8, public R&D is also indirectly related to GDP via its association with private R&D.

$$RD_{\text{private}} = \underset{***}{1.43\, RD_{\text{public}}} - \underset{***}{0.1\, Labor} + \underset{***}{0.02\, Imports} - 0.03\, Trend \tag{9}$$

Significance level of the β-coefficients:: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.10$.

Finally Equation 10 describes a reduced form long-term investment function, where private investment is determined by scale and innovation. Labor is associated with an approximately twofold increase in private investment, while Public R&D has a smaller positive association. Investment has a statistically significant and negative α-coefficient, whereas labor and public R&D are weakly exogenous, indicating that they drive the long-term equilibrium level of investment in this equation.

$$\underset{***}{} \quad Investment = \underset{***}{2.22}\, Labor + \underset{***}{0.27}\, RD_{\text{public}} \tag{10}$$

Significance level of the β-coefficients: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.10$.

5.2 Education Spending and GDP

Education spending and GDP do not exhibit a cointegrated long-term relationship. Therefore, a VAR in first differences was estimated, as reported in Table 6 below.

Table 6: VAR in 1st Differences: Education

	GDP_{t-1}	Education $Spending_{t-1}$	Constant
$\mathbf{GDP}_t$	0.512	0.051	0.010
	(0.126)***	(0.123)	
$\mathbf{Edu}_t$	0.108	-0.300	0.034
	(0.145)	(0.141)**	

GDP and education spending are largely driven by their own past values. GDP is highly persistent, with a 1% increase in the last period associated to a 0.5% increase in the current period. By contrast, education spending exhibits mean reversion, where a 1% increase in the past period is related to a 0.3% decrease in the current period. Cross-variable effects are statistically insignificant. Therefore, the analysis does not provide evidence of a dynamic relationship between education spending and GDP in either the short or the long term.

5.3 Robustness Analysis

Figures E1–E3 in Appendix E plot the residuals of the cointegration vectors, displaying white noise resembling fluctuation after the removal of deterministic trends. Partial autocorrelation functions (PACF) of the residuals, presented in Figures E4–E6, are consistent with the results of the Portmanteau test: autocorrelation is elevated at the first lag, but falls within the significance bounds for subsequent lags. Additionally, the Phillips-Perron test, applied to each residual, confirms the stationarity of the cointegration vectors.

Linear restriction tests were performed on the three cointegration vectors regarding R&D. Results, presented in Table E1 of Appendix E, indicate that all variables are necessary to explain the long-term equilibrium and none may be excluded without significantly altering the model. Joint restriction tests on GDP and labor, and on public and private R&D – variables exhibiting roughly inverse patterns in the long-term coefficient – were all rejected.

The stability of the VECM was assessed with the eigenvalues of the companion matrix of the corresponding VAR. The eigenvalues amount to $K * p$, where K is the number of lags, and p is the number of variables. The first three equaled unity, consistent with three cointegration vectors, while the remaining eigenvalue moduli are decreasing and lie strictly within the unit circle, suggesting that the VECM is stable over time.

Residual variance stability was evaluated by the multivariate ARCH-LM test. The null hypothesis of homoskedasticity was maintained. Furthermore, the null hypothesis of residual autocorrelation was rejected up to 15 lags using the Portmanteau test. Considerable autocorrelation at short lags was observed, which is expected given endogenous nature of the variables. This highlights the appropriateness of Johansen's procedure.

5.4 Discussion

In this subsection, I address the research questions (1) and (2) in light of the results, evaluate the results against previous empirical literature and endogenous growth theory, discuss the limitations of this study, and suggest directions for future research.

(1) Public R&D and GDP are positively associated over the time period 1975–2024. However, the direction of causality cannot be unambiguously established within the VECM framework.

These findings are consistent with previous studies from the Netherlands and the United States (Goel et al. 2008, Soete et al. 2020). Moreover,in line with Goel et al. (2008), private R&D and GDP exhibit a smaller positive long-term association than public R&D and GDP. The estimation finds no statistically significant association between education spending and GDP.

(2) Public R&D is strongly associated with private R&D in the long-term equilibrium. Public R&D is weakly exogenous in the corresponding equation, and it does not adjust to private R&D. In turn, private R&D adjusts to public R&D, consistent with a complementary interaction, where public R&D potentially reduces risk, alleviates cash constraints, or produces public knowledge for firms to utilize. This result aligns with Soete et al. (2020), who report a similar positive association in Netherlands, although their findings indicate mutual endogeneity between public and private R&D.

