ASECU South-Eastern Europe Journal of Economics 2 (2023) 75-94 SEEJE

ESTIMATING THE IMPACT OF CAPITAL IN A MULTISECTORAL PRODUCTION SETTING IN GREECE

PRODROMOS PRODROMIDIS*
Centre for Planning & Economic Research (KEPE), Athens, Greece
Hellenic Open University, Greece & Open University of Cyprus

Abstract
The paper estimates the impact of capital on output in Greece during 2010-18, across 62 sectors of economic activity. It suggests that deciding to invest in one sector over another may be more important than deciding what the investment is about (buildings, machinery, etc.) and that changes in multifactor productivity may be explained by variations in the composition of the inputs involved. It also identifies sectors in which a marginal increase or decrease in capital or substitution of capital with labor (or certain types of labor) or vice versa may affect an increase in output. This may improve decision making in the country's economic development planning.

Keywords: Types of capital, Output, Sectors of economic activity, Multifactor productivity, Translog production function, Recovery planning

JEL Classification: D24, 013, 014

Acknowledgements:
The comments made to an earlier version by participants at the International Conference on Business & Economics of the Hellenic Open University in 2022, and by an anonymous referee are greatly appreciated. The usual disclaimer applies.

****Corresponding address:*** Prodromos Prodromidis, Centre for Planning & Economic Research (KEPE); 11 Amerikis str., Athens 10672. Email: pjprodr@kepe.gr, (+30)2103676412

1. Introduction

The paper presents a short, flexible model to empirically estimate the impact on output of several manmade capital inputs -alongside labor inputs- across all production activities of a multisectoral economy, with the intention to inform and advise economic development policy.

To appreciate what is involved, it is useful to draw attention to issues raised in a very influential work on the matter. In his *Contribution to the Theory of Economic Growth*, Solow (1956): (a) explains that theory by and large depends on assumptions that simplify reality (hence, may not be quite true), yet are reasonably realistic; and (b) develops a model of a community producing a single composite commodity using labor and manmade capital (hereinafter, capital) in a way that the two inputs may substitute each other in production. *Inter alia*, he describes how an increased capital stock generates greater per capita production; suggests that in the absence of technological progress additional capital injections into the economy may result in ever smaller contributions to production due to diminishing yields; and demonstrates that technological development serves as the motor for economic growth in the long run (Royal Swedish Academy of Sciences, 1987).

Since reality is more complex than simplified assumptions, the economic system may involve more sectors and commodities (e.g., Temple and Wößmann, 2006; Lopez-Garcia and Szörfi, 2021; and sources cited therein). These commodities may also be at different stages of their life cycle, may be produced by different types of labor and capital input, and the inputs involved may be accumulated or combined in ways that in certain cases may be quite efficient,[1] while in other cases may be less efficient or even inefficient.[2] These are features that ought to be considered both when carrying out analyses and/or when contemplating policy interventions. Ideally, they should be identified empirically (based on relevant data), so that additional, more

1. For example, an empirical analysis carried out by Antonopoulos and Sakellaris (2009) found that in the 1990s and early 2000s, increasing the capital stock of computers, communication equipment, and software in Greece mostly benefited the finance, insurance, real estate and business services sector, as well as the wholesale and retail trade sector.

2. In a typical textbook production function graph, the latter is illustrated by a point beyond which, *ceteris paribus*, the employment of an additional unit of input causes output to decline (e.g., Samuelson and Nordhaus, 2010: 109-110). Intuitively, accumulating capital up to a certain level may be highly productive, but accumulating more (e.g., twice as much) may not be (Fernald, 1999). For various reasons (e.g., due to past projections) a firm or industry may find itself in a situation of possessing more capital than it needs (Arrow, 1966). Indeed, the received wisdom is that a good number of countries have regretted that their resources were tied up in huge capital projects by then inefficient (Begg et al., 2008: 582).

focused analyses may be carried out, and sectoral agents as well as policymakers may be informed so as to act accordingly.

The paper contributes to the relevant literature by showing that in an economy with multiple sectors, activities or commodities (*multi-sectoral* herein after, for the sake of simplicity), an injection of capital or injection of a particular type of capital (building, machinery, etc.) may positively affect output in one sector and negatively in another sector. Knowing this, economic planners may reach more informed decisions. (In the case of Greece, it turns out that deciding to invest in one sector over another may be more important than deciding what the investment is about.) In the process, the paper finds that the variation in a crucial measure of economic performance, namely, multifactor productivity, is to a considerable extent explained by variations in the composition of inputs.

In Greece, currently, considerable post-pandemic *recovery and resilience funds* are directed to investments that will shape the country's future production possibilities (European Commission, 2021; OECD, 2021). With this in mind, in the pages that follow, the country's recent evolution of capital and output is described across 62 sectors (Section 2), and a production model is set up (Section 3). Next, the impact of capital -both of overall capital and of nine distinct types of capital- on sectoral output in Greece is empirically estimated from data running from to 2010 to 2018,[3] with the purpose of advancing our understanding on how the country's multisectoral economy functioned until recently, prior to the pandemic (Section 4), and also draw policy lessons and conclusions in order to improve decision making regarding Greece's economic development planning (Section 5).

2. The Recent Evolution of Capital and Output in Greece

According to the annual figures of accumulated capital and output (gross value added) provided by Eurostat, the statistical service of the European Union, across Greece's 62 sectors of economic activities or groups of economic activities, in the course of 2010-18 (see Table I):

3. A break in the time series in 2010 hinders the consideration of earlier data. The break was dictated by an EU-wide sector-classification switch, which coincides with the time the Greek government took its first austerity measures to cope with the 2009 sovereign debt crisis. The crisis was followed by a recession (up to 2016) and a weak recovery period interrupted in 2020 by the coronavirus pandemic. Consequently, the last year for which data on capital existed at the time of carrying out the present analysis (2018) is a pre-pandemic year of economic expansion.

Table I: Statistical classification of economic activities according to Eurostat (2008)

Codes	Sector descriptions	Codes	Sector descriptions
01	Crop and animal production, hunting, related service activities	51	Air transport
02	Forestry, logging	52	Warehousing, support activities for transportation
03	Fishing, aquaculture	53	Postal and courier activities
05-09	Mining, quarrying	55-56	Accommodation, food and beverage service activities
10-12	Manufacture of food products, beverages, tobacco products	58	Publishing activities
13-15	Manufacture of textiles, wearing apparel, leather, related products	59-60	Motion picture, video and television program production, sound recording, music publishing activities; broadcasting, programming activities
16	Manufacture of wood, products of wood and cork, except furniture; manufacture of articles made of straw and plaiting materials	61	Telecommunications
17	Manufacture of paper and paper products	62-63	Computer programming, consultancy, related activities; information service activities
18	Printing and reproduction of recorded media		
19	Manufacture of coke and refined petroleum products	64	Financial service activities, except insurance and pension funding
20	Manufacture of chemicals and chemical products	65	Insurance, reinsurance, pension funding, except compulsory social security
21	Manufacture of basic pharmaceutical products and preparations	66	Activities auxiliary to financial services and insurance activities
22	Manufacture of rubber and plastic products	68	Real estate activities
23	Manufacture of other non-metallic mineral products	69-70	Legal and accounting activities; activities of head offices, management consultancy activities
24	Manufacture of basic metals		
25	Manufacture of fabricated metal products, except machinery and equipment	71	Architectural and engineering activities; technical testing, analysis
26	Manufacture of computer, electronic and optical products	72	Scientific R&D
27	Manufacture of electrical equipment	73	Advertising, market research
28	Manufacture of machinery and equipment not elsewhere classified	74-75	Other professional, scientific, technical, and veterinary activities
29	Manufacture of motor vehicles, trailers, semi-trailers	77	Rental and leasing activities
30	Manufacture of other transport equipment	78	Employment activities
31-32	Manufacture of furniture; other manufacturing	79	Travel agency, tour operator, other reservation service and related activities
33	Repair and installation of machinery and equipment	80-82	Security and investigation activities; services to buildings, land-scape activities; office administrative, office support, other business support
35	Electricity, gas, steam, and air conditioning supply		
36	Water collection, treatment, and supply	84	Public administration and defense; compulsory social security
37-39	Sewerage, waste collection, treatment, disposal activities; recovery of materials, remediation activities, other waste management services	85	Education
		86	Human health activities
41-43	Construction	87-88	Residential care activities; social work activities without accommodation
45	Wholesale and retail trade, repair of motor vehicles and motorcycles	90-92	Creative activities, arts, entertainment activities; libraries, archives, museums, other cultural activities; gambling, betting activities
46	Wholesale trade, except of motor vehicles and motorcycles		
47	Retail trade, except of motor vehicles and motorcycles	93	Sports activities, amusement and recreation activities
49	Land transport, transport via pipelines	94	Activities of membership organizations
50	Water transport	95	Repair of computers and personal and household goods
51	Air transport	96	Other personal service activities

