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Accounting for Productivity Growth: Schumpeterian versus Semi-Endogenous Explanations

Johannes W. Fedderke,* Yang Liu†

Abstract

This paper examines the nature and sources of productivity growth in South African manufacturing sectors, from an international comparative perspective. On panel data estimations, we find that the evidence tends to support Schumpeterian explanations of productivity growth for a panel of countries including both developed and developing countries, and a panel of South African manufacturing sectors. By contrast, semi-endogenous productivity growth is supported for a panel of OECD (Organisation for Economic Cooperation and Development) manufacturing sectors. However, we also report evidence that suggests that sectors are not homogeneous. For this reason time series evidence may be more reliable than panel data. Time series evidence for South Africa suggests that prospects for the sustained productivity growth associated with Schumpeterian innovation processes, is restricted to a narrow set of sectors, strongly associated with the chemicals and related sectors, machinery and transport equipment, and basic iron and steel sectors. Semi-endogenous growth finds much weaker support. For the OECD manufacturing sectors, both semi-endogenous and Schumpeterian growth finds support, with semi-endogenous growth more prevalent

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than for South African manufacturing. The sustained productivity growth associated with Schumpeterian growth frameworks is relatively rare everywhere.

Keywords: productivity growth, Schumpeterian productivity grwoth, semi-endogenous productivity growth

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I. Introduction

Sustained productivity growth is not readily achieved under standard growth theory. Under constant returns to scale production technology, steady state precludes increases in per capita welfare, save for exogenous growth in production technology. While under endogenous growth theory sustained productivity growth through investment in knowledge creation and the factors of production that generate knowledge is feasible, the strong rates of return to knowledge required in order to realize the increasing returns to scale requisite for sustained productivity growth have been challenged empirically. The result has been a debate between those who find a falling technological growth rate in the face of an accumulating knowledge base, and those who find the growth rate to be constant and undiminishing in rising stocks of knowledge.

Optimism concerning the possibility of sustainable productivity growth is integral to the standard accounts of Schumpeterian growth (see Aghion and Howitt, 1992, and Romer, 1990). Sustainable productivity growth was held to be empirically consistent with the observation of divergent per capita income over the post-colonial and industrialization eras. Empirical challenges to the theory rested on observations of strong increases in research and development personnel in the United States (US), which should have led to an commensurate increase in economic growth rates according to the Schumpeterian growth theory, but did not (Jones 1995a, 1995b).

In response, semi endogenous theory gives up the assumption that knowledge growth is subject to constant returns to scale in knowledge, with the result that the growth of knowledge would decrease as the knowledge stock increases, finally eliminating knowledge creation as a source of sustainable productivity growth (Jones, 1995a, 1995b). By contrast, Type II Schumpeterian growth models maintain a constant return to scale in knowledge and account for the non-response of productivity growth to increasing research and development ($R\&D$) personnel by pointing out that the $R\&D$ input is spread ever more thinly over a proliferating set of intermediate inputs into production with rising levels of per capita gross domestic product (GDP). The increased $R\&D$ input does not represent a deepening of $R\&D$ intensity, merely a broader dispersion of the input over more intermediate inputs.

Empirical findings are divergent. Ha and Howitt (2007) find support for Type II Schumpeterian productivity growth in an analysis of the U.S. manufacturing sector. Similarly Madsen (2008) reports time series findings that are consistent with Type II Schumpeterian productivity growth, though the theory is unable to account for cross-country total factor productivity growth rates. On the other hand, Barcenilla-Visús et al (2014) report that panel data evidence from a panel of 10 manufacturing sectors across six OECD countries is consistent with semi-endogenous productivity growth.

Which of these two competing theoretical frameworks holds matters profoundly for any country seeking sustained growth, in an immediate sense. If productivity growth is semi-endogenous in structure, then technological innovation offers only limited prospects for improvement in real per capita GDP. Investment in innovation can offer, at best, temporary growth spurts, with the economy in due course settling down into its natural rate of growth. Since the marginal rate of return to innovation will be diminishing, the incentive to continue to invest in technology declines. Thus under semi-endogenous productivity growth, investment in knowledge is no more a source of sustained welfare improvement than investment in standard factors of production under constant returns to scale production technology. Technology will not provide the means to sustained productivity growth, with real per capita GDP settling down into a stable value defined by the steady state of the economy.

By contrast, under Schumpeterian productivity growth, investment in knowledge does offer the prospect of sustained productivity growth. Given constant returns to innovation, the marginal rate of return to innovation does not decline, such that the incentive to invest in technology does not diminish either. This creates the possibility of a breakout of productivity growth allowing the economy to consistently maintain growth above the natural rate of growth and thus generating the possibility of sustained increases in real per capita GDP.

For policy purposes this matters. If productivity growth is semi-endogenous, investment in technological innovation has no immediate priority. If productivity growth is Schumpeterian, investment in technological innovation does carry priority as a source of sustained improvement in economic welfare.

In this paper we revisit the ongoing debate. We innovate in three senses. First, we compare the support to emerge for the two theoretical propositions across a range of distinct data sets, including panel data for developed and developing countries, for the manfacturing sector of a middle income country (South Africa), and for OECD manufacturing sectors. Second, we employ a range of estimation methodologies, to explore the sensitivity of results to alternative estimators. Third, we take seriously the possibility of sector heterogeneity by estimating sector-specific results by means of time series methodologies.

Under panel estimation, our results are mixed. For country-level data, which includes both developed and developing countries, as well as for the South African manufacturing sectors, results consistently favour the Schumpeterian account of productivity growth. By contrast, panel results favour semi-endogenous productivity growth for the six OECD country manufacturing sectors.

The panel data results also provide evidence of sector heterogeneity, such that panel data estimation may hide significant sector differences. The South African time series evidence confirms the presence of sector heterogeneity. Specifically, we find that productivity growth in South African manufacturing is likely to be significantly constrained, since Schumpeterian productivity growth is concentrated in the chemicals and related sectors, machinery and transport equipment, and basic iron and steel sectors. OECD manufacturing sectors also prove heterogeneous, with the preponderance of sectors being consistent with semi-endogenous productivity growth, though arguably Schumpeterian productivity growth is also more prevalent than in South African manufacturing.

The remainder of the paper is distributed as follows. Section II. reviews the theoretical background, and section III. the associated empirical methodology. In section IV. we report the data, in V. the estimation results, and section VI. wraps up the findings.

II. Semi-endogenous and Type II Schumpeterian growth theory

Under standard neoclassical growth theory,[1] the assumption of constant returns to scale in production technology ensures a declining marginal product of capital. This allows for the standard growth decomposition:

$$
\begin{aligned}
Y &= A \cdot F(K, L) \\
\frac{\dot{Y}}{Y} &= \left(\frac{F(K,L)}{Y}\right)\left(\frac{dA}{dt}\right) + \left(\frac{\partial Y}{\partial K}\right)\left(\frac{K}{Y}\right)\left(\frac{dK/dt}{K}\right) + \left(\frac{\partial Y}{\partial L}\right)\left(\frac{L}{Y}\right)\left(\frac{dL/dt}{L}\right) \\
&= \frac{\dot{A}}{A} + \eta_K \frac{\dot{K}}{K} + \eta_L \frac{\dot{L}}{L} \qquad (1)
\end{aligned}
$$

where Y denotes output, K capital, L labour, A the technology scaling factor, and η_K, η_L, the elasticity of output with respect to capital and labour respectively. This clarifies that under standard capital accumulation, such that $S_t = sY_t = I_t = dK/dt$ (with S denoting savings, s the savings rate, and I investment), and exogenous demographic growth, such that $\dot{L}/L$ is effectively a constant over extended time periods, the only source of sustained growth in growth in $\dot{Y}/Y$ in excess of the steady state condition of $\dot{K}/K = \dot{L}/L$, will be located in technology, $\dot{A}/A$. This is reinforced by the empirical regularity that in developed countries approximately 75 per cent of long-run growth is attributable to total factor productivity (TFP) growth ($\dot{A}/A$), substantially overshadowing the contribution of factor accumulation.[2] The South African evidence mirrors the international evidence, in the sense that growth has become increasingly reliant on TFP, rather than factor accumulation.[3]

The resultant onus to account for the source of technological progress, as met by Schumpeterian growth theory,[4] places the long-run source of knowledge accumulation in a knowledge producing sector. Thus, for instance, if final output continues to be produced under

[1] See Solow (1956, 1957) and Swan (1956).
[2] See Abramovitz (1956, 1993), Fagerberg (1994), and Lim 1994).
[3] See Fedderke (2002), Arora (2005), Du Plessis and Smit (2009).
[4] See Aghion and Howitt (1992) and Romer (1990).

constant returns to scale:

$$Y\left(H_Y, L, x\right) = H_Y^{\alpha} \cdot L^{\beta} \cdot \sum_{i=1}^{\infty} x_i^{1-\alpha-\beta} \tag{2}$$

where notation is defined as above, x_i denotes the intermediate inputs, and H_Y human capital engaged in final goods production, production will again be subject to steady state, and sustained output growth feasible only if $\overset{\bullet}{A}/A > 0$. Under the increased varieties approach (Romer, 1990) of Schumpeterian theory, the proposed production function of knowledge is simply:

$$\frac{dA}{dt} = \overset{\bullet}{A} = \delta \cdot H_A \cdot A \tag{3}$$

where H_A denotes the human capital employed in the production of knowledge (as opposed to final goods production), A denotes the accumulated stock of knowledge, and δ denotes a productivity (research success) factor. The linearity of the knowledge production function has the consequence that $\partial\left(\overset{\bullet}{A}/A\right)/\partial H_A = \delta$, $\partial^2\left(\overset{\bullet}{A}/A\right)/\partial H_A^2 = 0$, such that there is no diminishing product of the input into knowledge production. The result is that knowledge growth is unbounded under non-diminishing incentives to invest in technology, with symmetrical results for output growth, if these Schumpeterian conditions for knowledge creation are met. In addition, the non-declining returns are also present for the level of knowledge accumulation, $\partial\overset{\bullet}{A}/\partial A = \delta \cdot H_A$, $\partial^2\overset{\bullet}{A}/\partial A^2 = 0$. The radical prediction - while consistent with the experience of accelerating output and technological growth over the course of the Industrial Revolution,[5] and with suggestions of essentially boundless scope for knowledge accretion[6] - also faced immediate empirical challenge.

Specifically, while empirical findings have confirmed a positive impact of $R\&D$ on TFP, the magnitude of the impact falls well short of the strength predicted by Schumpeterian

[5] See Romer (1986).
[6] See Romer (1992, 1994).

theory. For instance, while the number of $R\&D$ scientists and engineers in the US increased by 500 per cent over the 1950-88 period, the growth rate of both Y/L and TFP remained unchanged - directly contradicting the predictions of the Schumpeterian theory.[7]

Here we consider the implications of two broad responses to this empirical contradiction. A generalization of the Schumpeterian knowledge production function might specify:

$$\dot{A} = \delta \cdot X^{\sigma} \cdot A, \; 0 \leq \sigma \leq 1 \tag{4}$$

where X denotes the input into knowledge production, such as human capital allocated to $R\&D$ (H_A), or the productivity-adjusted flow of $R\&D$ expenditure (R/A). It follows that $d\left(\dot{A}/A\right)/dX = \delta \cdot \sigma \cdot X^{\sigma-1} > 0$, $d^2\left(\dot{A}/A\right)/dX^2 = \delta \cdot \sigma \cdot (\sigma - 1) \cdot X^{\sigma-2} < 0$, a weaker inference than under (3), although the strength of the response to A remains undiminished. We term this the Schumpeterian Type I formulation.

