Capital productivity in industrialized economies: evidence from error-correction model and Lagrange Multiplier tests

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Abstract

The paper re-examines the "stylized facts" of the balanced growth in developed economies, looking specifically at capital productivity variable. The economic data is obtained from European Commission AMECO database, spanning 1961-2014 period. For a sample of 22 OECD economies, the paper applies univariate LM unit root tests with one or two structural breaks, and estimates error-correction and linear trend models with breaks. It is shown that diverse statistical patterns were present across economies and overall mixed evidence is provided as to the stability of capital productivity and balanced growth in general. Specifically, both upward and downward trends in capital productivity were present, while in several economies mean reversion and random walk patterns were observed. The data and results were largely in line with major theoretical explanations pertaining to capital productivity. With regard to determinants of the capital productivity movements, the structure of capital stock and the prices of capital goods were likely most salient.

JEL Codes: C12, C22, N10, O47

Keywords: Capital productivity, structural breaks, unit root tests, growth

1. Introduction

The idea that several economic variables are roughly constant over the course of economic growth has been central to economic theory in general and growth and distribution theories in particular. It dates back to early works by N. Kaldor (1961), who argued that economies operate at near balanced growth paths and that certain "stylized facts" are present. It was posited specifically (Kaldor, 1961, pp. 177-222; Jones & Romer, 2009, p. 2) that: 1). Labour productivity (Y/L) and capital per worker (capital intensity – K/L) grow at sustained and roughly similar rates with no tendency to fall; 2). Rates of return on capital remain steady; 3). Capital-output ratio (K/Y) shows no systematic trend; 4). Shares of labour and capital in national income remain

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stable; 5). There exist considerable variations in the rate of growth among fast growing countries, as well as in the rate of growth of productivity across countries.

Following Kaldor and Mirrlees (1962) and Romer (1989) among others, the identity-type relationships between the facts are acknowledged. Firstly, the rate of return on capital is a product of capital productivity (the inverse of capital-output ratio), and capital share. Secondly, the product of labour productivity and the inverse of capital intensity gives capital productivity (Y/L x L/K = Y/K). Thereby, the stability of the capital productivity and labour share implies stability of the rate of return. Likewise, the rate of change in capital productivity is sustained, if labour productivity and capital intensity grow at similar rates.

Capital productivity is thus a salient variable that reflects the patterns of technical change and that also determines the level of profitability in the economy. The purpose of the paper is to examine the dynamics of capital productivity in the industrialised economies, specifically to consider its statistical properties (stationarity versus mean reversion and random walk), its interaction with labour productivity, capital intensity and other relevant variables, and its implications for technical change, and balanced growth in the respective economies.

As put by Evans (2000, pp. 4-5) the theoretical economic growth literature tends to express the stylised facts in terms of constancy of factor shares, capital-output ratio and return on capital, while the real economies are inevitably stochastic economies. Hence, we consider it more appropriate to analyse respective variables using terms “steady”, “stable”, and “mean reverting”, and adopt this terminology throughout the paper.

The paper introduces two novelties. Firstly, it examines the balanced growth stylized facts as originally formulated by Kaldor, in contrast to more recent “balanced growth literature” (King et al., 1991, p. 819) that looks for empirical support of Kaldor’s facts based on consumption, investment and output variables (specifically considering consumption/output and investment/output ratios). Secondly, while Kaldor’s stylized facts are supposed to hold in the long-run, breaks and other disruptions to the balanced growth may nonetheless be present in the short-run. In this connection, the paper incorporates the analysis of the structural breaks into trend and error-correction modelling, as well as employs recently developed Lagrange Multiplier (LM) unit root tests with one or two structural breaks. Thirdly, a relationship between capital productivity and other relevant variables is examined in a narrative form.

2. Literature review

The stylized facts of balanced growth have been the cornerstone of neoclassical growth models. They were also a research object in a number of studies, both the analyses of individual stylized facts, as well as “multi-fact” studies. These were principally concerned with the empirical testing of long-run relationships between output, investment and consumption within neoclassical growth models framework (Kunst & Neusser, 1990; King et al., 1991; Mills, 2001; Harvey, 2003; Li & Daly, 2009, among others). The balanced growth patterns were identified in some cases, and rejected in the others.

Evans (2000, pp. 14-15) examined Kaldor’s stylised facts in the post-war US context using trend regressions and Dickey-Fuller unit root tests. He concluded that in the period considered the capital-output ratio, the net rate of return on capital, the net share of capital in output and the net investment rate have all been mean reverting. The growth rate of per capita output was also mean reverting and did not show downward trend. The Kaldor facts held despite sharp decline in capital-output ratio and sharp increase in the return to capital during WWII years.

The comparative empirical testing of the stylized facts of economic growth using Penn tables has recently been performed by Steger (2001) in the context of developing economies. However, the facts examined were different from those originally formulated by Kaldor and concerned the diversity of growth rates, correlation between savings rate and economic growth rate, between the growth rate and the level of income per capita, as well as convergence / divergence of per capita income.

Analysis of labour share and labour productivity concerned identification of factors that were responsible for slowdown and non-uniform growth rates of labour productivity (Nordhaus, 2002; Gordon, 2012, among others) or for deterioration of labour share (Acemoglu, 2002; Torrini, 2005; Dunhaupt, 2012).

The studies that examined capital intensity focused specifically at dynamics of factor proportions in economic growth and concluded that capital-labour ratio has been rising in the developed economies, albeit without investigating whether the growth was steady or declining (Mills, 2009; Karabarbounis & Neiman, 2014). The study by Lawrence (2015, p. 4) stands as exception, arguing in favour of declining effective capital-labour ratios in the US, resulting from the preponderant labour-augmenting (instead of labour-saving) technical change at both aggregate and industry levels.