- Sectors 68 (real estate) and 84 (public administration etc.) featured the most capital and output both at the beginning and at the end of the period, while each of the other sectors featured considerably less capital and output.
- The amount of capital decreased in sectors 01, 02, 10-12, 13-15, 16, 17, 18, 20, 23, 24, 25, 26, 27, 28, 29, 30, 31-32, 33, 41-43, 45, 49, 50, 51, 53, 58, 59-60, 61, 65, 66, 68, 69-70, 72, 73, 74-75, 77 (rental and leasing activities, which featured the largest overall fall in both absolute and percentage terms), 78, 80-82, 85, 86, 87-88, 90-92, 93, 94, 95, 96; and increased in sectors 03, 05-09, 19 (manufacture of coke and refined petroleum products, which featured the largest overall percentage rise), 21, 35, 36, 37-39, 46, 47, 52, 55-56, 64, 71, 79, 84 (which featured the largest overall rise in absolute terms); decreased for several years and subsequently increased in sector 62-63 (computer programming, information service activities etc.); and increased for some years and subsequently decreased in sector 22 (manufacture of rubber and plastic products).
- The gross valued added in the production process decreased in sectors 03, 05-09, 10-12, 13-15, 16, 18, 19, 20, 22, 23, 24, 25, 27, 28, 29, 31-32, 36, 37-39, 41-43, 45, 46, 47 (retail trade, which featured the largest overall fall in absolute terms), 49, 50, 53, 58, 59-60, 61, 64, 66, 69-70, 71, 73, 74-75 (other professional, scientific, technical activities etc., which featured the largest overall percentage fall), 77, 80-82, 84, 85, 86, 87-88, 96; increased in sectors 01, 02, 17, 21, 26, 30, 51, 52, 55-56 (accommodation, food services etc., which featured the largest overall rise in absolute terms), 62-63, 65, 68, 78 (employment activities, which featured the largest overall percentage rise), 79, 93, 94, 95; fluctuated and ended up lower in sectors 33 and 72 (repair-installation of machinery-equipment, scientific R&D), and higher in sectors 35 and 90-92 (electricity supply etc., creative activities etc.) as compared to the beginning of the period under consideration. (See Appendices 1 and 2.)

3. The Model

Next, following an identifiable strand in the literature (e.g., Miller and Upadhyay, 2000; Parrotta et al., 2014; Matos and Neves, 2020; and sources sited therein), the paper adopts a two-step analysis. Initially, it estimates the impact of the aggregate measures of labor (L) and capital (K) on output (Y) at the sectoral level (step 1). Then, it estimates the individual effects of the various types of the two inputs on the residual of the said output ─the so-called, total- or multi-factor productivity (MFP)─ (step 2). This way it can measure the distinct impact of a marginal change in the value of each of the many types of capital accumulated in a sector, on the sector's output.

More specifically, the first step considers a translog production function [4] in which the annual values of sectoral *Y* during 2010-18 are regressed on: (a) the sectoral labor and capital employed (i.e., the *L* and *K* employed in the same sector as *Y*), (b) a small number of possible cross-sectoral labor or capital inputs (to consider cases of combined or intermediate production, for the sake of completeness), (c) time trends, *t,* and changes in these trends to proxy sectoral MFP changes over time (e.g., Tzouvelekas, 2000; van Elk et al., 2019), and (d) a small number of temporal dummies, D, to proxy possible sectoral MFP shocks.[5] The expression is abbreviated as follows:

$$\ln(Y_{it}) = \ln(A_i) + a_i \ln(L_{it}) + b_i \ln(K_{it}) + c_i \ln^2(L_{it}) + d_i \ln^2(K_{it}) + e_i \ln(L_{it})\ln(K_{it}) \\ + f_i t_i + g_i t_i^2 + h_i D_{it} + m_{ij} \ln(L_{ijt}) + n_{ij} \ln(K_{ijt}) + u_{it.} \tag{1}$$

In order to address concerns usually expressed in cases of forecasts, the expression is reformulated in terms of first differences, *Δ*, from one year to the next:[6]

$$\Delta \ln(Y_{it}) = \Delta \ln(A_i) + a_i \Delta \ln(L_{it}) + b_i \Delta \ln(K_{it}) + c_i \Delta \ln^2(L_{it}) + d_i \Delta \ln^2(K_{it}) \\ + e_i \Delta \ln(L_{it}) \Delta \ln(K_{it}) + f_i t_i + g_i t_i^2 + h_i D_{it} + m_{ij} \Delta \ln(L_{ijt}) + n_{ij} \Delta \ln(K_{ijt}) + u_{it}. \tag{2}$$

Y is in terms of 2015 prices (i.e., deflated values) in million euro, *L* is in terms of thousand people employed, *K* stands for the gross fixed capital stock value in terms of 2015 prices in million euro, with the labor and capital parameters (coefficients) allowed to vary from one sector to another. In addition, *A* stands for the autonomous component of MFP, *u* stands for the error term, $i = 1, 2, \ldots, 62$, stands for the sectors of economic activity (a relatively large number, vis-a-vis the number considered in most analyses), *j* stands for any sector the inputs of which may affect other sectors' production (in the present analysis, j=1; see Table II, line 24),[7] $t = 1, 2, \ldots, 8$ or 9, and stands for the time periods concerned (i.e., the years), while the remaining

4. The *transcendental* logarithmic (translog) production function is generally thought to be more flexible than its Cobb-Douglas and Constant Elasticity of Substitution counterparts (e.g., Heathfield and Wibe, 1987; Pablo-Romero and Gómez-Calero, 2013; Diewert and Fox, 2019; Gecher et al., 2022). Vettas et at. (2022) employ the translog production function in a similar manner to estimate MFP trends in fifteen sectors using Greek firm-level data running from 2005 to 2019.

5. Both (b) and (d) are detected from the residuals: the former when a close resemblance of the patterns of the residuals with the patterns of the respective inputs is noted (r>90%), the later from the most prominent fluctuations of the residuals.