Under the semi-endogenous growth formulation, in addition Jones (1995b) proposed that:

$$\dot{A} = \delta \cdot X^{\sigma} \cdot A^{\phi}, \; 0 \leq \sigma \leq 1, \; \phi < 1 \tag{5}$$

such that now $\partial\left(\dot{A}/A\right)/\partial A = \delta \cdot (\phi - 1) \cdot X^{\sigma} \cdot A^{\phi-2} < 0$. The implication is that as technology becomes more complex (i.e. as A increases), *sustained growth* in $R\&D$ labour is required to maintain a constant rate of TFP growth. The prediction is that long-run TFP growth, and hence also per capita GDP growth, is again bounded by the population growth rate, returning the prediction to that of the neoclassical growth model, in which steady state growth is given by the natural rate of growth.[8]

An alternative response retains the Schumpeterian framework, while accounting for the Jones (1995a, 1995b) empirical contradiction. Under this approach, the assumption of

[7] See Jones (1995a, 1995b).

[8] See Jones (1995b), and Kortum (1997).

Theory:	$\boldsymbol{\sigma}$	$\boldsymbol{\phi}$	$\boldsymbol{\beta}$
Neoclassical	=0	=1	n/a
Schumpeter 1	>0	=1	=0
Semi-endogenous	>0	<1	=0
Schumpeter 2	>0	=1	=1

Table 1: Theory Predictions

constant returns to knowledge creation is retained. The empirical contradiction is accounted for by noting that over time, intermediate input product proliferation has a negative effect on productivity growth, since product variety dilutes the impact of $R\&D$ over an ever-increasing array of projects and innovation streams.[9] Now:

$$\frac{\overset{\bullet}{A}}{A} = \delta \cdot \left(\frac{X}{Q}\right)^{\sigma},\ 0 \leq \sigma \leq 1 \tag{6}$$

where Q, denoting product variety, is generally held to be proportional to population size (L), output (GDP) or the number of patent registrations. Growth in the $R\&D$ input, X, may thus be neutralised by the growth in intermediate product variety, accounting for the apparent empirical contradiction of Schumpeterian Type I theory. The normalization of the $R\&D$ input on product variety, provides what we term Schumpeterian Type II theory.

A general (nested) formulation, encompassing both semi-endogenous and Schumpeterian Type II theory, is then:

$$\begin{aligned} \frac{\overset{\bullet}{A}}{A} &= \delta \cdot \left(\frac{X}{Q}\right)^{\sigma} A^{\phi-1} \\ Q &\propto L^{\beta} \textit{ in steady state} \end{aligned} \tag{7}$$

with Schumpeterian Type I theory predicting that $\sigma > 0$, $\phi = 1$, $\beta = 0$, semi-endogenous theory predicting that $\sigma > 0$, $\phi < 1$, $\beta = 0$, and Schumpeterian Type II theory predicting that $\sigma > 0$, $\phi = 1$, $\beta = 1$. Neoclassical theory is the restrictive case in which $\sigma = 0$, $\phi = 1$. Table 1 summarises.

[9] See, for instance, Young (1998).

III. Empirical methodology

The general nested formulation provided by equation (7), now provides an immediate means of testing for the predictions of the semi-endogenous and Schumpeterian theories. Specifically, the general model that nests the competing hypotheses provides the empirical specification:

$$\ln(g_A) = \ln\delta + \sigma\ln\left(\frac{X}{Q}\right) + (\phi - 1)\ln A \tag{8}$$

where g_A denotes the growth rate of A, and would provide direct estimates of the critical relevant parameters, σ, ϕ.

The difficulty is that if $\ln(g_A) \sim I(0)$ and $\ln\left(\frac{X}{Q}\right), \ln A \sim I(1)$, specification (8) would not be balanced, and would lead to spurious estimation inferences. Hence, confirmation of any of the competing theories would then require that:

$$
\begin{aligned}
(9)\qquad & I(0) && \sim \ln\delta + \sigma\ln\left(\frac{X}{Q}\right) + (\phi - 1)\ln A \\
(10)\qquad & \Longrightarrow \ln X && = \mathbb{C} + \alpha\ln Q + \left(\frac{1-\phi}{\sigma}\right)\ln A \sim CI(0) \\
(11)\qquad & \mathit{or}\ \ln\left(\frac{X}{Q}\right) && = \mathbb{C} + \left(\frac{1-\phi}{\sigma}\right)\ln A \sim CI(0)
\end{aligned}
$$

with $(1-\phi)/\sigma = 0$ confirming Schumpeter Type II theory, and $(1-\phi)/\sigma > 0$ confirming semi-endogenous theory in both (10) and (11). In the (10) specification, Schumpeter Type II theory requires $\alpha = 1$, while semi-endogenous theory requires $\alpha = 0$. The discussion in Ha and Howitt (2007) and Madsen (2008) elaborates.

As an alternative specification, from (6) we can specify:

$$\ln\left(\dot{A}\right) = \ln\delta + \sigma\ln X - \sigma\ln Q + \phi\ln A \tag{12}$$

which, provided that $\ln\left(\overset{\bullet}{A}\right) \sim I(1)$ as it must be if $\ln(g_A) \sim I(0)$, and $\ln X$, $\ln Q$, $\ln A$,$\sim I(1)$, allows for a direct estimation of both the σ and ϕ parameters.[10] This identification of the precise parameter magnitudes is not feasible under the (10), (11), specifications.

In the present study we confirm first that $\ln(g_A) \sim I(0)$, such that testing under (10), (11) or (12) is required. We proceed accordingly.

A. Time series estimator

The time series methodology is the standard vector error correction mechanism (VECM) approach. The estimation technique is standard, so our exposition is brief.[11] Consider the general vector autoregressive estimation (VAR) specification given by:

$$z_t = A_1 z_{t-1} + ... + A_m z_{t-m} + \mu + \delta_t \tag{13}$$

where z_t is a $n \times 1$ matrix, m is the lag length, μ deterministic terms and δ a Gaussian error term. Reparametrization provides the VECM specification:

$$\Delta z_t = \sum_{i=1}^{k-1} \Gamma_i \Delta z_{t-i} + \Pi z_{t-k+1} + \mu + \delta_t \tag{14}$$

where $\Pi = \alpha\beta'$. We refer to α as the loading matrix, containing the short-run dynamics, while β is the matrix containing the long-run equilibrium (cointegrating) relationships. The rank, r, of the matrix represents the number of cointegrating vectors and is tested for using the standard Trace and Maximal Eigenvalue test statistics. Where $r > 1$ issues of identification arise.[12] Just identification can proceed by means of restrictions on α, β, or Γ.[13]

[10] A constant proportional growth rate of necessity requires a non-constant absolute change in a series.

[11] See the more detailed discussion in Johansen (1991), and Johansen and Juselius (1990, 1992).

[12] See Wickens (1996), Johansen and Juselius (1990, 1992), Pesaran and Shin (1995a, 1995b), and Pesaran, Shin and Smith (1996).

[13] See Greenslade, Hall and Henry (1999:3ff).

B. Pooled mean group estimator

In the panel data estimation, amongst others we employ the pooled mean group (PMG) estimator of Pesaran, Shin and Smith (1999). Consider the unrestricted error correction ARDL(p, q) representation:

$$\Delta y_{it} = \phi_i y_{i,t-1} + \boldsymbol{\beta}_i' \mathbf{x}_{i,t-1} + \sum_{j=1}^{p-1} \lambda_{ij} \Delta y_{i,t-j} + \sum_{j=0}^{q-1} \boldsymbol{\delta}_{ij}' \Delta \mathbf{x}_{i,t-j} + \mu_i + \varepsilon_{it}, \tag{15}$$

where $i = 1, 2, ..., N$, $t = 1, 2, ..., T$, denote the cross section units and time periods respectively. Here y_{it} is a scalar dependent variable, $\mathbf{x}_{it}$ $(k \times 1)$ a vector of (weakly exogenous) regressors for group i, and μ_i represents fixed effects. Allow the disturbances ε_{it}'s to be independently distributed across i and t, with zero means and variances $\sigma_i^2 > 0$, and assume that $\phi_i < 0$ for all i. Then there exists a long-run relationship between y_{it} and $\mathbf{x}_{it}$:

$$y_{it} = \boldsymbol{\theta}_i' \mathbf{x}_{it} + \eta_{it}, \ i = 1, 2, ..., N, \ t = 1, 2, ..., T, \tag{16}$$

where $\boldsymbol{\theta}_i = -\boldsymbol{\beta}_i' / \phi_i$ is the $k \times 1$ vector of the long-run coefficients, and the η_{it} are stationary with possibly non-zero means (including fixed effects). This allows (15) to be written as:

$$\Delta y_{it} = \phi_i \eta_{i,t-1} + \sum_{j=1}^{p-1} \lambda_{ij} \Delta y_{i,t-j} + \sum_{j=0}^{q-1} \boldsymbol{\delta}_{ij}' \Delta \mathbf{x}_{i,t-j} + \mu_i + \varepsilon_{it}, \tag{17}$$

where $\eta_{i,t-1}$ is the error correction term given by (16), and ϕ_i is thus the error correction coefficient measuring the speed of adjustment towards the long-run equilibrium.

This general framework allows for the formulation of the PMG estimator, which allows the intercepts, short-run coefficients and error variances to differ freely across groups, but the long-run coefficients to be homogenous; i.e. $\boldsymbol{\theta}_i = \boldsymbol{\theta} \ \forall \ i$. Group-specific short-run coefficients and the common long-run coefficients are computed by pooled maximum likelihood estimation. Denoting these estimators by $\tilde{\phi}_i$, $\tilde{\boldsymbol{\beta}}_i$, $\tilde{\lambda}_{ij}$, $\tilde{\boldsymbol{\delta}}_{ij}$ and $\tilde{\boldsymbol{\theta}}$, we obtain the PMG estimators by $\hat{\phi}_{PMG} = \frac{\sum_{i=1}^{N} \tilde{\phi}_i}{N}$, $\hat{\boldsymbol{\beta}}_{PMG} = \frac{\sum_{i=1}^{N} \tilde{\boldsymbol{\beta}}_i}{N}$, $\hat{\lambda}_{jPMG} = \frac{\sum_{i=1}^{N} \tilde{\lambda}_{ij}}{N}$, $j = 1, ..., p-1$, and $\hat{\boldsymbol{\delta}}_{jPMG} = \frac{\sum_{i=1}^{N} \tilde{\boldsymbol{\delta}}_{ij}}{N}$, $j = 0, ..., q-1$, $\hat{\boldsymbol{\theta}}_{PMG} = \tilde{\boldsymbol{\theta}}$.