The results of this thesis should be interpreted in light of several limitations, related to theoretical assumptions, methodological constraints and data availability. First, the selection of variables is guided by endogenous growth theory, which may disregard relevant determinants of long-term productivity growth, potentially rendering the model subject to omitted variable bias. The role of imported technology as a determinant of long-term GDP was explored, in addition to the contribution of domestic R&D. The R&D–GDP relationship remains robust to this inclusion, but imports appear to capture some effect, approximately to similar magnitude as private R&D. This suggests that imported technology may be relevant for long-term growth, particularly in small open economies such as Finland.

Methodologically, Johansen's procedure and the VECM are well suited for identifying cointegrated relationships, but they limit the research to variables integrated of the same order. Therefore, the research design is restricted to countries, where the dataset satisfies this condition. In addition, the lack of causal identification remains a limitation in the VECM framework, indicating a need for complementary micro-level research with exogenous variation as the identification strategy.

Substantial data limitations also exist. Current data do not allow distinguishing fundamental research and R&D subsidies within public R&D prior to 1990. Consequently, the key driver of the complementary association of public R&D and private R&D cannot be identified. Neither does data up to date enable a decomposition of public R&D subsidies at the instrument level, limiting the ability to estimate the effects of indirect tax incentives and direct subsidies.

In the case of education, data spending per educational level is missing in the UNESCO data set for the years 1977, 1978, 1997 and 1998. Furthermore, the UNESCO figures differ from the numbers reported by Statistics Finland in their corresponding dataset, where data collection starts from 2000. This renders examining the long-term economic effects of education by educational level unfeasible.

In contrast to Kokkinen (2012), who finds a strong positive long-term association between the human capital stock and GDP, the results of this thesis, estimated with aggregated education spending data, suggest that education spending has not been a driver of long-term GDP in the period 1970–2022. This indicates that the marginal utility of additional education is possibly decreasing in countries nearby the global technological frontier.

To the extent that the results of this thesis are reliable, the positive association of public R&D and GDP suggests a need for policy interventions enhancing public R&D spending. In the light of the public R&D spending and GDP trends presented in Figure 1, stagnating or decreasing government innovation expenditure may be socially unfeasible. Similar conclusions are reported in previous studies from the Netherlands Soete et al. (2020) and the United States (Goel et al. 2008).

6 Conclusion

This thesis examined the long-term relationships between public R&D, education spending, and GDP in Finland over the period 1970-2024, as well as the interaction between public and private R&D within a small open economy framework.

The R&D-related variables exhibited a long-term equilibrium with three cointegration vectors. The restricted VECM results indicated that: (1) public R&D is positively associated with GDP in the long term, (2) public and private R&D have a positive complementary association, (3) capital-intensive technology imports do not have a statistically significant long-term association with GDP.

No evidence of a long-term relationship between education spending and GDP was found by the trace test, and the subsequent VAR estimation did not indicate a dynamic short-term relationship. This contrasts prior Finnish research covering 1910–2000, which showed a positive long-term association between GDP and the human capital stock derived from public education investment. The difference in findings may reflect the use of more recent data from 1970–2022, during which Finland has been closer to the global technology frontier, emphasizing innovation relative to technology adaptation, although other explanations related to model specification cannot be ruled out.

Given that the results of this thesis are robust, the Finnish policy target of raising R&D expenditure to 4% of GDP appears consistent with the positive long-term association of public R&D and GDP. However, this result does not allow for a comprehensive evaluation of specific policy instruments. In particular, distinguishing the effects of fundamental research and support for private R&D, as well as evaluating the effectiveness of direct versus indirect R&D support instruments still require more research. In addition, future work should examine the economic effects of education spending across educational levels.

Overall, the results highlight the role of public R&D investment in long-term economic performance in Finland, and find no evidence of a growth effect of aggregate education spending.