6. Under the new setting, the Levin–Lin–Chu (2002), Harris–Tzavalis (1999), Breitung (2000; Breitung and Das 2005), Im–Pesaran–Shin (2003) and Fisher-type (Choi 2001) tests reject the hypothesis that all panels contain a unit root. See Appendix 3.

7. The case is identified in the manner described in footnote 5, item b.

lower-case letters (*a*, *b*, *c*, *d*, *e*, *f*, *g*, *h*, *m*, *n*) stand for the coefficients of the variables regressed on *Y*: i.e., the unknown terms estimated from the variables regressed on *Y*. Three of these coefficients (*f, g, h*) measure the impact of the time trends and of other patterns associated with sectoral MFP developments, while the rest (*a, b, c, d, e, m, n*; but not counting *A*) are used to calculate the sectoral MFP analyzed in the second step.

Table II: OLS estimates of capital on sectoral production in Greece, 2010-2018

The full expression analyzed is: $\Delta\ln(Y_{it}) = \Delta\ln(A_i) + a_i\,\Delta\ln(L_{it}) + b_i\,\Delta\ln(K_{it}) + c_i\,\Delta\ln^2(L_{it}) + d_i\,\Delta\ln^2(K_{it}) + e_i\,\Delta\ln(L_{it})\,\Delta\ln(K_{it}) + f_i\,t_i + g_i\,t_i^2 + h_i\,D_{it} + m_{ij}\,\Delta\ln(L_{ijt}) + n_{ij}\,\Delta\ln(K_{ijt}) + u_{it}$.

Explained variable: $\Delta\ln(Y_{it})$, Y_{it} = GVA (in million euro, in 2015 prices)

	Explanatory variables	Coef.	Explanatory variables	Coef.	Explan. var.	Coef.
	$\Delta\ln(K_{it})$, K_{it} = Capital (in mil. euro, in 2015 prices)					
1	Sect.66	-354.312	Sect.19, 45, 47, 62, 64, 65	-5.627	Sect.20, 35,	16.131
2	Sect.30, 95	-158.220	Sect.02, 17, 22, 59, 78	-1.812	61, 69	
3	Sect.72	-128.552	Sect.16, 21, 28, 41, 58, 90	0.470	Sect.27, 36,	24.024
4	Sect.50	-88.007	Sect.10, 24, 26, 46, 49, 86	2.510	84, 96	
5	Sect.01, 03, 23, 55, 85,	-44.244	Sect.52, 68, 80	6.083	Sect.31	34.476
	87					
6	Sect.51, 93, 94	-28.435	Sect.73, 77	7.840	Sect.18	89.462
7	Sect.13, 37, 53	-11.177	Sect.05, 25, 33, 71, 74, 79	9.542	Sect.29	202.145
	$\Delta\ln(K_{it})$ squared					
8	Sect.36, 50	-10,802.400	Sect.13, 41, 45, 53, 59, 62,	-102.521	Sect.10, 31,	336.217
9	Sect.66	-4,066.417	78		47, 96	
10	Sect.01, 72, 95	-2,868.247	Sect.02, 16, 17, 24, 28, 37,	-47.454	Sect.20, 27,	553.475
11	Sect.30, 84, 85	-1,825.281	90		35, 68, 86	
12	Sect.23	-1,295.123	Sect.52, 71	-22.600	Sect.19, 46	848.208
13	Sect.51, 87	-994.110	Sect.22, 49, 77, 80	29.112	Sect.03	1,141.900
14	Sect.93	-688.571	Sect.25, 73	92.058	Sect.55, 61,	2,504.232
15	Sect.05	-286.161	Sect.74	129.743	94	
16	Sect.21, 58, 65, 79	-173.174	Sect.26, 33, 64, 69	218.090	Sect.18	3,521.800
17					Sect.29	4,383.673
	$\Delta\ln(L_{it}) \times \Delta\ln(K_{it})$					
18	Sect.30, 64, 95	-244.109	Sect. 03, 05, 13, 17, 22, 24,	1.628	Sect.01, 51,	168.691
19	Sect.20, 47, 50	-121.328	33, 37, 41, 45, 52, 58, 68,		61	
20	Sect.02, 18, 23, 27, 29,		69, 71, 73, 77, 80, 96		Sect.36	392.517
21	35, 46, 49, 53, 62,	-16.208			Sect.66	1,737.756
22	79, 84, 85, 87, 93,		Sect. 16, 21, 25, 26, 31, 55,	23.574		
	94		59, 78		Sect.19	4,223.512
23			Sect.10, 28, 65, 72, 74, 86, 90	61.972		
	Other impact: $\Delta\ln(K_{ijt})$					
24	Capital in sect.79 on output of sect.35	4.579				

Observations: 496. Regressors-to-observations ratio: 28%. Model fitness: $R^2 = 0.9641$, $adjR^2 = 0.9497$. Ramsey RESET: Prob > F = 0.1463.

Notes: To save space, in cases of grouped sectors (e.g.,05-09, 10-12, etc., see Table I) only the code of the first sector is included. The regression is estimated with robust standard errors to address heterogeneity and normality issues.

A set of time and labor variables have been included as controls. The recovered P-values are equal to 0.000 except for the cases of line 3, center (P=0.182) and line 18, center (P= 0.181).

P-values help determine whether the relationships observed in a sample, also exist in the larger population; however, this analysis is carried out in the population.

Source: Eurostat (NAMA_10_A64_E, NAMA_10_NFA_ST), own calculations.

Like the annual figures of sectoral Y, L, K, the annual figures of the various types of sectoral K are provided by Eurostat. The nine types of capital comprise dwellings ($K1$), other buildings and structures ($K2$), transportation equipment ($K3$), computer hardware ($K4$), telecommunication equipment ($K5$), other machinery ($K6$), biological resources ($K7$), research and development (R&D) ($K8$), computer software and databases ($K9$).

In the second step the sectoral MFP (i.e., the portion of the production function attributed to the sum of the A, t, t^2, D and u components) is empirically explained in terms of the aforesaid nine types of capital (k=1, 2, …, 9) and six types of labor (l): [8]

$$\Delta\ln(Y_{it}) - [a_i \Delta\ln(L_{it}) + b_i \Delta\ln(K_{it}) + c_i \Delta\ln^2(L_{it}) + d_i \Delta\ln^2(K_{it}) + e_i \Delta\ln(L_{it})\Delta\ln(K_{it})$$
$$+ m_{ij} \Delta\ln(L_{ijt}) + n_{ij} \Delta\ln(K_{ijt})] = \sum_{l=1}^{6}\left(\lambda_{il}\ \Delta\frac{L_{itl}}{L_{it}}\right) + \sum_{k=1}^{8}\left(\kappa_{ik}\ \Delta\frac{K_{itk}}{K_{ik}}\right) + v_{it} \tag{3}$$

On the right-hand side of expression (3), lower-case letters, λ, κ, v, stand, respectively, for the coefficients of the shares of the various types of labor and capital considered, and for the error term. Existing literature attributes the left-hand difference (i.e., MFP growth) to human capital, the adoption and diffusion of information and communication technologies, R&D and knowledge spillovers, revolutions, wars, crises, shocks, policy changes, and other macroeconomic and institutional factors (Ahmed and Bhatti, 2020).

Expressions (2) and (3) involve (62 sectors x 8 years =) 496 observations. To preserve degrees of freedom in the respective econometric analyses, in each analysis explanatory variables with the same or similar coefficients are amalgamated. In particular, each component of input (i.e., the first difference, its square or its product) is amalgamated separately with another component of input in another sector (the first difference, its square or its product, respectively) if and only if their estimated impacts (coefficients) are the same or similar in line with *testparms* carried out in STATA 15.[9] Thus, both the approximate impact of each input, and a good number of degrees of freedom are preserved.