PMG estimation provides an intermediate case between the dynamic fixed effects (DFE) estimator which imposes the homogeneity assumption on all parameters except for the fixed effects, and the mean group (MG) estimator proposed by Pesaran and Smith (1995), which allows for the heterogeneity of all parameters. The PMGE exploits the statistical power offered by the panel through long-run homogeneity, while still admitting short-run heterogeneity.

The crucial question is whether the assumption of long-run homogeneity is justified, given the threat of inefficiency and inconsistency noted by Pesaran and Smith (1995). We employ a Hausman (1978) test (hereafter the h test) on the difference between MG and PMG estimates of long-run coefficients to test for long-run heterogeneity.[14]

Finally, it is worth pointing out that a crucial advantage of the estimation approach of this present paper, is that the dynamics generally argued to be inherent in the growth process are explicitly modelled, while recognising the presence of a long-run equilibrium relationship underlying the dynamics. The justification for the use of the PMG estimator is thus that it is consistent with both the underlying theory of an homogenous long-run productivity growth relationship and the possibly heterogeneous dynamic time series nature of the data.

IV. Data

In this study, we employ three distinct data sets. The data sets have the advantage that they present country-level data for countries at diverse levels of development, country-specific data for a wide range of sectors within the country, and country and sectoral data for developed economies. This allows us to explore whether the inferences drawn are conditional on the type of data employed, as well as on the level of development of the case studies being

[14]The authors thank Yongcheol Shin for the provision of the appropriate GAUSS code for estimation purposes.

employed for the study.

The first data set consists of panel data for 13 countries, drawn from the ISIC and World Bank databases from 1996 to 2010. We employ country-level data, because sectoral data on $R\&D$ expenditure is not readily available for many developing countries, forcing the use of aggregate country-level data.

The second data set is given by the South African manufacturing panel data set of Fedderke (2006), for 25 manufacturing sectors from 1973 to 1993. Unfortunately the South African data had to be truncated in 1993 since no reliable $R\&D$ data exist after the 1993 time point on a sectoral level.

The third data set is given by the Barcenilla-Visús et al (2014) panel data for six OECD countries, and 10 manufacturing sectors from the STAN database from 1979 to 2001.[15]

In terms of estimation, we employ both panel estimators (all three data sets), and time series estimators (the South African and OECD data).

Data across the following dimensions were collected:

- X: $R\&D$ input, measured by the Gross Domestic Expenditure on $R\&D$ (GERD) data, normalized on the level of TFP
- A: TFP level,
- L: total employment, measured either as the number of employees (all data sets), or total working hours (OECD)
- Y: GDP of country/sector
- P: patents applied for by residents of a country

The L, Y, P, variables are those conventionally used in the measurement for product variety, Q, in prior studies.

[15] The authors thank Barcenilla-Visús et al (2014) for making the data available.

Panel Unit Root Tests: Hadri Test Statistic						
	g_A		$\ln X$		$\ln\left(\frac{X}{L}\right)$	
	$\sim I(0)$	$\sim I(1)$	$\sim I(0)$	$\sim I(1)$	$\sim I(0)$	$\sim I(1)$
Panel 1	0.83 [0.20]	-1.94 [0.97]	10.08*** [0.00]	0.77 [0.22]	11.27*** [0.00]	0.56 [0.29]
Panel 2	0.78 [0.22]	4.18 [1.00]	26.42*** [0.00]	1.85 [0.32]	26.60*** [0.00]	1.47* [0.07]
Panel 3	-2.59 [1.00]	-6.99 [1.00]	71.80*** [0.00]	-0.95 [0.83]	75.33*** [0.00]	-0.62 [0.73]
	$\ln\left(\frac{X}{Y}\right)$		$\ln\left(\frac{X}{P}\right), \ln\left(\frac{X}{WH}\right)$		$\ln A$	
	$\sim I(0)$	$\sim I(1)$	$\sim I(0)$	$\sim I(1)$	$\sim I(0)$	$\sim I(1)$
Panel 1	11.81*** [0.00]	1.46* [0.07]	7.88*** [0.00]	0.27 [0.39]	11.95*** [0.00]	0.69 [0.24]
Panel 2	26.24*** [0.00]	0.80 [0.21]	$-$	$-$	14.98*** [0.00]	0.59 [0.28]
Panel 3	71.61*** [0.00]	-1.70 [0.96]	75.87*** [0.00]	-0.55 [0.71]	89.54*** [0.00]	-3.15 [1.00]
Figures in square parentheses are probability values						
*,**,*** denotes rejection of the null of stationarity at the 1, 5 and 10% levels of significance						

Table 2: Hadri Unit Root Test

V. Estimation results

The regression methods being applied on the three panel data sets include pooled mean group (PMG) estimation, mean group (MG) estimation, generalized method of moments (GMM), as well as ordinary least squares (OLS) and fixed effects (FE) estimators.

A. Panel estimation results

We find that the anticipated possibility that $\ln(g_A) \sim I(0)$ and $\ln\left(\frac{X}{Q}\right), \ln A \sim I(1)$, is confirmed for our panel data sets. We report the Hadri test for the order of integration of the data, which is defined under the null that the series being tested is stationary, in Table 2.

As demonstrated by the test statistics, we confirm that the growth rate of TFP is stationary in levels (hence necessarily in first differences), while both the $R\&D$ input measure (including when normalised on product variety) and the level of TFP prove to be level non-stationary.

The panel estimation results are reported in Tables 3 through 5.

We begin with the estimation of the general specification given by equation (10), with no restriction placed on either the α or $(1-\phi)/\sigma$ parameters, reported in Table 3. Estimation is for Panel 1 (the 13 country sample), Panel 2 (the 25 South African manufacturing sectors), and Panel 3 (the six OECD country data for 10 manufacturing sectors). In each case we estimate under GMM and PMG estimators, so as to control for the possibility of endogeneity.

For both Panel 1 and Panel 2, results consistently confirm that the $(1-\phi)/\sigma$-coefficient on the level of knowledge, lnA, is statistically significantly < 0, such that $\phi > 1$ provided only that the elasticity of $R\&D$ with respect to the growth of knowledge, $\sigma > 0$. This finding is invariant to the proxy employed for product variety (employment, output, or patents), and invariant to whether we employ the GMM or PMG estimators. The implication is thus that the Schumpeterian condition - that the response of $R\&D$ to the state of knowledge be at least proportional - is met.

In addition, for Panel 1, we find that the α-coefficient on our proxy for product variety, lnQ, is consistently statistically significantly > 0, such that $R\&D$ responds positively to product variety. This finding is also invariant to the proxy employed for product variety (employment, output, or patents), and invariant to whether we employ the GMM or PMG estimators. For Panel 2, the findings are mixed. Where the proxy for product variety is given by employment, in Panel 2 we find $\alpha < 0$ irrespective of PMG or GMM estimation, though where product variety is given by value added, $\alpha > 0$ for the GMM estimator, while $\alpha < 0$ under the PMG estimator. Note also that where $\alpha > 0$ is confirmed, the stricter Schumpeterian requirement that $\alpha = 1$ is generally not supported statistically.

The findings for Panels 1 and 2 are thus mixed. For Panel 1 (the 13 country data set) the findings support Schumpeterian Type II productivity growth. For Panel 2, the findings are mixed, with a strongly proportional response of $R\&D$ to the level of knowledge, consistent with Schumpeterian Type II productivity growth, but without strictly robust confirmation of the $R\&D$ response to product variety required by Schumpeterian theory. Two possibilities might account for this inconsistency. One is that the proxy for product variety (employment, value added) is imperfect at best, especially in the case of employment, which for South Africa is subject to the outcomes dictated by an inefficient labour market. Another possibility is indicated by the rejection of the long-run homogeneity by the Hausman h-test statistic in at least some of the Panel 2 specifications, which suggests that sector-specific time series evidence may be more reliable than panel data evidence.

Finally, the results for Panel 3 (the 6 OECD countries, with 10 manufacturing sectors) differ starkly from those reported for Panels 1 and 2. The results consistently confirm that the $(1-\phi)/\sigma$-coefficient on the level of knowledge, lnA, is statistically significantly > 0, such that $\phi < 1$, again provided that the elasticity of $R\&D$ with respect to the growth of knowledge, $\sigma > 0$. This finding is invariant to which proxy for product variety is employed (employment, output, or working hours), and invariant to whether we employ the GMM or PMG estimators. Reassuringly, this confirms the findings of Barcenilla-Visús et al (2014) on the Panel 3 data, which employed dynamic ordinary least squares estimation. The implication is thus that the semi-endogenous growth condition that the response of R&D to the state of knowledge be less than proportional, is met. For the α-coefficient on our proxy for product variety, lnQ, results are mixed. Where employment is the proxy for product variety, we find $\alpha > 0$ under both PMG and GMM estimation, with value added as proxy, $\alpha < 0$ under both PMG and GMM estimators, while with working hours as proxy we have $\alpha > 0$ under PMG and $\alpha < 0$ under GMM estimation. Note also that the strict semi-endogenous theoretical requirement that $\alpha = 0$ is nowhere met.

To test the robustness of these results, we undertook two additional sets of estimations. First, we reestimated the equation (10) specification under the restriction that $\alpha = 0$, thus forcing a strict semi-endogenous structure on our data. The results are reported in Table 4. In addition, we estimated with pooled OLS (OLS), FE, GMM, PMG, as well as MG estimators. Despite the $\alpha = 0$ restriction, we continue to find consistently that $\phi > 1$ for both Panels 1 and 2 ($(1-\phi)/\sigma < 0$), while for Panel 3 we find $\phi < 1$ under all estimators other than the PMG and MG. Thus the finding that the conditions of Schumpeterian theory

Estimation Results under (10)							
Measure of Product Variety:		Panel 1		Panel 2		Panel 3	
		PMG	GMM	PMG	GMM	PMG	GMM
Employment (L)	lnA	-0.81^{***} (-47.66)	-0.41^{***} (-26.00)	-0.93^{***} (-7.90)	-1.86^{***} (-47.43)	0.35^{***} (4.19)	1.19^{***} (66.41)
	lnQ	0.85^{***} (10.68)	0.35^{***} (17.12)	-0.06 (-0.43)	-0.16^{***} (-4.36)	1.68^{***} (11.09)	0.26^{***} (8.45)
h-statistic		1.87 [0.39]		5.90^{**} [0.05]		0.42 [0.81]	
Output (Y)	lnA	-1.60^{***} (-22.62)	-0.89^{***} (-36.32)	-1.38^{***} (-16.86)	-2.24^{***} (-52.11)	1.87^{***} (30.42)	1.92^{***} (73.75)
	lnQ	1.57^{***} (14.59)	0.79^{***} (31.37)	-0.36^{***} (-5.54)	0.89^{***} (25.72)	-1.42^{***} (41.46)	-0.82^{***} (-68.73)
h-statistic		5.39^{*} [0.07]		0.13 [0.93]		1.71 [0.42]	
Patents (P)	lnA	-0.95^{***} (-33.27)	-0.73^{***} (-55.72)				
	lnQ	0.43^{***} (28.98)	0.45^{***} (50.46)				
h-statistic		1.99 [0.37]					
Working Hours (WH)	lnA					-0.54^{***} (16.60)	1.15^{***} (63.79)
	lnQ					1.72^{***} (8.00)	-0.07^{***} (-2.33)
h-statistic						0.67 [0.72]	