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A Unit Root Tests and Lag Length

Panel A1: Unit Root				
Variable	**ADF** $I(0)$	**PP** $I(0)$	**ADF** $I(1)$	**PP** $I(1)$
GDP (log)	-2.31	-1.33	-4.87***	-4.05**
Public R&D (log)	-1.64	-1.67	-4.29***	-6.26***
Private R&D (log)	-1.59	-1.84	-3.01	-4.16***
Investment (log)	-4.39***	-2.97	-4.83***	-3.98**
Labor (log)	-3.21*	-2.07	-4.81***	-3.68***
Import Index	-3.26	-3.06	-7.24***	-7.18***
Education Spending (%)	-2.48	-2.67	-4.12***	-6.71***

Panel A2: Lag Length				
Variable	**AIC**	**HQ**	**SC**	**FPE**
R&D	6	6	6	6
Education	2	2	2	2

Statistical significance level of the ADF and PP test statistics are denoted by *, **, and ***, at the 10%, 5%, and 1% significance levels respectively.

All time series are stationary at $I(1)$. Private R&D is rejected by the Augmented Dickey Fuller test, but stationarity is implied by the Phillips-Perron test, which is a more reliable unit root test for small samples.

Lag length tests unanimously suggest six lags for the R&D system, which is unsustainable for the degrees of freedom with a data span of 50 years. Previous studies having chosen much scarcer lag lengths, and macroeconomic tradition generally applying one lag, I compromise to a smaller lag length. Increasing the lag from one to two improves model fit, whereas three lags deteriorates it, implying two lags to be the correct choice. Residual autocorrelation diagnostics presented in the robustness checks alleviate the concern for under-parametrization with two lags.

B Trace Test

Panel B1: Trace Test: R&D

	Test statistic	10pct	5pct	1pct
$r <= 5$	7.11	10.49	12.25	16.26
$r <= 4$	18.65	22.76	25.32	30.45
$r <= 3$	37.94	39.06	42.44	48.45
$r <= 2$	65.04	59.14	62.99	70.05
$r <= 1$	101.06	83.20	87.31	96.58
$r = 0$	156.27	110.42	114.90	124.75

Panel B2: Trace Test: Education

	Test statistic	10pct	5pct	1pct
$r <= 1$	7.88	10.49	12.25	16.26
$r = 0$	24.70	22.76	25.32	30.45

Trace test on the R&D system rejects the null hypothesis $r \leq k$ up to $k = 3$. Trace test for education rejects the null hypothesis $k = 0$ at the 10% significance level, but not at the 5% level. Consequently, the R&D VECM cointegration space is of rank 3, where as the education system is not cointegrated.

C Unrestricted VECM Results

Table C1: Unrestricted VECM: R&D

	GDP	Public R&D	Private R&D	Investment	Labor	Imports	Trend
ECT1	1.000	-0.038	-0.012	0.000	0.000	-0.009	-0.01
	(-0.183)*	(-0.387)**	(-0.368)*	(-0.598)***	(-0.176)***	(0.001)	
ECT2	0.000	-14.614	10.195	0.000	1.000	-0.165	0.339
	(-0.048)	(0.105)	(-0.836)*	(0.91)**	(-0.116)	(-0.091)	
ECT3	0.000	-32.752	22.661	1.000	0.000	-0.371	0.755
	(0.024)	(-0.03)	(0.376)*	(-0.394)**	(0.054)	(0.047)	

Significance level of the t-test on an α- coefficient is denoted by *, **, and ***, at the 10%, 5%, and 1% significance levels respectively.

D Identification of the Cointegration Space

ECT_1 of Table C1 is normalized on GDP to represent a long term production function:

$$ECT_1 = GDP - 0.038RD_{\text{public}} - 0.012RD_{\text{private}} - 0.009Imports - 0.01$$

$$GDP = 0.038RD_{\text{public}} + 0.012RD_{\text{private}} + 0.009Imports + 0.01$$

ECT_2 of Table C1 is normalized on Private R&D to represent the allocation dynamics of R&D:

$$ECT_2 = \mathit{Labor} - 14.614RD_{\text{public}} + 10.195RD_{\text{private}} - 0.165Imports + 0.339$$

$$10.195RD_{\text{private}} = 14.614RD_{\text{public}} - \mathit{Labor} + 0.165Imports - 0.339$$

$$RD_{\text{private}} = 1.434RD_{\text{public}} - 0.098\mathit{Labor} + 0.016Imports - 0.033$$

ECT_3 of Table C1 is normalized on Investment:

$$ECT_3 = Investment - 32.752RD_{\text{public}} + 22.661RD_{\text{private}} - 0.371Imports + 0.755$$

$$Investment = 32.752RD_{\text{public}} - 22.661RD_{\text{private}} + 0.371Imports - 0.755$$