---

8. The six types of labor relate to workers' highest formal educational attainment, namely, holding (a) a basic or lower-level education qualification, (b) an upper-secondary school diploma, (c) a post-secondary school certificate, (d) a technological institute or (e) bachelor's or (f) postgraduate degree. Figures are calculated based on data from the Hellenic Statistical Authority's (ELSTAT) Labor Force Survey (LFS) series. In particular, the annual changes in LFS estimates of the six types of people employed in each sector are fitted to Eurostat's annual changes of the sectoral labor figures.

9. The inclusion of the explanatory factors is not questioned. What is discussed is merging regressors recommended by theory in a way that the estimated values of their coefficients are

Table III: OLS estimates of the various types of capital, $\Delta K_{itk} / K_{it}$, on sectoral multifactor productivity in Greece, 2010-18

The expression analyzed is: $\Delta\ln(Y_{it}) - [a_i \Delta\ln(L_{it}) + b_i \Delta\ln(K_{it}) + c_i \Delta\ln^2(L_{it}) + d_i \Delta\ln^2(K_{it}) + e_i \Delta\ln(L_{it})\Delta\ln(K_{it}) + m_{ij} \Delta\ln(L_{ijt}) + n_{ij} \Delta\ln(K_{ijt})] = \sum_{l=1}^{6}\left(\lambda_{il}\, \Delta\frac{L_{itl}}{L_{it}}\right) + \sum_{k=1}^{8}\left(\kappa_{ik}\, \Delta\frac{K_{itk}}{K_{ik}}\right) + v_{it}$.
The left-hand side constitutes the explained variable.

K1: dwellings, K2: other buildings, structures, K3: transp. equip., K4: computer hardware, K5: telecom. equip., K6: other machinery, K7: biological resources, K8: R&D, K9: computer software, databases

	Explanatory variables (shares)	Coef.	Explanatory variables (shares)	Coef.	Explanatory variables (shares)	Coef.	Explanatory variables (shares)	Coef.
1	K2 in sect.01, 20, 65; K3 in sect.03 16, 19, 52, 53; K4 in sect.33, 68, 74; K5 in sect.94; K6 in sect.02, 33, 68; K8; K9 in sect.68 (reference)							
2	K4 sect.50; K9 sect.37	-354.727	K2 sect.29, 61; K3 sect.05, 31, 74, 93; K4 sect.22, 41; K5 sect.46, 52, 68, 86; K9 sect.33, 74	-1.725	K5 sect.03, 33, 65, 77; K6 sect.16	0.023	K2 sect.23; K4 sect.01, 28; K5 sect. 10, 19, 21, 27, 35, 36, 47, 59, 62, 71, 73, 93; K6 sect.62, 71; K9 sect. 24, 52, 53, 55, 66, 90	4.444
3	K2 sect.50; K9 sect.87	-124.575						
4	K3 sect.25	-94.413			K2 sect.02, 22, 80; K3 sect. 65, 80; K4 sect.69	0.062		
5	K3 sect.96; K4 sect.94	-77.710						
6	K4 sect.25, 31; K5 sect. 50, 85	-63.794	K2 sect.24, 35, 37, 62, 95; K3 sect.17, 47, 59; K4 sect.37, 51; K6 sect.28, 49, 96; K9 sect.78	-1.221	K2 sect.10, 66, 69, 77, 79; K3 sect.49, 69, 95; K4 sect.79; K6 sect.22, 29, 41, 66	0.147	K3 sect.26, 73; K4 sect.96; K9 sect. 05, 29, 96	7.461
7								
8	K5 sect.23; K6 sect.74	-50.100					K2 sect.25; K5 sect.18, 51, 80, 87	7.817
9	K5 sect.45; K6 sect.73	-36.139			K3 sect.41, 45; K4 sect.53, 77; K5 sect.20; K6 sect. 65; K7 sect.01	0.336	K4 sect.24, 73; K6 sect. 61; K9 sect.21, 49	9.462
10	K3 sect.61; K9 sect.23, 93	-29.040	K5 sect.16, 22, 41, 66, 69, 96	-1.019				
11	K3 sect.58; K4 sect.19	-21.906					K3 sect.36; K4 sect.45, 49, 66; K5 sect. 17, 30, 49, 55; K6 sect.37; K9 sect.16, 85	13.666
12	K3 sect.87; K5 sect.24; K9 sect.19, 45	-19.672	K1 sect.84; K4 sect.46; K6 sect.21, 64	-0.815	K1 sect.68; K2 sect.13, 28; K4 sect.17, 64, 84; K6 sect.72, 95; K9 sect.36, 51, 72	0.515		
13								
14	K2 sect.85, 87; K4 sect.23	-15.795	K6 sect.17; K7 sect.02, 84	-0.575			K2 sect.73; K9 sect.13, 31	16.163
15	K4 sect.13; K5 sect.05, 78	-14.044	K2 sect.17, 47, 86; K3 sect.13, 62, 90; K4 sect. 30, 47, 52; K5 sect.79; K6 sect.46, 53, 80	-0.486	K2 sect.16, 33, 49, 72; K3 sect.18, 46, 51; K5 sect. 72, 90; K6 sect. 03, 30, 86	0.739	K3 sect.85; K6 sect.78, 85	18.977
16	K3 sect.21; K4 sect.87	-12.111					K4 sect.05, 36; K5 sect.13, 58; K9 sect.17, 27	21.813
17	K3 sect.27, 66; K4 sect. 78, 85	-10.083					K3 sect.94	23.935
18					K2 sect.03, 68, 94; K3 sect. 10, 23, 24, 29, 37, 71, 72, 84, 86; K4 sect.95; K5 sect. 64; K6 sect.59; K9 sect.26	0.906	K9 sect.35, 58, 94	46.804
19	K2 sect.18, 51, 55, 78; K4 sect.55, 86; K5 sect.29; K9 sect.30	-8.459	K2 sect.26, 84; K4 sect.18, 62, 65, 72; K6 sect.05, 51, 77; K9 sect.47, 50, 73, 95	-0.267			K5 sect.74	49.833
20							K4 sect.93; K5 sect.31	66.199
21							K3 sect.68	187.760
22	K2 sect.71; K4 sect.16, 90	-6.903	K2 sect.05, 21, 64, 90; K3 sect.20; K6 sect.13, 19, 31, 35, 47, 50, 52, 79, 84, 90	-0.212	K6 sect.27, 69, 94	1.276	K9 sect.25	389.906
23	K2 sect.27; K4 sect.71	-5.791			K4 sect.20; K5 sect.95; K6 sect.18, 25; K9 sect.20, 46, 59, 79	1.584	K5 sect.25, 37	560.073
24	K3 sect.28, 35; K4 sect. 35, 59, 61	-4.581					K2 sect.96	1,751.080
25								
26	K2 sect.30, 59, 74; K4 sect.26, 58; K5 sect.01, 28, 84; K6 sect.36; K9 sect.22, 28, 77, 80	-3.194	K3 sect.01, 50, 79; K4 sect. 10, 21, 29; K6 sect.01, 10, 24, 58 87, 93; K9 sect.61, 64, 69, 84	-0.122	K2 sect.31, 36, 58; K3 sect. 22; K5 sect.26, 53; K6 sect.23, 45, 55; K9 sect.71	1.915		
27								
28								
29					K2 sect.19; K4 sect.27; K9 sect.86	2.935		
30								
31	K3 sect.55, 78; K4 sect. 80; K5 sect.61; K9 sect.10, 18, 41	-2.265	K2 sect.41, 46, 52, 53, 93; K3 sect.77; K6 sect.20; K9 sect.62, 65	-0.028	K2 sect.45	3.763		
32								

Observations: 496. Regressors-to-observations: 23%.
Model fitness: $R^2 = 0.9857$, $adjR^2 = 0.9816$.
Ramsey RESET: Prob > F = 0.477.
Notes 1 & 3: See respective notes in Table II.
Note 2: A set of labor variables has been included but not reported. All K1, K3-5, K7, K9 values except for those listed are equal to zero. All P-values are equal to 0.000 except those in line 2, column 3 (0.001).