Coefficients: $(1-\phi)/\sigma$ for lnA; σ for lnQ
The h-statistic is the Hausman test under the null of long-run homogeneity
Figures in round parentheses are t-statistics
Figures in square parentheses are probability values
***, **, * denotes significance at the 1, 5 and 10% levels

Table 3: Panel Estimation Results I

Estimation Results under (10) with $\alpha = 0$ restriction						
	OLS	FE	GMM	PMG		MG
				coeff.	h-stat	
Panel 1	-0.40^{***} (-7.98)	-0.81^{***} (-14.28)	-0.24^{***} (-17.80)	-0.91^{***} (-22.02)	0.26 [0.61]	$-1.0^{***}6$ (-3.53)
Panel 2	-1.36^{***} (-12.49)	-1.35^{***} (-12.36)	-1.89^{***} (-50.12)	-3.95^{***} (-9.85)	0.25 [0.61]	-5.99 (-1.48)
Panel 3	1.09^{***} (20.30)	1.13^{***} (20.85)	1.14^{***} (63.96)	-0.11 (-1.67)	0.16 [0.69]	-0.46 (-0.52)

Coefficients: $(1-\phi)/\sigma$
The h-statistic is the Hausman test under the null of long-run homogeneity
Figures in round parentheses are t-statistics
Figures in square parentheses are probability values
***, **, * denotes significance at the 1, 5 and 10% levels

Table 4: Panel Estimation Results II

Estimation Results under (10) with $\alpha = 1$ restriction							
	Measure of Product Variety	OLS	FE	GMM	PMG		MG
					coeff.	h-stat	
Panel 1	Employment	-0.78^{***} (-3.68)	-0.77^{***} (-10.52)	-0.81^{***} (-78.62)	-0.79^{***} (-40.23)	0.02 [0.89]	-0.72 (-1.29)
	Output	-0.16^{***} (-4.01)	-0.35^{***} (-6.39)	-0.12^{***} (-14.20)	-0.80^{***} (-20.67)	0.60 [0.44]	-0.15 (-1.37)
	Patent	0.22^{***} (4.11)	0.34^{***} (6.10)	-0.38^{***} (-24.69)	0.67^{***} (7.31)	0.07 [0.79]	0.54 (1.14)
Panel 2	Employment	-1.45^{***} (-13.15)	-1.43^{***} (-13.02)	-2.35^{***} (-58.57)	-0.35^{*} (-1.60)	1.20 [0.27]	20.15 (1.08)
	Output	-1.75^{***} (-14.52)	-1.74^{***} (-14.37)	-2.33^{***} (-53.09)	-0.98^{***} (-6.08)	0.01 [0.92]	-0.38 (-0.07)
Panel 3	Employment	0.23^{***} (4.10)	0.28^{***} (5.04)	0.29^{***} (16.17)	-0.55^{***} (-13.55)	0.03 [0.86]	-0.78 (-0.58)
	Output	-0.89^{***} (-8.19)	-0.79^{***} (-7.20)	-0.82^{***} (-18.44)	-2.46^{***} (-28.98)	0.03 [0.87]	-2.19 (-1.30)
	Working Hours	0.24^{***} (4.19)	0.30^{***} (5.13)	1.32^{***} (17.39)	-0.59^{***} (-18.16)	0.69 [0.41]	0.82 (0.48)
Coefficients: $(1-\phi)/\sigma$ The h-statistic is the Hausman test under the null of long-run homogeneity Figures in round parentheses are t-statistics Figures in square parentheses are probability values ***, **, * denotes significance at the 1, 5 and 10% levels							

Table 5: Panel Estimation Results III

are satisfied for Panel 1 and 2, while the conditions for semi-endogenous growth theory are confirmed for Panel 3, emerges for estimation under the $\alpha = 0$ restriction also.

Second, we reestimated the equation (10) specification under the restriction that $\alpha = 1$, thus forcing a strict Schumpeterian structure on our data. Again, we estimated under OLS, FE, GMM, PMG, as well as MG estimators. Again the results are broadly consistent to those reported for the α-neutral specification of Table 3. For Panels 1 and 2, irrespective of estimator, we consistently find that $\phi \geq 1$, as required by Schumpeterian theory, irrespective of which proxy for product variety is employed. The only exceptions emerge for Panel 1, under the patents proxy for product variety, where $\phi < 1$. Conversely, for Panel 3 (OECD), we find that $\phi < 1$, as required by semi-endogenous theory, except where product variety is proxied for by value added, or under PMG and MG estimation.

In summary, our results from the panel data estimation are thus not conclusive. Evidence for both Schumpeterian and semi-endogenous growth theory emerges, although it is never entirely consistent with the strict theoretical requirements of either framework. Surprisingly, the Schumpeterian case is also strongest for the data set that includes developing countries, and the middle-income case of South Africa, and weakest for the set of six developed OECD economies of Panel 3.

One possible reason for the observed inconsistencies that attaches to all the reported estimations, is that the proxies employed for product variety are imperfect at best. However, given that these measures are standard in studies of this type, and since more reliable measures of product variety are not available, this limitation is not easily remedied.

A second explanation of the panel result inconsistencies is that the panel estimators are being employed across potentially heterogeneous sectors (as indicated under PMG estimation), which include semi-endogenous, Schumpeterian, and neoclassical productivity growth consistent processes. For this reason, an examination of disaggregated sectoral time series evidence is desirable to allow for the possibility that the innovation process is not homogeneous across sectors.

B. Time series estimation results

Given our concerns regarding the possibility of heterogeneity across sectors, we also estimated the association between $\overset{\bullet}{A}$, the $R\&D$ input, product variety (Q), and the level of A by means of time series methodology for the South African and OECD data. To do so, we employed the equation (12) specification so as to identify the σ and ϕ parameters directly.

There are two estimation issues that need to be addressed in the equation (12) specification. In the event that $\ln A \sim I(1)$, it follows that strictly the absolute change in A cannot be stationary, $\overset{\bullet}{A} \nsim I(0)$, since $\ln A \sim I(1)$ implies that the proportional growth rate of A is stationary, $\overset{\bullet}{A}/A \sim I(0)$. However, in the event that tests for stationarity are applied to $\ln\left(\overset{\bullet}{A}\right)$ (as we do), the log compression of scale may make the non-stationarity of the absolute changes difficult to detect.

Additional concerns arise from the poor power and size characteristics of unit root tests in the presence of small samples and moving average (MA) processes in the data. To correct for any tendency of stationarity tests to over-reject the null in favour of stationarity, we err on the side of caution and impose a 1 per cent level of significance throughout our examination of the univariate time series characteristics of the data.

The South African results.—We consider the sector-specific results for 25 South African manufacturing sectors.

Despite our concerns regarding the robustness of univariate stationarity tests, as Table 6 shows we consistently find that all of the variables under the equation (12) specification test to be $I(1)$. For all sectors, and all variables, we report an $I(1)$ structure at the 1 per cent level of significance (with the sole exception of $\ln X$ for Wearing Apparel, and $\ln GDP$ for Basic Chemicals, which test $I(1)$ at the 1.42 per cent and 1.1 per cent levels of significance).

We therefore proceed with the estimation of (12) under the VECM methodology, using both employment and GDP as proxies for product variety. Sector-specific results are reported in Tables 7 and 8. We report the Trace statistic (λ) for the rank of the Π-matrix for the null of $r = 0$ against the alternative that $r > 0$,[16] the estimated σ and ϕ coefficients, the estimated error correction term in order to test for stability of the equilibrium adjustment ($-2 \leq ecm \leq 0$), and additionally whether the cointegrating vector manifests stability under a one standard-deviation shock. We also test for parameter equality across the $\ln X$ (σ_X) and $\ln Q$ (σ_Q) variables implied by specification (12) under the null of parameter equality.

The estimation results confirm the implication drawn from the panel evidence: sector heterogeneity. Recall also that the two theories accounting for productivity growth have specific parameter requirements. For semi-endogenous productivity growth, the requirement is that $\sigma > 0$ and $\phi < 1$. For Schumpeterian productivity growth by contrast the restrictions are $\sigma > 0$ and $\phi \geq 1$. Neoclassical productivity growth requires $\sigma = 0$ and $\phi = 1$. We summarise the detailed findings in terms of implied sector classifications in Table 9.

[16] We report the Trace statistic due to its superior small sample characteristics. We also generated the maximal eigenvalue statistic, though we do not report it for the sake of parsimony. In all instances the two test statistics generated consistent results.

	$\ln\left(\dot{A}\right)$		$\ln X$		$\ln Q(L)$		$\ln Q(Y)$		$\ln A$	
	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
Food	-2.04	-5.40*	-1.58	-2.99*	-2.56	-2.63*	-1.91	-3.74*	-2.16	-3.11*
Beverages	-1.94	-3.27*	-1.89	-2.69*	-2.48	-3.56*	-1.94	-3.54*	-2.14	-2.30*
Tobacco	-2.05	-7.85*	-1.84	-2.61*	-0.56	-3.76*	-2.04	-3.18*	-1.88	-3.41*
Textiles	-2.55	-3.27*	-1.84	-2.61*	-0.56	-3.76*	-1.30	-4.08*	-1.88	-3.41*
Wear. Appar.	-2.06	-6.58*	-1.18	-2.43‡	-2.00	-2.96*	-2.52	-3.28*	-1.20	-4.21*
Leather	-1.70	-4.83*	-1.68	-4.92*	-3.10	-2.92*	-1.96	-4.92*	-1.79	-4.38*
Footwear	-1.73	-5.17*	-2.10	-3.53*	-2.15	-3.23*	-2.35	-3.53*	-2.11	-3.51*
Wood	-2.67	-4.19*	-0.61	-2.89*	-1.28	-2.95*	-2.18	-2.89*	-2.49	-3.15*
Paper	-2.35	-3.69*	-1.13	-2.67*	-0.67	-1.32*	-1.32	-2.64*	-1.73	-3.13*
Coke&RP	-2.33	-3.51*	-2.39	-2.93*	-0.38	-3.31*	-1.45	-3.43*	-2.38	-2.71*
Basic Chem.	-1.17	-8.59*	-2.50	-4.48*	-2.11	-2.61*	-1.82	-3.53*	-1.72	-5.02*
Other Chem.	-2.05	-5.16*	-2.28	-2.84*	-0.98	-3.64*	-1.94	-2.52†	-2.29	-3.29*
Rubber	-2.46	-7.24*	-2.33	-3.94*	-1.65	-2.91*	-1.61	-2.80*	-1.99	-3.07*
Plastic	-2.54	-4.76*	-1.69	-5.33*	-0.28	-3.19*	-0.60	-3.73*	-1.77	-3.81*
Glass	-2.14	-4.06*	-2.05	-3.26*	-0.25	-3.42*	-1.60	-2.98*	-1.82	-2.62*
NMetal. Ind.	-2.16	-5.47*	-1.65	-3.48*	-2.03	-3.28*	-1.64	-2.81*	-2.57	-2.61*
BasIr&St.l	-2.42	-4.01*	-1.87	-2.78*	-0.76	-3.03*	-2.24	-3.31*	-2.97	-3.27*
BasNFerr Met	-2.11	-4.47*	-2.50	-3.30*	-1.01	-2.74*	-1.42	-5.69*	-1.18	-3.84*
Metal Products	-2.49	-6.14*	-2.20	-3.40*	-2.15	-2.96*	-0.95	-3.64*	-2.18	-2.99*
Machinery	-2.42	-4.76*	-1.42	-2.86*	-1.69	-3.06*	-1.71	-2.80*	-1.53	-4.10*
Electrical	-2.12	-5.32*	-0.98	-3.24*	-1.19	-2.64*	-1.43	-3.72*	-1.60	-3.10*
Motor	-2.47	-4.89*	-1.36	-3.40*	-1.65	-3.77*	-2.56	-3.47*	-2.54	-2.78*
Other Trans.	-0.38	-2.91*	-2.25	-4.27*	-2.12	-2.96*	0.80	-3.26*	-0.68	-3.12*
Furniture	-2.56	-5.16*	-0.29	-3.02*	-0.45	-3.08*	-1.13	-4.25*	-2.16	-3.41*
Other Indus.	-2.42	-10.75*	-1.42	-3.23*	-0.88	-3.08*	-0.69	-3.45*	-1.02	-3.25*
*, †, ‡ denote significance at 1%, 1.1% and 1.42% levels respectively										