The early analysis of capital productivity and capital-output ratio by Denison (1967) confirmed Kaldor stylised fact: the level of capital-output ratio was remarkably constant across countries of differing stages of development, implying that capital-output ratio is steady over time. In contrast, Klein and Kosobud (1961) based on the US data spanning 1900-1953 estimated linear trend model and established significant downward trend in capital productivity. More recent analyses of the fact included Mills (2009), Madsen et al. (2012) and D'Adda and Scorcu (2003). The analysis of the original Klein-Kosobud data by Mills suggested that Y/K was trend-stationary around downward trend, thus giving support to Klein and Kosobud's paper. Results by D'Adda and Scorcu are mixed: while Y/K ratio appeared to be stationary for extended periods in the US and Germany, there was also a tendency for reduction in the levels of Y/K across economies, e.g. capital productivity in the "follower" economies (Italy, France etc.) was converging to that of leader economy (USA). In contrast, Madsen et al. provide more robust support of stationarity of capital productivity (observed in 15 out of 16 OECD economies). This is in line with earlier work by Romer (1989) who reported remarkably similar growth rates in output and capital stock in the US over 1870-1913, 1913-1950, and 1950-1979 periods. In the developing countries' context Hofman (2000) considered capital productivity in Latin America. The mixed findings included increasing growth of capital productivity in few economies between 1950-80 and 1980-98 periods (Argentina, Bolivia, Chile, Peru) and slowdown in capital productivity in other economies of the region.

To provide theoretical account for the fall or slowdown of capital productivity, Foley and Michl (1999) pointed to the likelihood of labour-saving technical change over the course of economic development process. This respectively implies substitution of labour for capital, rising labour productivity in tandem with falling capital productivity (and hence impossibility of steady and trendless capital-output ratios). This argument was empirically tested for a set of developed and developing economies (King & Levine, 1994, pp. 22-23): the capital-output ratio was found to vary positively and significantly with income per capita.

In light of mixed evidence, the analysis of the capital productivity dynamics requires further empirical investigation. Most recent studies of capital productivity relied on the application of up-to-date econometric tests: Gregory-Hansen cointegration test with single endogenous break (D'Adda & Scorcu, 2003), Perron-Vogelsang, Clemente-Montanes-Reyes, and Carrion-i-Silvester tests (Madsen et al, 2012). This paper likewise uses a combination of methods to deliver robust conclusions - linear trend analysis with correction for serial correlation, error-correction (ECM) modelling with breaks, and univariate Lagrange Multiplier tests with up to two endogenously determined structural breaks. In contrast to other studies of capital productivity, the paper also looks at the relationship of capital productivity with other variables of interest and analyses capital productivity within a broader context of economic growth and productivity.

3. Empirical results

3.1 Data

The data for this paper was obtained from European Commission AMECO database that collects national accounts data for respective European and selected non-European economies. The original data is prepared by Eurostat or national statistic bodies.

Capital productivity variable (AVGDK) is defined as the ratio of GDP at constant market prices to net capital stock at constant prices. The latter for any particular period was calculated using perpetual inventory method (PIM) and depreciation rates from respective national accounts, as net capital stock at constant prices in the previous period plus gross fixed capital formation at constant prices (total economy) minus consumption of fixed capital (total economy) divided by price deflator for gross fixed capital formation. Instead of assuming homogenous capital stock, separate estimates of the capital stock were obtained for structures (residential and non-residential), equipment, agricultural assets, mineral exploration assets, and various intangible assets (Caselli & Wilson, 2004). The starting capital stock in the series was calculated assuming fixed K/Y ratio in 1960 (K/Y=3).

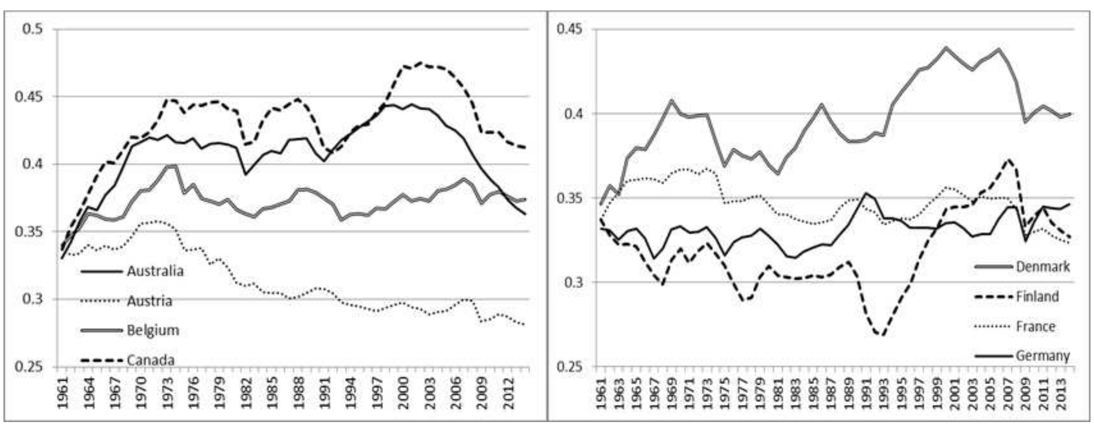
We note that dynamics of capital productivity is intertwined with movements in labour productivity and capital intensity. These latter variables were considered and defined as follows. Labour productivity variable (RVGDE) was defined as the ratio of GDP at constant market prices to total employment in all domestic industries. The latter included both residents and non-residents, covered employed and self-employed persons, and was calculated as year average. Capital intensity variable (RKNDE) was defined as the ratio of net capital stock at constant prices to total employment in all domestic industries.