Sources: Eurostat (NAMA_10_NFA_ST), ELSTAT (Greek LFS estimates of 2010-18), Table II, own calculations.

In this way, the regressors-to-observations ratio comes to 28% in the former and to 23% in the latter of two analyses, while supplying a relatively detailed sense of regressor differences. At the same time, the Ramsey regression equation specification error test finds no evidence of functional form misspecification (variable omission) at the 1%, 5% and 10% significance levels; model fitness is good (the adj. R^2s ranges between 95 and 98%); and the residuals of the two expressions (regressions) are uncorrelated with each and every regressor employed (r=0%).

4. Econometric Findings, Further Calculations

The results regarding the effects of capital in expressions (2) and (3) are provided in Tables II and III, respectively. With circumstances varying across sectors, coefficients come out ranging from large positive to large negative numbers in Table II. As for Table III, the coefficient regarding the capital share of non-dwelling buildings and structures in sector 96 (see line 24, last column)[10] dwarfs all other coefficients. This brings to light the considerable effect the particular asset (the specific form of capital) had on the MFP component of sectoral output during the period under examination. Last but not least, the high value of the adj. R^2 in the analysis carried out in Table III, suggests that the autonomous, the temporal, and the error components of sectoral MFP are by and large explained by variations in the composition of the two inputs (i.e., by variations in the shares of the types of the two inputs), presumably reflecting technological shifts.

Next, based on the findings some additional calculations are performed. In particular, the impact of a marginal increment −say, by a thousand euro− on (top of) the capital available in 2018, in each sector, is calculated using the results of both Tables II and III. This involves: (a) the results of expression (2), associated with the aggregate sectoral measure of capital, its square, and two other capital-related effects -all based on the *K* and *L* figures of 2018- and (b) the corresponding figure from expression (3) associated with the particular type of capital (i.e., the thousand euro change in the particular type of capital, as if it was the only type of capital that changed), which are added up.[11] It turns out that the effect obtained from Table II dominates the effect obtained in Table III. In other words, the individual marginal

maintained. Merging (combining) regressors is given some leeway in the literature (e.g., Maj-Kańska et al., 2015; Quinn and Erb, 2020).

10. Regarding washing and (dry-) cleaning textile and fur products, hairdressing and other beauty treatments, funeral and related activities, physical well-being activities, and other personal service activities not classified elsewhere.

11. For instance, in the case of sector 96 the impact on output of a marginal increase in (non-dwelling) buildings-and-structures (K2) inputs takes into account the results (estimated coefficients) supplied in line 24 (last column) of Table III (with the marginal increment being applied to

sectoral effects of all types of capital presented in Table III are smaller than (or subordinate to) the overall marginal sectoral effect estimated in Table II of the opposite sign when both are expressed in euro. This suggests that in the setting described in the paper, deciding to invest in one sector over another may be more important than deciding what the sectoral investment, (i.e., what the increment in the stock of capital) is to be in: a building, machinery, software, etc.[12] See Table IV.

Table IV

The impact of a marginal capital increment (e.g., 1000 euro on top of the capital available in 2018) on sectoral Gross Value Added in Greece, based on the empirical findings of Tables II-III as per the effects of $b_i\,\Delta\ln(K_i) + d_i\,\Delta\ln^2(K_i) + e_i\,\Delta\ln(L_{it})\Delta\ln(K_{it}) + n_{ij}\,\Delta\ln(K_{ijt}) + \kappa_{ik}\,\Delta(K_{ik}/K_i)$, estimated from data spanning 2010-2018

Sectors	K1	K7	K2	K6	K3	K4	K5	K9	K8
84	–	–	–	–	–	–	–	–	–
01	o	–	–	–	–	–	–	o	–
05-09, 13-15, 16, 17, 21, 23, 24, 28, 36, 37-39, 41-43, 51, 52, 53, 58, 59-60, 62-63, 65, 71, 72, 85, 87-88, 90-92, 95	o	o	–	–	–	–	–	–	–
45, 50, 66, 78, 93	o	o	–	–	–	–	–	–	o
02	o	–	–	–	o	o	o	o	o
30	o	o	–	–	o	–	–	–	–
03	o	o	+	+	+	o	+	o	+
68	+	o	+	+	+	+	+	+	o
47, 79, 96	o	o	+	+	+	+	+	+	o
26	o	o	+	o	+	+	+	+	+
33, 64	o	o	+	+	o	+	+	+	+
10-12, 18, 19, 20, 22, 25, 27, 29, 31-32, 35, 46, 49, 55-56, 61, 69-70, 73, 74-75, 77, 80-82, 86, 94	o	o	+	+	+	+	+	+	+

K1: dwellings, K2: other buildings, structures, K3: transportation equipment, K4: computer hardware, K5: telecommunication equipment, K6: other machinery, K7: biological resources, K8: R&D, K9: computer software & databases

Key for symbols: "+" positive effect, "–" negative effect, "o" zero value/missing data; hence, unclear effect.

Source: See Tables II and III.

corresponding share), and the results supplied in lines 4 and 9 (last column) and line 20 (central column) of Table II.

12. This is not to say that the type of the sectoral investment chosen is unimportant or that the differences among the coefficients supplied in Table III are trivial.

Consequently: (a) In 29 of the country's economic sectors, namely, sectors 03, 10-12, 18, 19, 20, 22, 25, 26, 27, 29, 31-32, 33, 35, 46, 47, 49, 55-56, 61, 64, 68, 69-70, 73, 74-75, 77, 79, 80-82, 86, 94, 96, a marginal increment in the types of capital for which data is available, would probably have a positive effect on output, especially, in sectors 18 (printing etc.) and 20 (manufacture of motor vehicles etc.), where the highest positive marginal productivity is expected. These 29 sectors include sectors 46-47, 61, 64, 68-70, 73-75, 77, 79-82, in which an increased efficiency of certain forms of capital was detected by Antonopoulos and Sakellaris (2009) in the 1990s and early 2000s (see footnote 1).[13] (b) In 32 sectors, namely, sectors 01, 02, 05-06, 13-15, 16, 17, 21, 23, 24, 28, 30, 36, 37-39, 41-43, 45, 50, 51, 52, 53, 58, 59-60, 62-63, 65, 66, 71, 72, 78, 85, 87-88, 90-92, 93, 95, the same increment is expected to have a negative effect on output, especially, in sectors 30 (manufacture of other transport equipment), 66 (activities auxiliary to financial services etc.), and 95 (repair of computers etc.), where the highest negative marginal productivity is expected. It is not theoretically impossible or factually uncommon for a resource (in this case, capital) to have become inefficient or to have been or be employed inefficiently (see footnote 2). (c) In sector 84 (public administration etc.) a marginal increment in all types of capital is expected to have a negative effect on output. It is conceivable that in 2018, the capital accumulated in the sector was (or was about to become) inefficient. The multitude of sectors operating inefficiently prior to the pandemic perhaps ought, to some extent, to be attributed to the causes of the country's eight-year-long economic recession and the turbulence the recession triggered.