Table 6: Augmented Dickey Fuller Test Statistics

Under these parameter restrictions, six sectors satisfy the strict requirements for Schumpeterian productivity growth ($\sigma > 0$, $\phi \geq 1$). A further six sectors are weakly consistent with Schumpeterian productivity growth, in the sense of returning $\sigma = 0$ and $\phi \geq 1$. Two sectors provided the $\phi \geq 1$ estimate required by Schumpeterian productivity growth, but also the more puzzling finding of $\sigma < 0$.

Only one sector fulfilled the requirements of neoclassical productivity growth.

Semi-endogenous productivity growth finds only incomplete support. No sector meets the strictest requirement for semi-endogenous productivity growth ($\sigma > 0$, $0 < \phi < 1$), and only two sectors meet the weaker requirement of $\sigma = 0$, $0 < \phi < 1$. However, a number of sectors report a finding of $\phi = 0$, which technically satisfies the requirement that the parameter fall below unity, although it does imply that there is no impact at all on the time rate of change of technology in the level of technology. For two sectors $\phi = 0$ is paired with a finding of $\sigma > 0$, and for seven sectors with $\sigma = 0$. For one sector we find that $\phi = 0$ and $\sigma < 0$.

Finally, for six sectors the requirement of a unique cointegrating vector under the estimation of (12) is not satisfied, such that these sectors cannot be classified under any of the productivity growth theories.

In summary, we note that industry characteristics are certainly heterogeneous, suggesting that time series estimation is a useful supplement to the panel data findings. In addition, the time series evidence favours Schumpeterian productivity growth with greater preponderance (in the strict sense) than it does semi-endogenous productivity growth for South African manufacturing. This finding is thus consistent with the implication drawn from the panel data evidence for South African manufacturing. Note also that Schumpeterian growth appears to be associated with the chemicals and related sectors, Machinery and Transport equipment, and Basic iron and steel.

While there is thus good news in terms of the possibility for sustained productivity growth, this is tempered by the fact that the prospects of sustained productivity growth is relatively narrowly focused among the South African manufacturing sectors.

The OECD Evidence.—We consider sector-specific results for 10 manufacturing sectors in six OECD countries, providing results for a total of 60 sectors.

The univariate time series characteristics of the data are reported in Tables 10 and 11. In general, all sectors and all variables report an $I(1)$ structure. There are only two qualifications. First, the presence of a structural break in the early 1990s for a number of countries necessitated the use of the Perron (1989) version of the augmented Dickey-Fuller (ADF) test statistic under the critical values reported in Perron (1989, 1990). This applied most extensively to the employment and working hour time series, and especially for Finland. Second, the poor power characteristics of unit root tests are in evidence for the employment and working hour time series particularly for France, and to a lesser degree for Spain, with the tests struggling to establish even $\sim I(1)$. Under this caveat, given the theoretical implausibility of an $I(2)$ structure, our estimation proceeds under the assumption that all series are stationary in first differences.

We therefore proceed with the estimation of equation (12) under the VECM methodology, using employment (L), GDP (Y) and working hours (WH) as proxies for product variety. Sector-specific results are reported in Tables 12 through 17. We report the Trace statistic (λ) for the rank of the Π-matrix for the null of $r = 0$ against the alternative that $r > 0$,[17] the estimated σ and ϕ coefficients, the estimated error correction term in order to test for the stability of the equilibrium adjustment ($-2 \leq ecm \leq 0$), and additionally whether the cointegrating vector manifests stability under a one standard-deviation shock. We also test for parameter equality across the $\ln X$ (σ_X) and $\ln Q$ (σ_Q) variables implied by specification (12) under the null of parameter equality.

The estimation results again confirm the implication drawn from the panel evidence of sector heterogeneity, under the classification requirements implied by the theoretical re-

[17] We report the Trace statistic due to its superior small sample characteristics. We also generated the maximal eigenvalue statistic, though we do not report it for the sake of parsimony. In all instances the two test statistics generated consistent results.

Results for: $\ln\left(\overset{\bullet}{A}\right) = \ln\delta + \sigma_X \ln X - \sigma_Q \ln Q + \phi \ln A$								
Sector	Prod. Var. Meas.	Trace λ	lnX σ_X	lnQ $(-1)*\widehat{\sigma_Q}$	lnA ϕ	ecm	$\sigma_X = \sigma_Q$	Stable
Food	L	$r>1$						
	Y	$r>1$						
Beverages	L	68.62**	0.05 (0.37)	−0.31 (0.94)	1.40** (0.66)	−0.45* (0.25)	0.04 [0.85]	Yes
	Y	67.29**	−0.46e3 (0.32)	−0.29 (0.36)	1.08 (0.60)	−0.43 (0.25)	0.18 [0.67]	Yes
Tobacco	L	80.86***	0.72*** (0.27)	−1.98 (1.08)	1.41*** (0.49)	−0.93*** (0.21)	2.53 [0.11]	Yes
	Y	73.78***	−0.19 (0.56)	2.99** (1.23)	0.91 (0.74)	−0.76*** (0.18)	1.24 [0.27]	Yes
Textiles	L	$r>1$						
	Y	83.58***	−0.56** (0.22)	3.29** (0.81)	2.65** (0.61)	−0.80 (0.19)	4.52** [0.03]	Yes
Wearing Apparel	L	73.35***	0.09 (0.22)	−2.99** (1.07)	−0.55 (0.65)	−1.08*** (0.23)	2.93* [0.09]	Yes
	Y	$r>1$						
Leather	L	$r>1$						
	Y	$r>1$						
Footwear	L	75.10***	0.26 (0.18)	0.12 (0.41)	−1.27 (0.82)	−1.10*** (0.11)	0.08 [0.78]	Yes
	Y	88.21***	0.15 (0.11)	0.18 (0.33)	−0.36 (0.51)	−1.04*** (0.11)	0.01 [0.94]	Yes
Wood	L	73.04***	0.06 (0.15)	−2.58 (1.56)	−1.07 (0.65)	−0.71*** (0.21)	2.38 [0.12]	Yes
	Y	72.79***	0.29** (0.09)	−0.53 (0.57)	−0.62 (0.58)	−0.69*** (0.21)	1.28 [0.26]	Yes
Paper	L	68.92***	0.10 (0.11)	0.38 (0.86)	0.56** (0.30)	−0.60** (0.23)	0.09 [0.76]	Yes
	Y	73.15***	0.13 (0.14)	0.96 (0.62)	0.52** (0.22)	−0.66 (0.23)	1.16 [0.28]	Yes
Coke&RP	L	70.41***	0.49 (0.36)	−0.39 (0.31)	2.10*** (0.54)	−0.58** (0.31)	2.01 [0.16]	Yes
	Y	85.84***	0.77 (0.52)	−0.04 (0.25)	2.20*** (0.72)	−0.60*** (0.28)	1.02 [0.31]	Yes
BasChem	L	111.04***	0.60*** (0.17)	−1.08*** (0.13)	2.10*** (0.27)	−0.79*** (0.28)	19.23*** [0.00]	Yes
	Y	$r>1$						
OthChem	L	88.23***	0.64 (0.53)	0.31 (0.54)	2.66*** (1.06)	−0.82*** (0.22)	0.57 [0.45]	Yes
	Y	$r>1$						
Rubber	L	66.09***	0.47 (0.90)	1.79 (3.28)	1.92* (1.11)	−0.77*** (0.23)	0.06 [0.80]	Yes
	Y	70.35***	1.83*** (0.76)	3.74*** (1.39)	5.95*** (1.00)	−0.60*** (0.18)	0.61 [0.43]	Yes
Plastic	L	53.10**	−0.38 (1.17)	0.18 (1.17)	0.12 (1.85)	−1.08*** (0.24)	0.02 [0.88]	Yes
	Y	52.88**	−2.27 (1.41)	1.83 (1.03)	−0.28 (1.90)	−0.97*** (0.24)	1.30 [0.25]	Yes

Table 7: South African Manufacturing Sector VECM Estimation Results I

Results for: $\ln\left(\dot{A}\right) = \ln\delta + \sigma_X \ln X - \sigma_Q \ln Q + \phi \ln A$

Sector	Prod. Var. Meas.	Trace λ	lnX σ	lnQ $(-1)*\widehat{\sigma_Q}$	lnA ϕ	ecm	$\sigma_X = \sigma_Q$	Stable
Glass	L	59.05^{***}	0.06	1.05	0.83	-0.79^{***}	0.61	Yes
			(0.20)	(1.07)	(0.85)	(0.23)	[0.44]	
	Y	57.85^{***}	0.12	0.53	0.24	-0.83^{***}	0.18	Yes
			(0.20)	(0.75)	(0.86)	(0.22)	[0.67]	
NMetMin	L	$r > 1$						
	Y	$85.42^{***/}$	0.06	2.43	-0.23	-1.05^{***}	7.93^{***}	Yes
			(0.10)	(0.61)	(0.40)	(0.20)	[0.00]	
BIroSteel	L	67.61^{***}	0.30	1.00	3.06^{***}	-0.77^{***}	0.83	Yes
			(0.21)	(0.73)	(0.68)	(0.29)	[0.36]	
	Y	70.03^{***}	0.31	0.51	3.16^{***}	-0.78^{***}	0.03	Yes
			(0.24)	(0.92)	(0.91)	(0.28)	[0.86]	
Basic NFer	L	67.65^{***}	0.02	1.21	0.80^{***}	-1.15^{***}	0.23	Yes
			(0.28)	(1.21)	(0.29)	(0.30)	[0.63]	
Metals	Y	$r > 1$						
MetProd	L	$r > 1$						
	Y	$r > 1$						
Machinery	L	65.13^{***}	0.08	-0.65	1.91^{***}	-0.75^{***}	0.71	Yes
			(0.13)	(0.91)	(0.50)	(0.23)	[0.40]	
	Y	76.65^{***}	0.19^{**}	0.88^{**}	3.11^{***}	-0.70^{***}	1.31	Yes
			(0.08)	(0.37)	(0.47)	(0.20)	[0.25]	
Elec	L	$r > 1$						
Mach	Y	$r > 1$						
Motor	L	$r > 1$						
	Y	$r > 1$						
Other	L	$r > 1$						
Transport	Y	114.30^{***}	-0.02	0.18^{**}	1.56^{***}	-0.55	1.90	Yes
			(0.01)	(-0.08)	(0.12)	(0.52)	[0.17]	
Furn	L	$r > 1$						
	Y	$r > 1$						
Other	L	64.77^{***}	-0.01	-0.05	1.05^{***}	-0.88^{***}	0.001	Yes
			(0.06)	(1.17)	(0.29)	(0.27)	[0.98]	
Industry	Y	69.88^{***}	0.02	-1.31	-0.28	-0.90^{***}	1.21	Yes
			(0.04)	(0.07)	(1.01)	(0.27)	[0.27]	