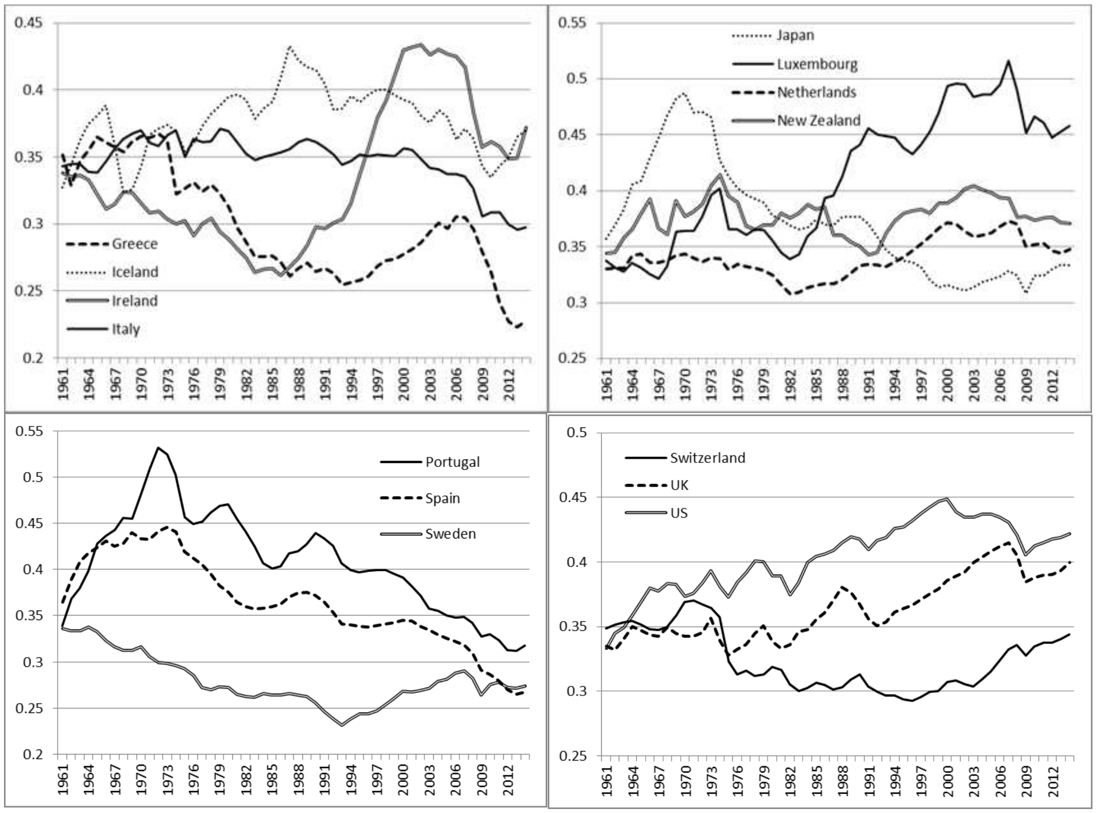
The period covered for each economy was set sufficiently long to examine variation of capital productivity, spanning 1960-2014. For other variables of interest that determine capital productivity the period covered 1961-2014 (labour productivity growth rates) and 1963-2014 for capital intensity growth rates. The paper considers following developed economies – Australia, Austria, Belgium, Canada, Denmark, Finland, France, Greece, Iceland, Ireland, Italy, Japan, Luxembourg, Netherlands, New Zealand, Portugal, Spain, Sweden, Switzerland, UK, and USA.

3.2 Empirical results

As a first step, the visual inspection of the series was performed (Figure 1). A number of economies demonstrated rising capital productivity (Belgium, Denmark, Luxembourg, UK, and USA). Capital productivity was falling in Austria, Greece, Italy, Spain and Portugal. Trendless patterns or random walk behavior appeared to characterize capital productivity in Australia, Finland, France, Ireland, Netherlands, Iceland and New Zealand.

Figure 1. Capital productivity in industrialized economies (1961-2014)





As a second step, a trend model was estimated using semi-logarithmic equation as follows:

$$\ln x_{it} = c + \beta_i t + \mu_{it}, \tag{1}$$

Where x is a variable in question for country i, t is the year of observation, and μ_{it} is a random disturbance term. Parameter β_i indicates the average annual change of variable x along the linear trend. To correct for possible autocorrelation, Prais-Winsten iterative procedure is adopted (Canjels & Watson, 1997).

It is acknowledged following Nelson and Kang (1984) that making assessments based on visual inspection of the series or estimation of the linear trend prior to consideration of the unit root properties of the series may be erroneous, due to the possibility of the spurious regression (or spurious cyclicality or breaks). On the other hand, Canjels and Watson (1997) provide arguments in favour of AR models. We therefore retain trend estimates to be interpreted in conjunction with other tests.

The results of linear trend estimation are presented in Table 1. The negative trend in capital productivity was present in 9 out of 22 economies (statistically significant only in the case of Austria, Greece, Italy, Spain and Sweden). Positive and significant trend was identified in Belgium, Denmark, Germany, Luxembourg, UK and the USA. The largest significant decline was experienced in Greece (-41.40%), the largest increase in Luxembourg (36.86%).

Table 1. Trend estimates of capital productivity

Country	Trend	Cumulative change (%)	p-value	rho	Break	Model
Austria	-0.0039	-20.44	0.00	0.86		TS
Australia	0.0018	9.43	0.45	0.99		
Belgium	0.0011	5.72	0.09	0.82		TS
Canada	0.0037	19.69	0.13	0.98		
Denmark	0.0026	13.96	0.02	0.88		TS
France	-0.0010	-5.52	0.11	0.86		
Finland	0.0003	1.70	0.86	0.92		
Germany	0.0009	4.55	0.04	0.67		TS
Greece	-0.0078	-41.40	0.00	0.93		TS
Iceland	0.0014	7.59	0.36	0.86		
Ireland	0.0021	11.27	0.52	0.97		
Italy	-0.0026	-13.63	0.08	0.94		TS
Japan	-0.0019	-10.14	0.47	0.97		
Luxembourg	0.0070	36.86	0.00	0.89		TS
Netherlands	0.0012	6.20	0.29	0.93		
New Zealand	0.0009	4.62	0.35	0.79		
Portugal	-0.0014	-7.49	0.71	0.99		
Spain	-0.0059	-31.53	0.02	0.98		TS
Sweden	-0.0038	-20.33	0.08	0.97		TS
Switzerland	-0.0004	-2.09	0.83	0.98	1975-6	
UK	0.0036	19.01	0.00	0.84	2009	TS
USA	0.0041	21.83	0.00	0.88		TS

Notes: TS indicates the presence of deterministic trend.