We plug in the expression for Private R&D obtained from ECT_2:

$$\begin{aligned} Investment = {} & (32.752 - 22.661 \times 1.434)RD_{\text{public}} - (22.661 \times (-0.098))\mathit{Labor} \\ & + (0.371 - 22.661 \times 0.016)Imports - 0.755 - 22.661 \times (-0.033) \end{aligned}$$

$$Investment = 0.267RD_{\text{public}} + 2.223\mathit{Labor} + 0.004Imports$$

Thus, the normalized unrestricted VECM can be summarized in the following table:

Table D1: Normalized Unrestricted VECM: R&D

	GDP	Public R&D	Private R&D	Investment	Labor	Imports	Trend
ECT1	1.000	-0.038	-0.012	0.000	0.000	-0.009	-0.01
	(-0.183)*	(-0.387)**	(-0.368)*	(-0.598)***	(-0.176)***	(0.001)	
ECT2	0.000	-1.434	1.000	0.000	0.098	-0.016	0.033
	(-0.489)	(1.071)	(-8.523)*	(9.277)**	(-1.182)	(-0.928)	
ECT3	0.000	-0.267	0.000	1.000	-2.223	0.004	0.000
	(0.131)	(-0.263)	(2.235)*	(-2.417)**	(0.312)	(0.249)	

Significance level of the t-test on an α- coefficient is denoted by *, **, and ***, at the 10%, 5%, and 1% significance levels respectively.

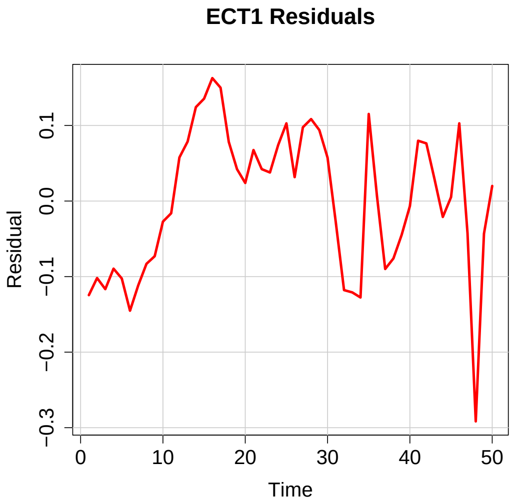
To fully identify the cointegration space, linear restrictions are then imposed on the beta coefficients approximately corresponding to zero, and calculate the Wald test statistics and the corresponding p-values. The results, provided in Table D2 below, show that this set of linear restrictions is justified, and the cointegration space is correctly identified.

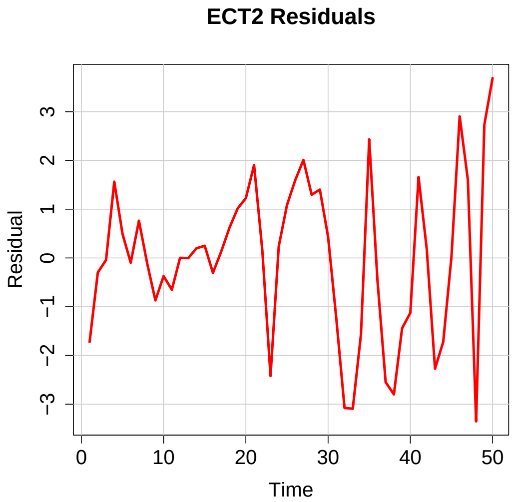
Table D2: Linear Restriction Tests

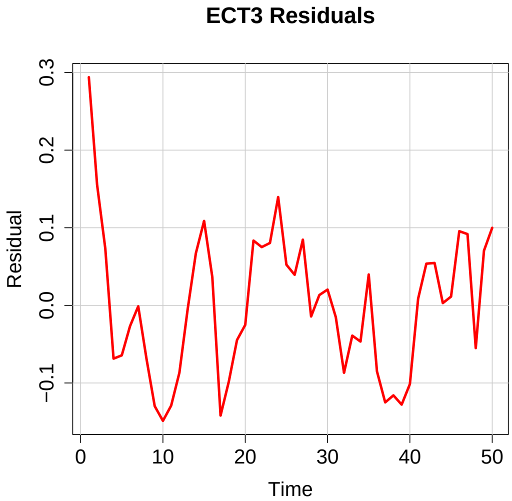
Null Hypothesis	Wald test statistic	p-value	Reject H_0
ECT_1: Labor: $\beta = 0$	4.079e-32	1	No
ECT_1: Investment: $\beta = 0$	5.997e-32	1	No
ECT_2: GDP: $\beta = 0$	0.000	1	No
ECT_2: Investment: $\beta = 0$	8.204e-29	1	No
ECT_3: GDP: $\beta = 0$	1.797e-28	1	No
ECT_3: Private R&D: $\beta = 0$	0.000	1	No