Table 8: South African Manufacturing Sector VECM Estimation Results II

	$\phi < 0$	$\phi = 0$	$0 < \phi < 1$	$\phi = 1$	$\phi > 1$
$\sigma < 0$		Wear.App			Textiles (σ_X) Bas. Chem. (σ_Q)
$\sigma = 0$		Beverages (Y) Footwear Wood (L) Plastic Glass NonMetMin Oth. Ind. (Y)	Paper BasNonFerrMin	Oth. Ind. (L)	Beverages (L) Coke & RP Oth. Chem. Rubber (L) BasIronSteel Machinery (L)
$\sigma > 0$		Tobacco (Y) Wood (Y)			Tobacco (L) Textiles (σ_Q) Bas. Chem. (σ_X) Rubber (Y) Machinery (Y) Oth. Transport
r>1	Food Furniture	Leather	Met Prod	Elec.Mach.	Motor

Y,L indicate estimation under GDP and Employment product variety.

Results are consistent where neither product variety proxy (Y or L) is indicated.

σ_X, σ_Q indicates elasticity parameter under R&D input and product variety respectively.

Results are consistent where neither elasticity parameter (σ_X, σ_Q) is indicated.

Table 9: Time Series Data South African Industry Classification

	$\ln\left(\dot{A}\right)$		$\ln X$		$\ln Q(L)$		$\ln Q(Y)$		$\ln Q(WH)$		$\ln A$	
	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
Canada												
Food	-2.75	-4.98*	-2.99	-3.71†	-2.57	-4.10*	–1.01	-3.78*	-2.66	-3.71†	-2.81	-3.92*
Textiles	-2.69	-4.95*	-1.41	-5.09*	-1.58	-3.24†	-1.34	-4.96*	-1.53	-3.44†	-1.17	-4.15*
Paper	-2.65	-6.04*	-1.17	-3.57†	-2.32	-3.50†	1.29	-3.76*	-2.86	-3.09‡	-0.31	-3.37†
Chemicals	-2.20	-3.70†	-0.49	-3.95*	-0.49	-3.62†	-0.38	-3.81*	-0.83	-3.53†	-0.46	-3.47†
Rubber	-2.34	-4.85*	-0.59	-3.60†	-0.31	-3.18†	0.19	-3.03‡	-0.42	-3.29†	-1.40	-3.93*
NMM	-2.62	-4.73*	-1.81	-4.32*	-2.87	-3.48†	-0.65	-2.23	-2.86	-3.84*	-0.29	-3.84*
B&F Met.	-1.94	-3.79*	-1.83	-3.23†	-2.81	-3.08‡	2.64	-1.39	-2.69	-3.06‡	-0.41	-3.54†
Machinery	-2.81	-3.69†	-0.57	-3.69†	-2.43	-3.44†	0.31	-4.40*	-2.70	-3.71†	-0.81	-3.25†
Elec.	-0.68	-14.00*	-2.09	-3.33†	-2.09	-3.62†	-0.21	-3.58†	-2.34	-3.15†	-0.28	-1.79
Transport	-2.27	-5.56*	-0.91	-4.36*	-1.78	-4.48*	-1.03	-4.47*	-1.63	-4.28	-1.79	-3.35†
Finland												
Food	-1.77	-5.87*	-2.19	-4.37*	0.17#	-5.61*#	-0.40	-4.71*	-0.89#	-5.01*#	0.39	-4.82*
Textiles	-2.70	-5.31*	-2.13	-4.42*	-1.62#	-3.98†#	-1.09	-6.19*	-1.19#	-4.01†#	-0.42	-4.41*
Paper	-2.78	-6.00*	-2.01	-3.03‡	-0.14#	-5.12*#	-0.16	-4.96*	-0.13#	-4.29†#	0.30	-4.75*
Chemicals	-2.84	-6.05*	-2.35	-5.84*	-1.50#	-7.70*#	0.14	-5.26*	-0.91#	-6.73*#	-0.09	-5.05*
Rubber	-2.94	-5.53*	-0.86	-4.39*	-2.77#	-4.13†#	-0.01	-8.00*	-3.28#	-4.43*#	-1.16	-3.84*
NMM	-1.83	-5.28*	-2.78	-4.08*	-0.87#	-7.72*#	-0.91	-6.83*	-2.25#	-7.68*#	0.62	-4.24*
B&F Met.	-2.12	-5.99*	-2.15	-5.47*	-0.54#	-3.98†#	0.39	-4.41*	-1.63#	-4.45*#	-0.78	-4.47*
Machinery	-2.69	-6.54*	-2.24	-6.69*	-1.51#	-5.19*#	0.01	-3.84*	-2.24#	-5.83*#	0.14	-4.99*
Elec.	-2.54	-5.64*	-1.01	-6.49*	1.69#	-3.96†#	1.72	-5.55*	1.48#	-3.71†#	1.14	-7.51*
Transport	-2.45	-6.13*	-2.78	-3.36†	-1.39#	-4.05†#	-0.90	-7.75*	-2.07#	-4.52*	-0.23	-4.78*
France												
Food	-3.85	-11.04*	-1.26	-7.55*	-2.10	-1.72	-1.45	-4.92*	-0.85	-3.23†	-4.65	-5.40*
Textiles	-1.15	-7.99*	-1.67	-3.91*	-2.05#	-4.87*#	-2.78	-4.52*	0.92#	-4.75*#	0.61	-3.83*
Paper	-2.46	-5.42*	-2.64	-4.17*	-1.58	-2.64	-1.12	-3.97*	-0.01	-2.26	-1.76	-4.40*
Chemicals	-2.30	-10.79*	-3.17	-4.51*	-0.85	-1.78	1.14	-4.59*	-0.57	-3.86*	1.42	-3.98*
Rubber	-2.67	-11.78*	-0.89	-4.53*	-2.16	-1.29	0.78	-5.64*	-2.70	-2.41	0.71	-6.44*
NMM	-2.43	-6.32*	-0.61	-4.43*	-1.88	-2.53	-1.13	-5.02*	-1.66	-2.74	-2.09	-4.11*
B&F Met.	-2.84	-6.49*	-1.55	-3.89*	-1.93	-2.45	-0.19	-4.99*	-2.10	-2.67	-0.76	-5.59*
Machinery	-2.89	-8.48*	-1.42	-4.80*	-2.14	-3.19†	0.30	-5.20*	-2.31	-2.47	-0.12	-4.98*
Elec.	-1.40	-3.95*	0.85	-3.16†	0.75	-1.33	2.13	-4.32*	-1.25	-3.78*	1.76	-4.02*
Transport	-2.63	-6.34*	-1.38	-5.20*	-1.41	-1.92	0.50	-4.10*	-2.20	-2.27	0.20	-4.80*

*, †, ‡ denote significance at 1%, 2.5% and 5% respectively. # denotes Perron test under structural break.

Table 10: Augmented Dickey Fuller Test Statistics

	$\ln\left(\dot{A}\right)$		$\ln X$		$\ln Q(L)$		$\ln Q(Y)$		$\ln Q(WH)$		$\ln A$	
	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
Italy												
Food	-2.48	-5.65*	-1.68	-4.97*	-1.71	-3.11‡	-1.13	-3.52†	-1.80	-3.53†	-2.20	-4.06*
Textiles	-2.77	-3.85*	-1.23	-4.01*	-0.75	-4.15*	-0.45	-4.81*	-1.08	-4.08*	-0.82	-3.09‡
Paper	-2.62	-4.78*	-1.19	-4.40*	-2.00	-3.99*	-1.11	-4.50*	-2.95	-4.96*	-2.72	-3.25†
Chemicals	-0.87	-5.70*	-1.31	-3.22†	-1.37	-3.80*	-2.05	-3.08‡	-1.70	-3.70†	-1.93	-1.49
Rubber	-2.48	-4.81*	-2.14	-2.93	-1.05	-3.13†	-0.87	-4.35*	-1.26	-3.48†	-2.88	-4.15*
NMM	-3.12	-8.75*	-1.51	-4.22*	-0.75#	-4.76*#	-0.10	-4.02*	-1.00#	-4.16†#	-1.52	-5.64*
B&F Met.	-1.23	-3.79*	-0.75	-3.96*	-2.35	-3.24†	-0.81	-3.27†	-2.28	-4.42*	-2.27	-5.75*
Machinery	2.43	-3.64†	-2.51	-3.92*	-2.64	-3.06‡	-0.29	-4.53*	-2.61	-3.28†	-1.77	-4.10*
Elec.	-2.20	-4.03*	-0.58	-1.43	-2.32	-3.21†	-0.71	-3.51†	-2.46	-3.37†	-0.96	-2.34
Transport	-2.02	-3.61†	-2.06	-3.13†	-1.39	-3.10‡	-2.09	-3.18†	-1.61	-3.52†	-1.93	-3.06‡
Spain												
Food	-2.53	-4.61*	-0.08	-6.09*	-1.50	-3.22†	-1.43	-4.08*	-2.37	03.26†	-2.67	-3.29†
Textiles	-2.42	-5.78*	-0.11	-6.11*	-1.76	-3.03‡	-0.28	-5.49*	-1.85	-2.88	-2.92	-3.56†
Paper	-2.34	-5.44*	-1.20	-3.89*	-1.04	-2.67	-0.08	-3.86*	-1.16	-2.68	-1.44	-2.93
Chemicals	-2.21	-5.63*	-1.49	-4.36*	-1.66	-3.21†	-0.70	-3.91*	-2.06	-3.88*	-0.93	-3.80*
Rubber	-2.26	-5.29*	-1.15	-4.84*	-0.16	-3.31†	-0.41	-4.81*	-0.47	-3.16†	-2.29	-6.04*
NMM	-2.77	-4.34*	-0.85	-3.97*	-2.57	-2.24	0.77	-1.79	-3.01	-2.19	-0.39	-4.47*
B&F Met.	-2.60	-5.35*	-0.77	-3.80*	-1.42	-2.48	1.56	-2.30	-1.80	-3.01‡	-1.76	-3.70†
Machinery	-2.99	-4.00*	-2.20	-5.19*	-1.05	-2.05	-0.14	-4.38*	-1.39	-2.05	-1.59	-5.22*
Elec.	-2.04	-5.20*	-2.02	-3.11‡	-1.67	-3.59†	1.11	-3.16†	-2.45	-3.96*	0.17	-3.86*
Transport	-2.85	-4.88*	-0.96	-4.93*	-0.04	-4.65*	-0.61	-4.30*	-0.76	-4.18*	-1.70	-4.91*
USA												
Food	-1.30	-5.32*	-0.97	-5.45*	-2.68	-3.85*	-1.49	-4.61*	-1.59	-3.49†	-0.61	-4.18*
Textiles	-2.66	-5.03*	-2.89	-4.00*	0.51#	-3.69‡#	-1.11	-3.50†	0.17	-4.36*	-1.70	-3.51†
Paper	-2.27	-5.32*	0.91	-3.85*	-1.93	-1.40	-2.25	-3.69†	-2.09	-1.51	0.02	-4.08*
Chemicals	-2.12	-5.49*	-1.62	-4.34*	-1.16	-4.07*	-1.81	-4.45*	-2.82	-4.24*	2.87	-3.79*
Rubber	-2.47	-4.22*	-1.82	-6.83*	-1.31	-4.04*	-1.18	-5.66*	-1.43	-4.82*	-1.51	-6.08*
NMM	-1.58	-4.85*	-1.40	-3.21†	-3.05	-4.88*	-1.07	-5.30*	-2.82	-5.62*	-1.67	-4.23*
B&F Met.	-2.47	-6.34*	-1.62	-3.99*	-2.25	-5.54*	-0.99	-4.82*	-1.73	-6.82*	-0.60	-3.84*
Machinery	-2.06	-6.12*	-1.69	-3.93*	-2.98	-4.22*	1.33	-3.70†	-2.92	-4.63*	1.46	-3.95*
Elec.	-1.42	-4.09*	0.53	-3.41†	-0.88	-3.49†	0.77	-2.09	-0.81	-3.41†	1.41	-3.12†
Transport	-2.59	-4.71*	-1.31	-2.45	-2.37	-3.56†	-2.91	-3.07‡	-2.61	-3.65†	-1.62	-3.37†