As a third step, an error-correction model (ECM) was considered that avoids spurious results, by incorporating both trend-stationary and difference-stationary model components (Bleaney & Greenaway, 1993).

The model equation is:

$$\Delta \ln x = \alpha + \beta t + \psi \ln x_{t-1} + \delta \Delta \ln x_{t-1} + v_t \quad (2)$$

Where x is a respective variable, β is a trend coefficient, v_t is a random disturbance term, and ψ is an error-correction term. The ECM model is correctly specified when $\psi < 0$. The variable in question follows random walk with zero mean, when $\beta = 0, \psi = 0$; reverts to historical mean, when $\beta = 0, \psi < 0$; performs random walk with drift (i.e. has stochastic trend), when $\beta \neq 0, \psi = 0$ and $\beta > 0$ or $\beta < 0$; and reverts to non-zero deterministic trend, when $\beta \neq 0, \psi < 0$, specifically $\beta < 0, \psi < 0$ or $\beta > 0, \psi < 0$. In the fourth case, when trend was present, the annual rate of change of x along the trend was estimated as $-\beta\psi^{-1}$. Also, the reliable guide as to the future behaviour of the series is obtained only in second and fourth case (i.e. series with no random walk). Standard t-ratio statistics is used to determine significance of all terms except $\ln x_{t-1}$ (in which case Dickey-Fuller unit root t-statistics is used).

Impulse or shift dummies were added to capture the break in the level or trend of the series. When heteroscedasticity was present and/or autocorrelation was not removed, ECM with Newey-West and/or Huber-White terms was estimated.

ECM model results are presented in Table 2. The coefficient of error-correction term (ψ) was negative and hence the model was considered valid. Deterministic trend for capital productivity was observed in 11 economies based on t-statistics, and 3 economies based on Dickey-Fuller statistics. The latter economies are Germany, UK and the US. Positive and significant trends in capital productivity were observed in Finland, Germany, Ireland, Luxembourg, Sweden, UK and the US). Negative significant trend were present in Austria, Australia, France, Japan, Portugal and Spain.

Table 2. Results of error-correction model

Country	δ	p-value	ψ	t-statistics	Break	Trend	R^2	Notes	Model
Austria	-0.0006	0.08	-0.140	-1.98	2009	-0.43	0.19		DT
Australia	-0.0005	0.01	-0.043	-1.25	1982	-1.09	0.48		ST
Belgium	-0.0001	0.45	-0.147	-1.78	1975	X	0.24		MR
Canada	-0.0001	0.47	-0.100	-2.44	1982	X	0.47		MR
Denmark	0.0003	0.27	-0.143	-2.13	2009	X	0.19		MR
France	-0.0002	0.04	-0.106	-1.84	1975, 2009	-0.23	0.48		DT
Finland	0.0005	0.03	-0.107	-2.40	1991, 2009	0.45	0.50		DT
Germany	0.0005	0.00	-0.379	-4.34	2009	0.13	0.38	HW	DT
Greece	-0.0007	0.18	-0.152	-2.29	1974	X	0.21	HW	MR
Iceland	-0.0004	0.10	-0.188	-3.64	1967-8	-0.21	0.53		DT/MR
Ireland	0.0006	0.03	-0.047	-1.70	2008	1.29	0.43		DT
Italy	-0.0005	0.05	-0.069	-1.12	1975, 2009	-0.67	0.40	NW	ST
Japan	-0.0010	0.00	-0.090	-2.41	1974, 2010	-1.09	0.59		DT
Luxembourg	0.0012	0.07	-0.132	-1.90	2008-9	0.91	0.23		DT
Netherlands	0.0002	0.18	-0.061	-1.34	2009	X	0.29		RW
New Zealand	-0.0002	0.37	-0.237	-2.83	1967	X	0.24		MR
Portugal	-0.0012	0.00	-0.105	-2.96	1975	-1.16	0.55		DT
Spain	-0.0010	0.01	-0.115	-2.99	2009	-0.90	0.55		DT
Sweden	0.0003	0.10	-0.028	-0.80	2009	1.16	0.26	NW	ST
Switzerland	0.0001	0.45	-0.011	-0.31	1975	X	0.52		RW
UK	0.0008	0.01	-0.226	-3.25	1974	0.34	0.38		DT
USA	0.0006	0.03	-0.206	-3.33	1982, 2009	0.30	0.34		DT

Notes: DT, ST, MR and RW indicate deterministic trend, stochastic trend, reversion to historical mean, and random walk respectively. X implies that trend coefficient is not significant and is considered to be zero. HW indicates Huber-White heteroscedasticity-consistent standard errors due to presence of heteroscedasticity. NW indicates Newey-West standard errors to overcome heteroscedasticity and autocorrelation.

The largest increase along deterministic trend was present in Ireland and Luxembourg (1.29% p.a. and 0.91% p.a.), while largest decrease took place in Portugal (-1.16% p.a). Series in Belgium, Canada, Denmark, Greece and New Zealand were reverting to historical mean, while series in Netherlands and Switzerland were following random walk. Capital productivity in Australia, Italy and Sweden was following stochastic trend. In the case of Iceland, ECM findings are inconclusive, with either deterministic trend or mean reversion possible.