E Robustness Checks

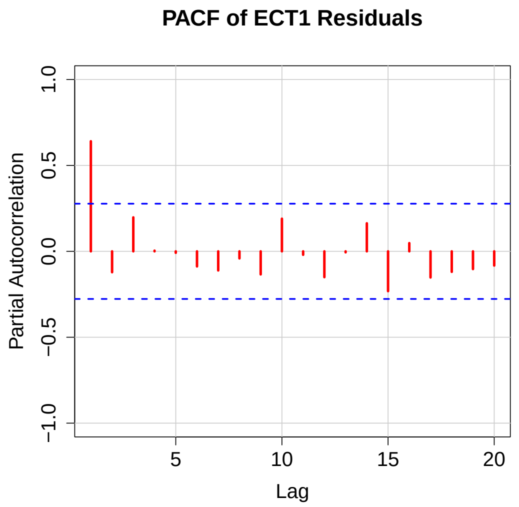
Figures E1-E3: Residual Diagnostics

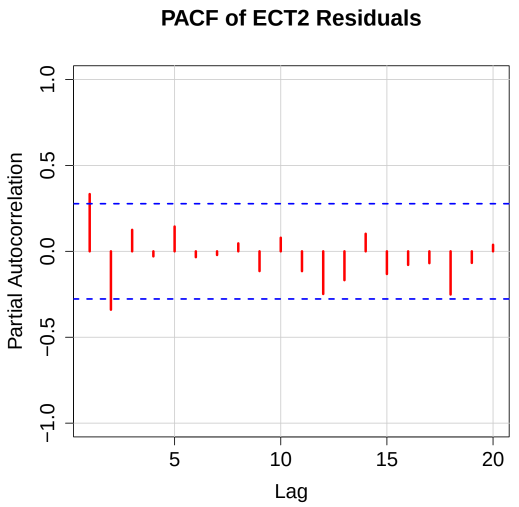






Figures E4-E6: Cointegration Vector Residuals





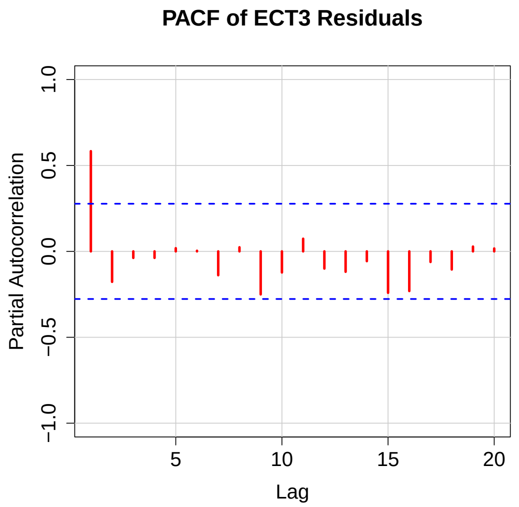


Table E1: Linear Restriction Tests

Null Hypothesis	χ^2	p-value	Reject H_0
Panel A: R&D			
GDP $\beta = 0$	22.4613***	2.14×10^{-6}	Yes
Labor $\beta = 0$	38.5994***	5.20×10^{-10}	Yes
Investment $\beta = 0$	36.1973***	1.78×10^{-9}	Yes
Public R&D $\beta = 0$	23.1267***	1.52×10^{-6}	Yes
Private R&D $\beta = 0$	31.4136***	2.09×10^{-8}	Yes
Imports $\beta = 0$	32.5846***	1.14×10^{-8}	Yes
Public & Private R&D are jointly zero	36.7440***	1.35×10^{-9}	Yes
GDP & Labor are jointly zero	43.5284***	4.18×10^{-11}	Yes

Notes: $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.