*, †, ‡ denote significance at 1%, 2.5% and 5% respectively. # denotes Perron test under structural break.

Table 11: Augmented Dickey Fuller Test Statistics

quirements of semi-endogenous growth ($\sigma > 0$, $\phi < 1$), Schumpeterian productivity growth ($\sigma > 0$, $\phi \geq 1$), or neoclassical productivity growth ($\sigma = 0$, $\phi = 1$). Again, we summarise the detailed estimation evidence in terms of the implied sectoral classification in Tables 18 and 19.

Under these parameter restrictions, nine sectors satisfy the strict requirements for Schumpeterian productivity growth ($\sigma > 0$, $\phi \geq 1$). Seven sectors are weakly consistent with Schumpeterian productivity growth, in the sense of returning $\sigma = 0$ and $\phi \geq 1$. Five sectors provided the $\phi \geq 1$ estimate required by Schumpeterian productivity growth, but also $\sigma < 0$.

Neoclassical productivity growth again finds little support, with only one sector potentially satisfying the parameter restrictions.

While semi-endogenous productivity growth again finds only incomplete support, it does so for a greater proportion of sectors (compared to South African manufacturing). No sector fulfills the strictest requirement for semi-endogenous productivity growth ($\sigma > 0$, $0 < \phi < 1$), and two sectors satisfy the weaker requirement of $\sigma = 0$, $0 < \phi < 1$.

However, a number of sectors report a finding of $\phi = 0$, which technically satisfies the requirement that the parameter fall below unity, although it does imply that there is no impact at all on the time rate of change of technology in the level of technology. For 14 sectors $\phi = 0$ is paired with a finding of $\sigma > 0$. For 19 sectors $\phi = 0$ is paired with a finding of $\sigma = 0$. For eight sectors, we find that $\phi = 0$ and $\sigma < 0$.

While in South African manufacturing no estimation result returned a finding of $\phi < 0$, for the tested OECD countries this is the case for a number of sectors. Again, while technically meeting the $\phi < 1$ requirement of semi-endogenous theory, the finding carries the even more dramatic implication that the time rate of change of technology declines in the level of technology. For 10 sectors, $\phi < 0$ and $\sigma > 0$, for two sectors $\phi < 0$ and $\sigma = 0$, and for four sectors, $\phi < 0$ and $\sigma < 0$.

Finally, for 12 sectors the requirement of a unique cointegrating vector under the estimation of (12) is not met, such that these sectors cannot be classified under any of the productivity growth theories.

In summary, as for South African manufacturing, OECD industry characteristics are certainly heterogeneous, again suggesting that time series estimation is a useful supplement to the panel data findings. While for South African manufacturing the preponderance of findings favoured Schumpeterian productivity growth, for the OECD countries tested the preponderance of sectors aligns with semi-endogenous productivity growth although Schumpeterian productivity growth is also supported for a number of OECD manufacturing sectors. Again, therefore, the time series evidence is consistent with the panel data evidence.

However, note also that the sector-specific findings show considerable variation across both the precise magnitude of the σ and the ϕ parameters, which may serve to explain why panel data evidence has been inconsistent across previous studies. For the OECD countries tested as for South Africa, then, the prospect of sustained Schumpeterian productivity growth is narrowly concentrated in a few sectors, although relative to South Africa there is more extensive evidence for the weaker semi-endogenous form of productivity growth.

VI. Conclusion and evaluation

This paper examines the nature and sources of productivity growth across a range of data sets, covering developed and developing countries, 25 South African manufacturing sectors, as well as the manufacturing sectors of six OECD countries. Our test is for the presence of semi-endogenous or Schumpeterian patterns of productivity growth.

Under panel estimation, our results are mixed. For our country-level data, which include developed and developing countries, as well as for the South African manufacturing sectors, the results consistently favour the Schumpeterian account of productivity growth, indicating strong rates of return to knowledge creation. By contrast, for the six OECD country manufacturing sectors, the panel results favour semi-endogenous productivity growth, with the associated inference of weaker returns to knowledge creation. These findings are robust to

Results for: $\ln\left(\overset{\bullet}{A}\right) = \ln\delta + \sigma_X \ln X - \sigma_Q \ln Q + \phi \ln A$

Sector	Prod.	Cointegration		lnX	lnQ	lnA	ecm	$\sigma_X = \sigma_Q$	Stable
		λ		σ	$(-1)*\widehat{\sigma_Q}$	ϕ			
Food	L	58.91^{***}		-1.78^{**} (0.79)	2.91 (2.47)	2.20 (1.77)	0.95^{***} (0.32)	1.39 [0.24]	No
	Y	58.94^{***}		-0.16 (1.15)	2.56 (2.90)	5.11 (3.20)	-0.92^{***} (0.29)	1.25 [0.26]	Yes
	WH	60.28^{***}		-1.49^{**} (0.77)	2.95 (2.83)	2.09 (1.90)	-0.95^{***} (0.31)	1.14 [0.29]	Yes
Textiles	L	$r > 1$							
	Y	78.30^{***}		-1.03^{***} (0.21)	1.22 (0.96)	6.38^{***} (0.93)	-1.01^{***} (0.31)	3.29^{*} [0.07]	Yes
	WH	$r > 1$							
Paper	L	79.90^{***}		-0.15 (0.23)	2.69^{***} (1.01)	0.88 (0.87)	-0.73^{***} (0.26)	$4,43^{**}$ [0.04]	Yes
	Y	$r > 1$							
	WH	$r > 1$							
Chem.	L	75.98^{***}		-2.65^{***} (0.67)	-5.47^{***} (1.63)	3.59^{***} (0.72)	-0.17 (0.23)	2.62 [0.11]	Yes
	Y	$r > 1$							
	WH	$r > 1$							
Rubber	L	$r > 1$							
	Y	$r > 1$							
	WH	$r > 1$							
NMM	L	52.56^{**}		1.49^{***} (0.46)	3.58^{***} (1.04)	1.94 (1.29)	-0.83^{***} (0.25)	3.46^{*} [0.06]	Yes
	Y	53.90^{**}		1.17^{***} (0.41)	4.40^{***} (1.23)	7.10^{***} (1.52)	-0.83^{***} (0.27)	4.33^{**} [0.04]	Yes
	WH	47.28^{*}		1.29^{***} (0.48)	3.02^{***} (1.08)	2.43^{*} (1.33)	-0.82^{***} (0.25)	2.05 [0.15]	Yes
B&F.Met.	L	$r > 1$							
	Y	$r > 1$							
	WH	$r > 1$							
Machinery	L	64.64^{***}		0.16 (0.39)	0.50 (0.73)	1.54^{***} (0.57)	-0.76^{***} (0.24)	0.25 [0.61]	Yes
	Y	65.36^{***}		0.38 (0.44)	1.06 (0.85)	2.88^{***} (1.11)	-0.77^{***} (0.25)	0.70 [0.40]	Yes
	WH	66.56^{***}		0.27 (0.36)	0.94 (0.63)	1.52^{***} (0.55)	-0.78^{***} (0.25)	1.02 [0.31]	Yes
Elec.	L	93.86^{***}		-60.54^{***} (8,28)	-38.37^{*} (20.43)	65.36^{***} (3.94)	-0.02^{**} ($7.9e{-3}$)	0.77 [0.38]	Yes
	Y	89.85^{***}		-33.19^{***} (5.71)	-12.82 (15.58)	18.84 (18.29)	0.03^{*} (0.02)	1.77 [0.18]	No
	WH	92.20^{***}		-152.19^{***} (22.56)	-77.49 (57.98)	116.19^{***} (10.43)	0.01^{***} (0.003)	1.13 [0.29]	No
Trapsp.	L	134.57^{***}		0.02 (0.11)	0.01 (0.24)	1.21^{***} (0.14)	-0.96^{***} (0.11)	0.00 [0.96]	Yes
	Y	133.05^{***}		-0.20 (0.15)	-0.33 (0.22)	0.77^{**} (0.34)	-0.95^{***} (0.11)	0.90 [0.34]	Yes
	WH	133.86^{***}		0.003 (0.11)	-0.03 (0.22)	1.20^{***} (0.14)	-0.96^{***} (0.11)	0.04 [0.84]	Yes