In the majority of cases, the correctly specified ECM was obtained if dummy variables (of impulse of shift form) representing structural breaks in series were included. These breaks largely correspond to country-specific or global economic events and developments. The breaks were principally located during business cycle troughs - global recession of 2008-10 (13 cases), recession of 1973-75 that followed 1973 oil crisis and collapse of Bretton-Woods (8 cases), recession of the early 1980s in the USA (triggered by contractionary monetary policy), 1967-8 recession in Iceland (attributed to the fall in fish exports and decline in export prices), 1967 recession in New Zealand (associated with the collapse of wool prices in international market). Breaks also represented major structural changes in respective economies (1991 in Finland, corresponding to collapse of COMECON and trade with Eastern bloc), and possibly political changes (such as 1974 break, indicating restoration of democratic rule in Greece).

It is known that Augmented Dickey-Fuller test, upon which ECM is based, tends to have low power in the presence of structural breaks, and has bias towards non-rejection of the unit root null. Lee and Strazicich (2003, 2004) Lagrange Multiplier (LM) tests adopted in this paper address this shortcoming, and also have other advantages: determine up to two structural breaks endogenously, and solve the problem of spurious rejections typical to other tests with breaks (consideration of time series as stationary when they are non-stationary with breaks).

Lee-Strazicich LM tests are based on

$$y_t = \delta' Z_t + e_t \qquad (3)$$

and

$$e_t = \beta e_{t-1} + \mu_t \tag{4}$$

data-generating process, where y_t are series, δ is coefficients' vector, μ_t is error term, and Z_t is a matrix of exogenous variables. While two models (A and C) are available for LM test, this paper uses C model as more general and encompassing Model A (Sen, 2003). In Model C, $Z_t = [1, t, D_t, DT_t]$, i.e. allows for shift in intercept and change in the trend slope under H_a. The LM unit root statistics is obtained from

$$\Delta x_t = d' \Delta Z_t + \phi \tilde{S}_{t-1} + \sum x_i \Delta \tilde{S}_{t-i} + \varepsilon_t , \tag{5}$$

where $\tilde{S}_t = x_t - \hat{\psi}_x - Z_t \hat{\delta}_t$, $t = 2,...,T$; $\hat{\delta}$ are coefficients in the regression of Δx_t on ΔZ_t; $\hat{\psi}_x$ is given by $x_t - Z_t \delta$; and x_1 and Z_1 are first observations of x and Z. LM test statistics is derived assuming $H_0 : \phi = 0$. The relevant structural breaks are grid searched over trimmed $(0.1T, 0.9T)$ region, where T is a sample size. The optimal lag length is determined through general-to-specific procedure (maximum number of lags of k=8, and 10% significance value of the last lag is equal to 1.645). The breaks are located where LM t-statistics is at the minimum.

LM tests were implemented in a sequential manner. LM unit root test with two endogenous structural breaks (Model C) was run. The results of the test were considered final and series were seen as either trend stationary with two breaks or containing unit root with two breaks, if based on t-statistics critical values, one of the following held: 1) Two level (B_{jt}) and two trend (D_{jt}) dummies were significant; or 2) Two trend dummies and one level dummy were significant; or 3) Two trend dummies were significant. In other cases, LM unit root test with one endogenous break was run. If the trend dummy was significant, the series were seen as either trend stationary with single or containing unit root with single break.

The LM unit root tests with breaks demonstrate mixed results (Table 3). Up to two structural breaks were identified in all economies (single break in Austria, Finland, Ireland and Sweden).

Table 3. Lagrange Multiplier test results

Country	LM test (2 breaks)					LM test (1 break)				Model
	Break significance			Break dates		Break significance			Break date	
Austria						-4.150	[8]	D1	1983	URB
Australia	-4.844	[8]	D1D2	1987	1991					URB
Belgium	-5.986**	[4]	B1D1B2D2	1979	2002					TSB
Canada	-4.603	[5]	D1D2	1973	1997					URB
Denmark	-5.115	[8]	D1B2D2	1986	1992					URB
France	-4.097	[6]	D1D2	1973	1995					URB
Finland						-3.956	[3]	D1	1997	URB
Germany	-5.974**	[1]	D1D2	1987	1994					TSB
Greece	-4.586	[3]	D1D2	1978	2000					URB
Iceland	-6.788*	[3]	B1D1D2	1985	2007					TSB
Ireland						-5.642*	[5]	B1D1	1993	TSB
Italy	-5.710**	[3]	B1D1B2D2	1974	2005					TSB
Japan	-4.355	[4]	B1D1D2	1978	1996					URB
Luxembourg	-4.996	[7]	D1D2	1984	2002					URB
Netherlands	-4.177	[1]	D1D2	1980	1998					URB
New Zealand	-6.450*	[5]	B1D1D2	1973	1998					TSB
Portugal	-7.461*	[2]	D1D2	1973	1988					TSB
Spain	-7.426*	[4]	B1D1D2	1973	1993					TSB
Sweden						-4.785**	[6]	D1	1993	TSB
Switzerland	-5.966**	[4]	B1D1D2	1979	2003					TSB
UK	-5.117	[5]	B1D1D2	1973	2001					URB
USA	-5.230	[1]	D1D2	1980	1999					URB

Notes: B1, B2, D1 and D2 indicate significant level and trend break points at 5% significance level (for the first and second break respectively). Lags selected by general-to-specific procedure are shown in square brackets. Series are considered trend stationary with breaks at 5% significance level; symbol (*) indicates significance at 1% and symbol (**) significance at 10% levels. LM test (Model C with 1 break) 5% critical values range from -4.45 to -4.51 depending on break location. LM test (Model C with 2 breaks) 5% critical values range from -5.59 to -5.73 depending on break location.