Considered in conjunction with the sectoral marginal products of labor by one worker, reported by Prodromidis (2022) (see Table V), these effects suggest that the following would have a positive effect on output: a marginal:

- reduction in capital and labor in sectors 05-09, 13-15, 21, 23, 28, 30, 37-39, 52, 53, 59-60, 62-63, 66, 71, 72, and 84;
- substitution of capital with any type of labor in sectors 01, 17, 24, 51, 65, 85, 90-92, 93, and 95;
- substitution of capital with: (a) workers holding post-secondary school qualifications in sector 02; (b) workers holding upper-secondary school or post-secondary school qualifications in sector 36; (c) workers holding basic or lower-level education qualification or technological institute qualifications in sector 50; (d) workers holding tertiary education level qualifications in sector 58; (e) labor members other than workers holding a bachelor's degree or postgraduate qualifications in sectors 16 and 45; (f) labor members other than workers holding

13. However, in several sectors a marginal increase in the capital stock of computers (esp., in sectors 25, 50, 94), of communication equipment (esp., in sectors 23, 50, 85), and of software (esp., in sectors 37, 87) turn out to be associated with a negative effect. See top left corner of Table III.

Table V

The impact of marginal increments in capital and labor in 2018 estimated from data spanning 2010-2018

Sectors	K1	K7	K2	K6	K3	K4	K5	K9	K8	L0	L1	L2	L3	L4	L5
01	o	–	–	–	–	–	–	o	–	+	+	+	+	+	+
17, 24, 51, 65, 85, 90-92, 95	o	o	–	–	–	–	–	–	–	+	+	+	+	+	+
93	o	o	–	–	–	–	–	–	o	+	+	+	+	+	+
02	o	–	–	–	o	o	o	o	o	–	–	+	–	–	–
16,	o	o	–	–	–	–	–	–	–	+	+	+	+	–	–
36	o	o	–	–	–	–	–	–	–	–	+	+	–	–	–
41-43	o	o	–	–	–	–	–	–	–	+	+	+	–	+	–
58	o	o	–	–	–	–	–	–	–	–	–	–	+	+	+
87-88	o	o	–	–	–	–	–	–	–	+	+	+	–	+	+
45	o	o	–	–	–	–	–	–	o	+	+	+	+	–	–
50	o	o	–	–	–	–	–	–	o	+	–	–	+	–	–
78	o	o	–	–	–	–	–	–	o	+	+	+	+	+	–
05-09, 13-15, 21, 23, 28, 37-39, 52, 53, 59-60, 62-63, 71, 72,	o	o	–	–	–	–	–	–	–	–	–	–	–	–	–
84	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
30	o	o	–	–	o	–	–	–	–	–	–	–	–	–	–
66	o	o	–	–	–	–	–	–	o	–	–	–	–	–	–
03	o	o	+	+	+	o	+	o	+	–	–	–	–	–	–
27, 35, 94	o	o	+	+	+	+	+	+	+	–	–	–	–	–	–
68	+	o	+	+	+	+	+	+	o	–	–	–	–	–	–
47	o	o	+	+	+	+	+	+	o	–	–	–	–	–	–
96	o	o	+	+	+	+	+	+	o	–	–	+	+	–	+
22	o	o	+	+	+	+	+	+	+	+	+	–	+	+	+
25	o	o	+	+	+	+	+	+	+	–	–	+	–	–	–
29, 73	o	o	+	+	+	+	+	+	+	–	–	+	+	–	–
31-32	o	o	+	+	+	+	+	+	+	+	+	–	+	+	–
46	o	o	+	+	+	+	+	+	+	–	+	–	+	–	+
49	o	o	+	+	+	+	+	+	+	–	–	–	–	–	+
55-56, 69-70	o	o	+	+	+	+	+	+	+	–	+	–	–	–	–
74-75	o	o	+	+	+	+	+	+	+	+	+	+	+	+	–
79	o	o	+	+	+	+	+	+	o	+	+	+	+	+	+
26	o	o	+	o	+	+	+	+	+	+	+	+	+	+	+
33, 64	o	o	+	+	o	+	+	+	+	+	+	+	+	+	+
10-12, 18, 19, 20, 61, 77, 80-82, 86,	o	o	+	+	+	+	+	+	+	+	+	+	+	+	+

K1: dwellings. K2: other buildings, structures. K3: transportation equipment. K4: computer hardware. K5: telecommunication equipment. K6: other machinery. K7: biological resources. K8: R&D. K9: computer software & databases.

L0: workers holding a basic or lower-level education qualification. L1: workers with an upper-secondary school diploma. L2: workers with a post-upper-secondary school certificate. L3 workers with a technological institute qualification. L4 workers with a bachelor's degree. L5: workers with a postgraduate degree.

Key for symbols: "+" positive effect, "–" negative effect, "o" zero value/missing data; hence, unclear effect.

Source: See Table IV and Prodromidis (2022).

technological institute or postgraduate qualifications in sectors 41-43; (g) labor members other than workers holding postgraduate qualifications in sector 78; (h) labor members other than workers holding technological institute qualifications in sectors 87-88;

- increase in capital and labor in sectors 10-12, 18, 19, 20, 26, 33, 61, 64, 77, 79, 80-82, and 86;
- increase in capital and (a) labor members with upper-secondary school qualifications in sectors 55-56 and 69-70; (b) labor with post-secondary school qualifications in sector 25; (c) labor members holding postgraduate degrees in sector 49; (d) labor with post-secondary school or technological institute qualifications in sectors 29 and 73; (e) labor members with post-upper-secondary school, technological institute or postgraduate qualifications in sector 96; (f) labor members with upper-secondary school, technological institute or postgraduate qualifications in sector 46; (g) labor members other than workers holding post-secondary school or postgraduate qualifications in sectors 31-32; (h) labor members other than workers holding post-secondary school qualifications in sector 22; (i) labor members other than workers holding postgraduate qualifications in sector 74-75;
- increase in K and reduction in L (i.e., substitution of capital with labor) in sectors 03, 27, 35, 47, 68, and 94.

5. Policy Implications - Conclusions

The paper econometrically estimates in two steps the impact of capital on production in Greece during 2010-18, across 62 sectors of economic activity. In particular, the paper first estimates in each sector the impact that a marginal change on the level of capital has on each sector's gross value added, in a translog production function setting. Next, the paper considers a marginal change for each of the various types of sectoral capital (buildings, machinery, software, etc.) and estimates the impact such a change has on the output-residual of the capital and labor effects obtained in the first step (i.e., the sectoral multi-factor productivity). Eventually, the paper calculates the collective impact of the marginal change on the amount of each type of sectoral capital onto the output figures of 2018 (a relatively recent pre-pandemic year of economic expansion).