The timing of these breaks had moderate correspondence with major events and developments – out of 40 breaks, only 1 break can be tallied with global recession of 2008-10, further 7 breaks with 1973-4 recession, and another 7 with early-1980s recession. We acknowledge in this regard that LM is a test for unit root with break versus trend stationarity with breaks, rather than test for the timing of breaks, and hence breaks suggested by the test may have no or little relation to actual economic changes. Trend stationarity with break(s) was observed in Belgium, Germany, Iceland, Ireland, Italy, New Zealand, Portugal, Spain, Sweden and Switzerland. In other economies, capital productivity series were seen to contain unit root with break(s).

The three types of estimates (linear trend with Preis-Winsten correction for autocorrelation; error-correction modelling; and Lee-Strazicich tests) tended to identify in many instances different behaviour in the series. Acknowledging that ECM and Lee-Strazicich tests are based on more robust methodologies (but that linear trend model and visual inspection may nonetheless provide insights as to the series' patterns), the following conclusion is made as to the series. 1). If all three methods suggest significant trend (with or without breaks) in the series, the series are considered to be trend stationary (with or without breaks). The opposite holds if trends are not identified. 2). If either ECM or Lee-Strazicich test points to significant trend, while the other method does not, the conclusion is made based on linear trend model with correction for autocorrelation (i.e. whether this model suggests significant trend or not) and visual examination. 3). If both ECM and Lee-Strazicich test point to the significant trend, but this contradicts linear trend model and the "eyeball test", statistically significant trend is deemed to be present. The rule will also apply to the opposite situation (i.e. if ECM and Lee-Strazicich indicate no trend, but linear trend model and visual observation do, no significant trend is seen to be present).

We conclude overall that empirical results are mixed. Taking into account all three tests, capital productivity was following trend with breaks in 11 cases, and was reverting to historical mean or exhibiting stochastic patterns in other 11 cases. All three tests unequivocally indicated trend stationary with two breaks in Germany and

Spain, and non-stationary behaviour in Australia, Canada and Netherlands. Of these three economies, capital productivity in Canada was mean reverting (in line with balanced growth predictions), while in Australia and Netherlands series were following random walk or random walk with drift. In all other countries, tests yielded conflicting results and the decision was made as per aforementioned sequential procedure. Interpreting LM test and ECM results in conjunction, the mean reversion could also be identified in Denmark, Greece, and possibly New Zealand and Iceland.

3.3 Economic significance

The empirical results attest to a number of tendencies and developments taking place in the industrialised economies.

The fall in capital productivity in several economies illustrates ongoing economic growth process and convergence to the steady-state as per Solow model in the long-run (Jones & Manuelli, 1990). While arguably none of the OECD economies was in a steady state by 1960s (complete substitution of labour for capital and per capita income determined solely by technological factors), such economies as Japan, Italy, Greece, Portugal and Spain were the furthest away from the most advanced economies of the time (USA) as attested by the respective GDP per capita differentials. Falling capital productivity in these economies thus demonstrates lower per-capita capital stock in these economies at the beginning of the period and catching up proceeding at a higher speed than in the remainder of the economies considered. This result is in line with observations of capital productivity in Italy and Japan made by Feu (2003). The use of this theoretical cadre however leaves unexplained why capital productivity fell in Sweden and Switzerland (countries likely to be near or at steady state) and did not fall in Ireland and Iceland (countries that had similarly low GDP and capital per capita in the early 1960s). Overall, capital productivity estimates on AMECO set confirm results by D'Adda and Scorcu (2003) as to direction and general pattern of the variable for Japan, Italy, Netherlands, but not France, UK, USA and Germany.

The levels and trends in capital productivity were also considered in terms of the efficiency and effectiveness of the use of capital. The study by McKinsey Global Institute (1996) on capital productivity identifies German and Japan "productivity puzzles" (despite much saving and increase in labour inputs in Japan and capital-deepening in Germany, the labour productivity levels lag behind US levels). Results of the analysis confirmed McKinsey's "puzzles": the levels of capital productivity (and efficiency of capital use) in these economies was much lower than in the US (indeed falling in Japan and virtually stable in Germany), translating into sizeable slowdowns in labour productivity (in contrast to rising Y/L in the US). In Germany, Japan and the US, the growth rates of capital productivity in 1964-69 were 4.78%, 3.05% and 2.06% per annum, in 1990-99 were 0.50%, 1.06% and 2.01% per annum, and in 2000-09 were 0.35%, 0.755 and 1.33% per annum respectively. Results showed high level of Y/K on par with the US in Canada (due to tight economic integration) and higher than US level in Luxembourg (in line with higher GDP per capita and labour productivity). The lowest levels of Y/K were identified in Greece known for inefficient use of capital inputs particularly in agriculture (Polyzos & Arabatzis, 2006), and Sweden, where low capital productivity is due to high depreciation rates (specifically for period since the 1970s) used in AMECO (Perez & Garcia, 2014).

The paper showed that in the short-run the movements in capital productivity and capital-labour ratio growth rates were attributed to business cycle fluctuations. Specifically, the segments of falling capital productivity coincided with recessions or periods of sluggish growth. This regularity applied to most economies (to smaller extent to Austria, Greece and Japan) with the exception of Portugal and Spain, where falls in capital productivity were driven more by structural and policy factors. Capital deepening was also accelerating during recessions, when the job destruction is the highest and opportunity costs of job reallocation and shedding are the lowest (Caballero & Hammour, 1996), resulting in capital productivity falls. Spikes in capital-labour ratio were observed in Canada, USA, Italy, Belgium, and Netherlands during three recessions of early 1980s, early 1990s and global financial crisis of 2008-09. In other economies, capital-labour ratio increased during one or two major recessions, while in Japan, Germany and New Zealand capital-labour ratio was acyclical.