Therefore, the paper (i) identifies sectors for which additional analyses may have to be carried out to determine the causes of high or low marginal productivity, while also discussing related prospects; and (ii) draws people's attention to sectors that conditions may be ripe for introducing new investments and new production paradigms. The paper also finds that: (a) The situation is more complex compared to that in the original Solow model. So, in the multisectoral (multi-product) economy of Greece, where various types of labor and capital are employed, a marginal capital injection may result not only in a trivial or modest or considerable production increase, but, in certain sectors may result in a trivial, modest or considerable production decrease. It follows that the features of the new capital added may be crucial for future growth, and may have different effects across sectors. (b) The autonomous, the temporal, and the error components of expression (1), i.e., of MFP, are explained, to considerable extent, by variations in the composition of the two inputs (i.e., by technological shifts). (c) The marginal product of capital in a sector is superior to the marginal product of each of the nine types of sectoral capital featuring an opposite sign. In this respect, deciding to invest in one sector over another is more important than deciding what the investment is to be in: i.e., building, machinery, etc. (d) The increased efficiency of certain forms of capital detected in a number of sectors in Greece in the 1990s and early 2000s is, in a general sense (when looking at the overall impact supplied in Table IV), confirmed in 2018. (e) If capital and other inputs are, by and large, expected to contribute to output in the same manner they contributed in the recent past (in 2018), it might be better if efforts were made in Greece focusing on: Drawing more investments in sectors where changes to the level of capital are associated with positive effects, preferably, where the marginal product of capital (MPC) is both positive and high; selling overseas a portion of capital assets from sectors in which the MPC is negative (i.e., associated with negative effects on output as per Tables II and III, and collectively presented in Table IV):[14] In certain cases (the top twelve cases of Table V) substituting capital with labor or certain types of labor, and in other cases substitute labor with capital, and types of labor with other types of labor or capital. Alternatively, decision makers may opt to organize (manage) the latter sectors in ways that will enable assets to be used more efficiently compared to the recent past, and/or to educate staff, and/or apply new practices, so that assets are employed more efficiently, and/or add new assets that are technologically improved, more efficient, and easier to use.

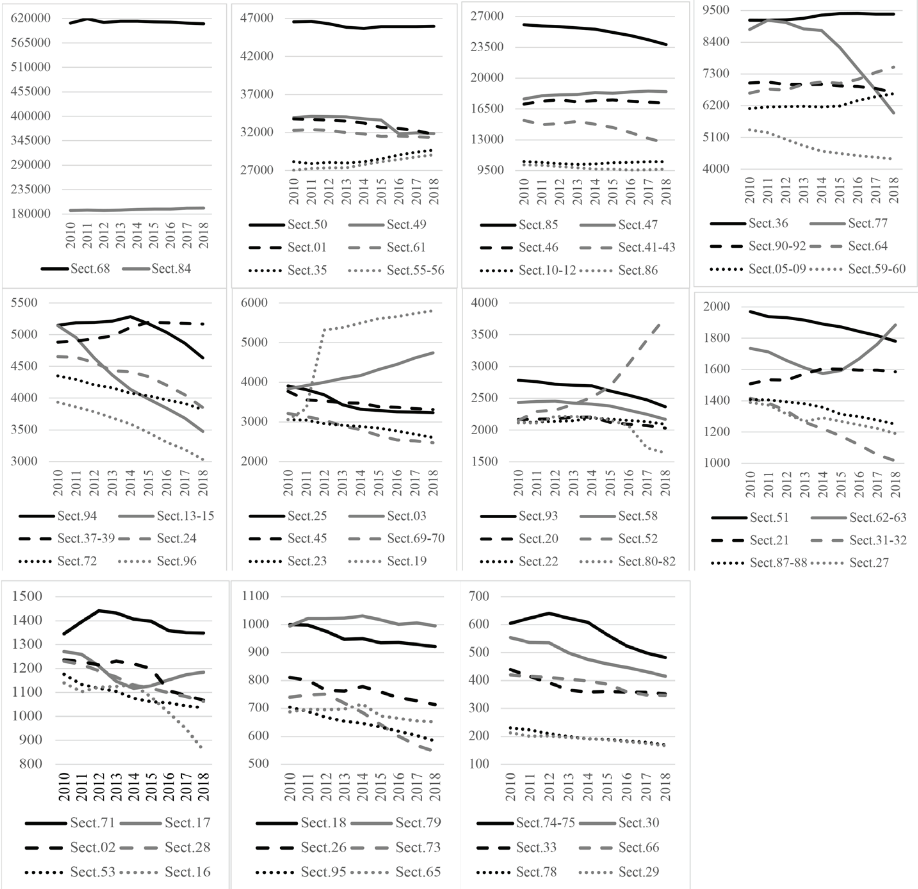
By assessing the impact on sectoral output that various types of capital assets have (or have until recently had) in Greece, the paper contributes to the discussion taking place in the country regarding the prospects of alternative economic development courses. Since data comparable to those used in the paper, i.e., concerning many sectors and types of capital inputs, are held by a good number of statistical institutes around the world, similar analyses and treatments of complexity may be performed for many countries in order to highlight baseline prospects, inform policy,

14. This is not to say to do get rid of the capital employed in a whole sector, but (based on the marginal feature of the analysis) to start from selling assets featuring the largest negative coefficients in each sector, i.e., start from selling some assets described in the top left corner of Table III, then sell some additional assets described lower in first column (moving down the first column), and, if necessary, continue by moving down the along the second column.

and improve aggregate performance. Overall, this paper contributes to the literature regarding decision making on investment projects and prospects.

Appendix 1

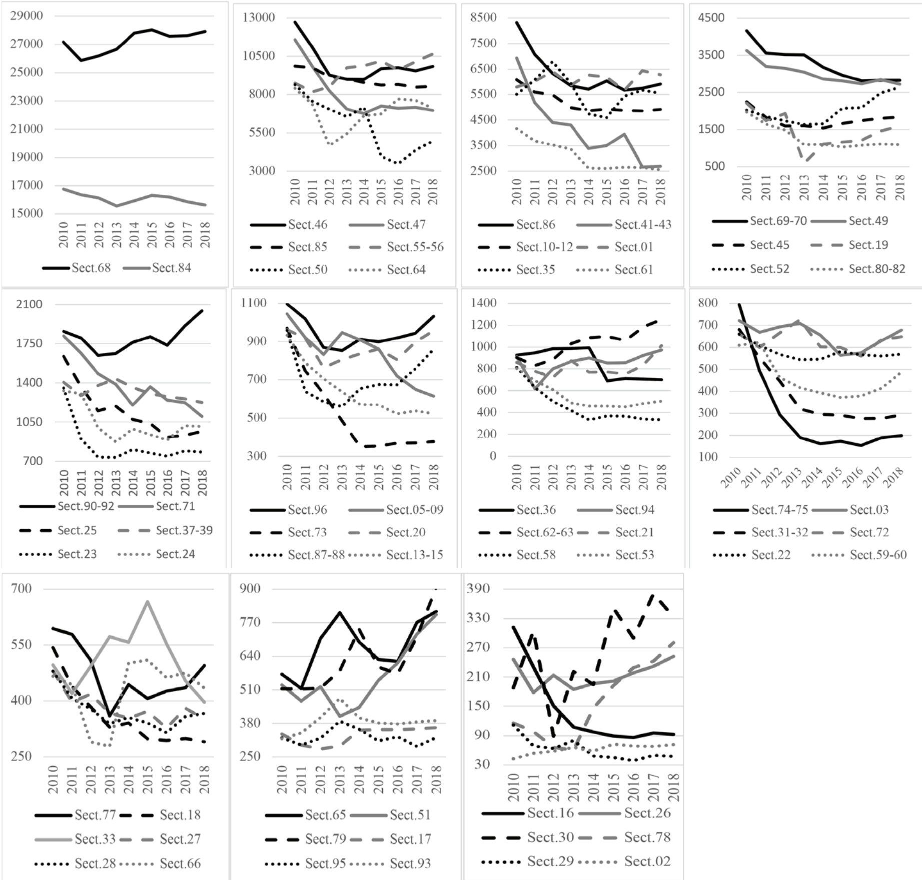
The Evolution of the Gross Fixed Capital Stock Value across Greece's Sectors of Economic Activity in Terms of 2015 Prices in Million Euro, 2010-18



Source: See Table II.