Regarding factors underpinning capital productivity movements, Mohun (2009) identifies three drivers: 1). The relationship between growth in labour productivity and growth in capital intensity (capital deepening), with capital productivity falling when the latter exceeds the former and rising otherwise, as per identity relationship; 2). Changes in the relative price of capital goods (rising prices lead to falling capital productivity); 3). The structure of capital stock (specifically the proportion of capital stock in productive versus non-productive and less productive activities, and the changing composition of aggregate capital stock).

Regarding the first factor, as shown in Table 4, growth in labour productivity was exceeding growth in capital intensity in 16 economies in the 1960s, 9 economies in the 1970s and the 1980s, 11 economies in the 1990s, 4 economies in the 2000s and 7 economies in 2010s, indicating gradual deterioration of capital productivity in most economies. On the other hand, positive trends in capital productivity were present in many instances (the growth rates ratio $\Delta Y/L{:}\Delta K/L$ was greater than 100% in 16 economies in the 1960s, and 11 economies in the 1990s, i.e. during the periods of likely growth or resurgence in capital productivity).

This latter observation is in line with trend model results presented in Table 1 (showing positive trends in capital productivity in 13 economies), and also the results presented by Mohun (2009) and Weiss (1998).

If the whole period (1964-2014) is examined, capital productivity was far from stable: the growth rates ratio fell within (95%; 105%) band only in New Zealand, Portugal and the UK. On a decade-by-decade basis, the ratio fell within (95%; 105%) in Austria, Belgium, Germany and the UK in the 1970s, Finland and Iceland in the 1980s, Finland, Luxembourg and Netherlands in the 1990s, and Austria in the 2000s. The ratio exceeded the band in all economies in the 1960s and the 2010s.

This lack of stability in capital productivity (together with other discrepancies, such as slowing down and reversal of capital deepening, as shown in Table 5) may cast doubts about the presence of balanced growth in the OECD economies during the study period.

Table 5 also shows that both labour productivity and capital intensity were both growing at a diminishing rate: labour productivity was slowing down in all economies, and capital intensity in all economies except Australia, Canada, New Zealand and the USA (indeed in some of the economies capital deepening was put on halt, as was the case of Australia and Canada in the 1960s, Ireland in the 1990s and Switzerland in the 2000s).

In addition, the actual movements in capital productivity did not appear to reflect factor input substitution. The substitution process implies that the rise in real wages encourages firms to substitute capital for labour, thereby increasing capital intensity of production and reducing capital productivity (the opposite changes will take place, if real wage falls).

Table 4. Comparison of labour productivity and capital intensity average annual growth rates ($\Delta Y/L$ and $\Delta K/L$).

Country	1964-2014	1964-69	1970-79	1980-89	1990-99	2000-09	2010-14
Austria	106.4	127.0	99.1	116.8	86.5	97.2	125.5
Australia	117.2	227.8	69.4	112.4	231.2	36.3	126.7
Belgium	108.7	107.3	100.9	106.5	88.6	61.7	-964.4
Canada	106.5	87.4	80.1	91.3	-572.8	55.7	156.9
Denmark	75.4	108.6	81.8	-16.7	110.9	118.7	-48.3
France	74.2	128.1	73.9	91.7	53.6	28.4	50.2
Finland	92.5	111.8	90.3	96.0	103.2	48.1	75.8
Germany	87.7	124.9	103.5	90.3	81.1	0.8	42.1
Greece	172.5	195.4	107.4	241.0	213.0	-50.7	142.7
Iceland	105.3	114.0	87.7	96.3	420.2	66.9	86.9
Ireland	87.2	113.5	87.7	69.6	87.7	63.5	67.3
Italy	90.0	228.9	107.9	77.8	76.6	32.3	59.7
Japan	101.0	90.2	92.0	112.2	126.1	107.3	57.4
Luxembourg	83.0	75.5	54.1	79.6	97.1	111.5	280.1
Netherlands	120.7	108.0	108.8	153.8	103.9	115.0	1242.6
New Zealand	102.9	32.8	195.1	272.0	71.1	63.3	-3.3
Portugal	95.4	109.0	50.3	80.1	44.7	-900.4	-74.9
Spain	132.9	385.2	169.7	152.7	148.1	57.3	291.7
Sweden	92.1	190.2	66.1	91.4	36.4	82.2	-618.4
Switzerland	126.9	-2174.3	190.5	88.3	137.7	35.0	70.0
UK	102.4	-1433.3	104.7	109.7	130.7	33.0	42.7
USA	110.6	2623.9	2.3	80.6	320.2	76.8	64.0

Notes: The comparison is performed by constructing the ratio of labour productivity growth rate to capital intensity growth rate (expressed in percentages). Values equal to or close to 100 indicate similar or roughly similar growth rates in a specific period.

As shown in Table 5, capital deepening was decelerating in 18 economies over 1964-2014 period and proceeding at a sustained or increasing rate in the remaining four (Australia, Canada, New Zealand and the USA). In particular, over 1964-1989 period, deceleration took place in all economies except the above-mentioned as well as Portugal, and over 1990-99 period in all economies except Australia, Belgium, Canada, Iceland, Sweden, UK, and the USA. However, the four Anglo-Saxon economies mentioned were the ones that witnessed negative growth in real wages (Western & Healy, 1999), while other economies only experienced slowdown in real wage growth (and some, such as Austria, Finland, Germany and the UK experienced solid growth). Also, Australia, Canada, New Zealand and the USA experienced increased growing capital productivity despite sustained capital deepening.

These apparent contradictions between actual movements in capital productivity on one hand and real wage, labour productivity and capital intensity changes on the other may be explained by reference to relative prices of capital and structure of capital stock.

Regarding relative prices of capital and structure of capital stock, these factors were likely behind the reversal of capital productivity in the 1980s and the 1990s. On a decade-by-decade basis, the visual observation and analysis of trend segment suggests that the highest incidence of rising capital productivity was in the 1960s and the 1990s (14 cases each), followed by 1980s (9 instances), 2000s (3 instances), 2010s (2 cases) and 1970s (1 case), implying preponderance of negative trends in capital productivity in the 1970s, followed by positive trends in the 1980-90s, and again sluggish capital productivity in the 2000s and 2010s (Weiss, 1998; Mohun, 2009). As put by Eichengreen (2015) and Fisher (2006), capital goods prices were rising in the 1970s (due to the increased energy intensity of investment goods) and falling ever since, reaching the minimum in the 2000s. This was distorting the capital investment incentives (in the corporate sector in particular): firms were pushed to invest less in order to support underlying capital goods prices, resulting in higher capital productivity. We note that this price factor seems to explain well capital productivity movements in the 1980-90s, but less so in the 2000s (when capital prices fall reached its limits).

Table 5. Average annual growth rates in capital intensity and real wages.

Country	ΔK/L by decade (%)					Real wages growth	
	1964-69	1970-79	1980-89	1990-99	2000-14	1974-82	1983-92
Australia	*-0.16*	*1.32*	***1.04***	**1.90**	2.19	1.30	-1.53
Austria	4.90	3.95	2.71	2.35	0.95	2.61	1.98
Belgium	3.51	3.26	**1.78**	**1.85**	0.68	2.90	0.29
Canada	*-0.11*	*0.69*	***0.89***	**0.98**	1.43	1.52	-0.11
Denmark	1.97	2.53	1.29	0.92	1.24	1.70	1.15
France	4.48	3.75	2.04	1.56	1.26	3.11	0.68
Finland	5.03	4.29	2.46	2.26	0.85	1.17	2.19
Germany	4.45	2.96	0.98	0.57	0.33	1.56	2.08
Greece	8.78	6.07	1.50	1.15	1.82		
Iceland	2.64	1.92	**0.41**	**1.73**	2.17		
Ireland	5.05	4.92	4.01	-0.56	2.68	3.77	0.83
Italy	4.57	3.05	2.01	2.00	1.25	2.41	1.83
Japan	4.55	6.62	3.85	2.91	0.54	1.38	1.50
Luxembourg	1.88	1.28	1.31	0.67	0.38		
Netherlands	4.16	3.35	1.50	0.36	1.31	0.94	0.70
New Zealand	*0.06*	*0.53*	*2.04*	0.43	1.15	-0.41	-2.05
Portugal	*2.44*	*4.64*	*4.35*	3.43	2.42		
Spain	4.59	5.58	2.54	2.06	2.73		
Sweden	4.69	2.98	**1.95**	**2.60**	0.98	0.22	0.83
Switzerland	2.98	2.81	0.58	0.50	-0.25	0.67	0.87
UK	2.84	2.15	**1.34**	**1.86**	0.64	1.01	2.76
USA	*0.54*	*0.65*	***0.90***	**1.36**	1.69	-0.49	-0.74

Notes: Values indicated in bold represent increasing growth rate in capital intensity over 1990-99 period relative to 1980-89 period. Values shown in italics demonstrate acceleration of capital deepening over 1964-89 period. Growth in real wages is taken from Western and Healy (1998, Table 1, p. 234).

The resurgence of capital productivity in 1980-90s was also due to structural changes in capital and production. As put by Weiss (1998), the relative importance of capital intensive sectors (heavy industries, manufacturing) has been on decline, while services sector (that is less capital-intensive and requires lower capital inputs for a given level of labour productivity) was growing in importance, thereby lifting economy-wide capital productivity. The counter-argument could be that services sector has lower productivity than manufacturing, and hence fall in capital intensity coupled with lower labour productivity in services may prevent capital productivity from rising.

Another likely explanation of rising capital productivity is the growing importance of human capital and relative decline in the importance of physical capital, the latter being used in the calculation of capital productivity (McCloskey, 2016, p. 175).

Also acknowledged is the possibility of capital intensity moving in tandem with labour productivity (i.e. higher capital intensity of production enhances labour productivity, due to more capital goods available for worker and hence capital productivity is stable), or alternatively of the growth in capital stock lagging behind employment growth (i.e. labour productivity growth rate exceeds capital intensity growth rate and capital productivity rises). In Netherlands and Ireland in the 1990s, capital productivity took sharp increase due to substantial increase in employment and active employment creation policies with capital accumulation lagging behind, reducing the rate of capital deepening (Ederveen et al, 2007).

4. Conclusion

The stability of capital productivity variable has been part and parcel of the balanced growth theory and one of the stylized facts of balanced growth. The paper examined systematically the statistical properties of the variable in the industrialized economies and also considered capital productivity in relation to other economic growth variables, and more broadly as a variable in economic models.

To this end a set of tests (trend analysis with autoregressive term, error-correction model and univariate Lagrange Multiplier tests) as well as qualitative analysis were performed. Overall, diverse capital productivity patterns were present: in half of the economies in the sample trend stationarity with breaks was identified, while in the other half capital productivity was following stochastic patterns or reverted to historical mean.

In a broader theoretical context, the following results emerged. Firstly, for some of the “late-comer economies” capital productivity convergence to the US level was shown. Secondly, results seem to confirm some of the productivity puzzles, where slack labour productivity was attributed to low capital productivity, in turn conditioned by microeconomic factors related to inefficient use of capital. Thirdly, in many cases capital productivity movements tracked well business cycle.

As to the driving forces of capital productivity, the analysis revealed that the growth rates of labour productivity and of capital-labour ratios were not equal and the slowdown in the variables was observed, thereby confirming tests results that balanced growth was unlikely. The effect of real wages and the capital-labour substitution played minor role in explaining capital productivity movements. In contrast, the decline in capital goods' prices and changing economic structure and composition of the capital stock could be an important factor behind capital productivity resurgence in the 1980-90s.

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