Appendix 2

The Evolution of the Gross Value Added across Greece's Sectors of Economic Activity in Terms of 2015 Prices in Million Euro, 2010-18



Source: See Table II.

Appendix 3

Appendix: Panel unit root tests for output, capital, labor, involving 62 panels and 8 periods

Method	Output (Y)		Capital (K)		Labor (L)	
	Statistic	P-value	Statistic	P-value	Statistic	P-value
Ho: Panels contain unit roots Ha: Panels are stationary						
• Levin-Lin-Chu test	-14.5411	0.0000	-63.6074	0.0000	-22.6162	0.0000
• Harris-Tzavalis test	-0.1779	0.0000	0.2099	0.0000	-0.0894	0.0000
• Breitung test	-4.9799	0.0000	-3.7352	0.0001	-7.4294	0.0000
Ho: All panels contain unit roots Ha: Some panels are stationary						
• Im-Pesaran-Shin test	-5.8594	0.0000	-2.6386	0.0042	-5.7801	0.0000
Ho: All panels contain unit roots Ha: At least one panel is stationary						
• Fisher-type unit-root test						
Inverse X^2	447.4910	0.0000	317.3166	0.0000	364.5660	0.0000
Inverse normal	-10.7098	0.0000	-5.0740	0.0000	-9.8621	0.0000
Inverse logit	-14.2627	0.0000	-7.8354	0.0000	-11.3069	0.0000
Modified inv. X^2	20.5417	0.0000	12.2756	0.0000	15.2760	0.0000

References

Ahmed T. and Bhatt A.A. 2020. Measurement and determinants of multifactor productivity: A survey of literature. Journal of Economic Surveys, 34.2: 293-319.

Antonopoulos C. and Sakellaris P. 2009. The contribution of Information and Communication Technology investments to Greek economic growth: An analytical growth accounting framework. Information Economics and Policy, 21.3: 171-191.

Arrow K.J. 1966. Optimal capital policy with irreversible investment. Stanford CA: Stanford University.

Begg D., Fisher S. and Dornbusch R. 2008. Economics. 9th edition. New York NY: McGraw-Hill.

Breitung J. 2000. The local power of some unit root tests for panel data. In B.H. Baltagi, T.B. Fomby and R. Carter Hill (Eds.) Nonstationary Panels, Panel Cointegration, and Dynamic Panels (Advances in Econometrics, Vol. 15). Leeds: Emerald, pp. 161-177.

Breitung J. and Das S. 2005. Panel unit root tests under cross-sectional dependence. Statistica Neerlandica, 59.4: 414–433.

Choi I. 2001. Unit root tests for panel data. Journal of International Money and Finance, 20.2: 249–272.

Diewert W. E. and Fox K. J. 2019. Productivity Indexes and National Statistics: Theory, Methods and Challenges. In T. ten Raa and W.H. Greene (Eds), The Palgrave Handbook of Economic Performance Analysis. Cham CH: Springer Nature, pp. 707-759.

European Commission. 2021. The performance framework for the EU budget, Vol. II, Luxembourg: Publications Office of the European Union.

Eurostat. 2008. NACE Rev. 2 - Statistical classification of economic activities in the European Community. Luxembourg: Office for Official Publications of the European Communities.

Fernald J.G. 1999. Roads to Prosperity? Assessing the Link between Public Capital and Productivity. American Economic Review, 89.3: 619-638.

Gecher S., Havranek T., Irsova Z. and Kolcunova D. 2022. Measuring capital-labor substitution: The importance of method choices and publication bias. Review of Economic Dynamics, 45 (July): 55-82.

Harris R.D.F. and Tzavalis E. 1999. Inference for unit roots in dynamic panels where the time dimension is fixed. Journal of Econometrics, 91.2: 201–226.

Heathfield D.F. and Wibe S. 1987. An Introduction to Cost and Production Functions, Houndmills and London: Macmillan.

Im K.S., Pesaran M.H. and Shin Y. 2003. Testing for unit roots in heterogeneous panels. Journal of Econometrics, 115.1: 53–74.

Levin A., Lin C.F. and Chu C.S.J. 2002. Unit root tests in panel data: Asymptotic and finite-sample properties. Journal of Econometrics, 108.1: 1–24.

Lopez-Garcia P. and Szörfi B. 2021. Key factors behind productivity trends in euro area countries. ECB Economic Bulletin, 7/2021: 92-114.

Maj-Kańska A., Pokarowski P. and Prochenka A. 2015. Delete or merge regressors for linear model selection. Electronic Journal of Statistics, 9.2: 1749-1778.

Matos P. and Neves P. 2020. The Determinants of Total Factor Productivity in the Portuguese Quaternary Sector. Office for Strategy and Studies (GEE) of the Portuguese Ministry of Economy Paper 149. Lisbon.

Miller S. M. and Upadhyay M. P. 2000. The effects of openness, trade orientation, and human capital on total factor productivity. Journal of Development Economics, 63.2: 399-423.

OECD. 2021. The Territorial Impact of COVID-19: Managing the Crisis and Recovery across Levels of Government. Paris: Organisation for Economic Co-operation and Development.

Pablo-Romero M.P. and Gómez-Calero M.P. 2013. A translog production function for the Spanish provinces: Impact of the human and physical capital in economic growth. Economic Modelling, 32.3: 77-87.

Parrotta P., Pozzoli D. and Pytlikova M. 2014. Labor Diversity and Firm Productivity? European Economic Review, 66.3: 144-179.

Prodromidis P.I. 2022. The impact of workers' education on production in Greece, 2010-18. Hellenic Open Business Administration Journal, 8.1-2: 75-87.

Quinn T.P. and Erb I. 2020. Amalgams: data-driven amalgamation for the dimensionality reduction of compositional data, NAR Genomics and Bioinformatics, 2.4.

Royal Swedish Academy of Sciences. 1987. The Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel 1987 was awarded to Robert M. Solow "for his contributions to the theory of economic growth". Press release, October 21, 1987.

Samuelson P. A. and Nordhaus W.D. 2010. Economics. 19th edition. New York NY: McGraw-Hill.

Solow R.M. 1956. A contribution to the Theory of Economic Growth. Quarterly Journal of Economics, 70.1: 65-94.

Temple J. and Wößmann L. 2006. Dualism and cross-country growth regressions. Journal of Economic Growth, 11.3: 187-228.

Tzouvelekas E. 2000. Approximation Properties and Estimation of the Translog Production Function with Panel Data. Agricultural Economics Review, 1.1: 33-47.

van Elk R., ter Weel B., van der Wiel K. and Wouterse B. 2019. Estimating the Returns to Public R&D Investments: Evidence from Production Function Models. De Economist, 167.1: 45–87.

Vettas N., Louka A., Peppas K., Pountouraki Y. and Vasileiadis M. 2022. Trends in total factor productivity in Greece and its determinants during the period 2005-2019. Bank of Greece Economic Bulletin, 56: 7-43.