Table 12: Canada VECM Time Series Evidecne

Results for: $\ln\left(\overset{\bullet}{A}\right) = \ln\delta + \sigma_X \ln X - \sigma_Q \ln Q + \phi \ln A$									
Sector	Prod. Variety	Cointegration λ		lnX σ	lnQ $(-1)*\widehat{\sigma_Q}$	lnA ϕ	ecm	$\sigma_X = \sigma_Q$	Stable
Food	L	59.70***		1.12** (0.49)	1.92 (2.37)	2.19 (1.56)	−1.24*** (0.16)	0.05 [0.83]	Yes
	Y	62.54***		1.70*** (0.49)	3.79 (3.82)	1.89 (2.48)	−1.20*** (0.16)	0.14 [0.70]	Yes
	WH	66.36***		1.90*** (0.49)	0.70 (1.98)	−1.47 (1.57)	−1.15*** (0.16)	0.14 [0.70]	Yes
Textiles	L	61.60***		−0.99*** (0.32)	0.34 (0.32)	0.49 (0.83)	−1.56*** (0.25)	2.97* [0.08]	Yes
	Y	57.33***		−0.27 (0.41)	0.50 (0.49)	−0.80 (0.76)	−1.41*** (0.18)	0.54 [0.46]	Yes
	WH	58.68***		−0.17 (0.42)	0.44 (0.40)	−1.60 (1.07)	−1.37*** (0.17)	0.37 (0.54)	Yes
Paper	L	65.26***		0.93** (0.38)	3.47** (1.45)	−1.75*** (0.63)	−1.46*** (0.14)	2.23 [0.14]	Yes
	Y	63.44***		2.21*** (0.45)	5.74** (2.74)	4.05* (2.29)	−1.30*** (0.13)	1.24 [0.26]	Yes
	WH	73.52***		1.83*** (0.43)	3.45** (1.42)	−2.38*** (0.71)	−1.26*** (0.12)	0.72 [0.40]	Yes
Chem.	L	76.89***		7.48*** (0.87)	43.82*** (7.43)	20.96*** (2.11)	−0.35*** (0.06)	9.24*** [0.00]	Yes
	Y	68.73***		5.07*** (1.03)	20.05*** (5.42)	19.00*** (6.12)	−0.93*** (0.13)	5.99** [0.01]	Yes
	WH	75.50***		4.02*** (0.77)	27.34*** (5.39)	−15.37*** (1.82)	−0.47*** (0.08)	6.99** [0.01]	Yes
Rubber	L	54.71***		−0.01 (0.36)	2.17** (1.19)	0.23 (0.60)	−1.51*** (0.21)	4.07** [0.04]	Yes
	Y	53.79**		−0.07 (0.37)	2.72* (1.54)	−3.44** (1.46)	−1.59*** (0.22)	3.66* [0.06]	Yes
	WH	52.75**		−0.27 (0.33)	1.64 (1.05)	0.50 (0.59)	−1.56*** (0.22)	3.89** [0.05]	Yes
NMM	L	53.90**		0.22 (0.36)	0.35 (0.81)	−1.41* (0.83)	−1.39*** (0.17)	0.01 [0.91]	Yes
	Y	53.60**		0.27 (0.35)	0.49 (1.07)	−0.98 (0.81)	−1.38*** (0.17)	0.02 [0.87]	Yes
	WH	53.26**		0.25 (0.37)	0.39 (0.73)	−1.49* (0.84)	−1.38*** (0.17)	0.02 [0.90]	Yes
B&F Met.	L	$r > 1$							
	Y	$r > 1$							
	WH	$r > 1$							
Machinery	L	48.47**		0.65 (0.67)	0.88 (1.44)	−0.70 (0.72)	−1.33*** (0.18)	0.01 [0.92]	Yes
	Y	48.56**		0.75 (0.67)	0.94 (1.69)	0.24 (1.71)	−1.32*** (0,18)	0.01 [0.94]	Yes
	WH	47.71**		0.67 (0.68)	0.81 (1.14)	−0.76 (0.73)	−1.32*** (0.18)	0.00 [0.94]	Yes
Elec..	L	68.94***		0.99** (0.54)	1.01 (0.99)	0.07 (0.29)	−1.40*** (0.21)	0.00 [0.99]	Yes
	Y	73.89***		1.27** (0.55)	1.84 (1.15)	2.09 (1.47)	−1.32*** (0.20)	0.23 [0.63]	Yes
	WH	69.52***		1.06** (0.50)	0.64 (0.85)	−0.08 (0.27)	−1.39*** (0.20)	0.19 [0.67]	Yes
Trapsp.	L	76.58***		0.86*** (0.27)	1.67** (0.70)	−1.91*** (0.65)	−1.35*** (0.17)	0.55 [0.46]	Yes
	Y	150.76***		−0.04*** (0.00)	−0.03 (0.10)	0.08*** (0.01)	−1.90*** (0.20)	0.18 [0.67]	Yes
	WH	70.26***		0.89*** (0.26)	1.37** (0.57)	−1.87*** (0.62)	−1.36*** (0.17)	0.30 [0.58]	Yes

Table 13: Finland VECM Time Series Results

Results for: $\ln\left(\dot{A}\right) = \ln\delta + \sigma_X \ln X - \sigma_Q \ln Q + \phi \ln A$									
Sector	Prod. Variety	Cointegration λ		lnX σ	lnQ $(-1){*}\widehat{\sigma_Q}$	lnA ϕ	ecm	$\sigma_X = \sigma_Q$	Stable
Food	L	72.91^{***}		0.08 (0.23)	6.30 (5.24)	-10.54^{***} (1.67)	-0.95^{***} (0.11)	1.16 [0.28]	Yes
	Y	$r>1$							
	WH	$r>1$							
Textiles	L	71.21^{***}		0.51^{***} (0.16)	0.76^{***} (0.26)	-3.02^{**} (1.37)	-1.37^{***} (0.17)	0.75 [0.39]	Yes
	Y	71.14^{***}		0.64^{***} (0.20)	0.87^{***} (0.32)	-1.81 (1.12)	-1.38^{***} (0.18)	0.64 [0.42]	Yes
	WH	83.93^{***}		-0.38^{**} (0.19)	2.60^{***} (0.50)	-7.67^{***} (1.69)	-1.31^{***} (0.13)	6.83^{***} [0.00]	Yes
Paper	L	57.70^{***}		-0.92^{**} (0.57)	10.43^{**} (4.85)	-7.73^{*} (4.22)	-1.20^{***} (0.18)	3.82^{**} [0.05]	Yes
	Y	52.55^{**}		1.36 (1.13)	8.81^{**} (4.82)	-0.98 (6.69)	-1.12^{***} (0.17)	3.10 [0.08]	Yes
	WH	52.04^{**}		-1.81^{**} (0.86)	9.31^{**} (4.99)	-10.16^{**} (5.10)	-1.15^{***} (0.18)	3.27^{*} [0.07]	Yes
Chem.	L	61.51^{***}		0.97^{*} (0.55)	1.80 (3.79)	0.58 (1.41)	-1.32^{***} (0.21)	0.03 [0.87]	Yes
	Y	75.61^{***}		0.28 (0.35)	0.19 (2.52)	1.57 (2.60)	-1.25^{***} (0.24)	0.00 [0.97]	Yes
	WH	79.47^{***}		0.94^{***} (0.48)	-2.95 (2.01)	2.74^{***} (0.89)	-1.30^{***} (0.25)	1.26 [0.26]	Yes
Rubber	L	$r>1$							
	Y	$r>1$							
	WH	$r>1$							
NMM	L	64.90^{***}		$-1.2e-3$ (0.60)	0.32 (2.04)	0.61 (1.41)	-1.11^{***} (0.24)	0.01 [0.92]	Yes
	Y	$r>1$							
	WH	$r>1$							
B&F Met.	L	$r>1$							
	Y	$r>1$							
	WH	$r>1$							
Machinery	L	66.04^{***}		-0.84^{***} (0.32)	4.00^{**} (1.74)	0.90 (1.05)	-1.59^{***} (0.24)	4.84^{**} [0.03]	Yes
	Y	72.83^{***}		-0.05 (0.26)	5.20^{**} (2.23)	6.04^{***} (1.88)	-1.55^{***} (0.20)	2.79 [0.09]	Yes
	WH	72.44^{***}		-0.48 (0.33)	3.58^{**} (1.75)	-0.23 (1.13)	-1.53^{***} (0.20)	2.37 [0.12]	Yes
Elec.	L	$r>1$							
	Y	64.11^{***}		-2.76^{**} (1.26)	-4.97 (4.50)	-5.89 (5.21)	-0.81^{***} (0.25)	0.27 [0.60]	Yes
	WH	63.30^{***}		-1.11 (0.88)	-5.13 (4.71)	0.73 (0.96)	-0.80^{***} (0.25)	0.39 [0.53]	Yes
Transp.	L	$r>1$							
	Y	$r>1$							
	WH	$r>1$							

Table 14: France VECM Time Series Results

Results for: $\ln\left(\dot{A}\right) = \ln\delta + \sigma_X \ln X - \sigma_Q \ln Q + \phi \ln A$									
Section	Prod.	Cointegration		lnX	lnQ	lnA	ecm	$\sigma_X = \sigma_Q$	Stable
		λ		σ	$(-1)*\widehat{\sigma_Q}$	ϕ			
Food	L	78.98***		0.92***	6.95***	−4.32***	−0.74***	3.99**	Yes
				(0.22)	(2.18)	(1.45)	(0.18)	[0.05]	
	Y	81.79***		1.50***	3.41*	−4.04	−0.76***	0.68	Yes
				(0.42)	(2.00)	(2.52)	(0.17)	[0.41]	
	WH	76.57***		0.67***	4.97***	−5.05***	−0.76***	2.80*	Yes
				(0.20)	(1.85)	(1.47)	(0.18)	[0.09]	
Textiles	L	$r > 1$							
	Y	$r > 1$							
	WH	$r > 1$							
Paper	L	59.67***		0.14	−9.16*	−8.08***	−0.83***	1.83	Yes
				(0.21)	(5.51)	(2.38)	(0.19)	[0.18]	
	Y	66.80***		−0.71***	−8.42***	−26.29***	−0.88***	8.00***	Yes
				(0.21)	(2.16)	(4.15)	(0.18)	[0.00]	
	WH	60.34***		0.33*	−7.88	−5.48**	−0.76***	1.71	Yes
				(0.19)	(5.39)	(2.65)	(0.19)	[0.19]	
Chem.	L	$r > 1$							
	Y	$r > 1$							
	WH	$r > 1$							
Rubber	L	71.35***		0.33	0.01	0.60	−1.05***	0.24	Yes
				(0.41)	(0.69)	(1.09)	(0.23)	[0.63]	
	Y	66.02***		0.46	0.08	1.02	−1.03***	0.32	Yes
				(0.40)	(0.64)	(1.51)	(0.23)	[0.57]	
	WH	69.72***		0.26	−0.09	0.41	−1.06***	0.26	Yes
				(0.40)	(0.70)	(1.02)	(0.23)	[0.61]	
NMM	L	50.03***		0.57	4.53	3.87*	−1.24***	1.18	Yes
				(0.39)	(3.30)	(2.06)	(0.27)	[0.28]	
	Y	42.18**		0.33	2.80	9.37**	−1.26***	0.62	Yes
				(0.37)	(2.55)	(3.82)	(0.27)	[0.43]	
	WH	50.49***		0.60	4.19	3.27	−1.24***	1.39	Yes
				(0.40)	(2.81)	(2.26)	(0.26)	[0.24]	
B&F.Met.	L	70.24***		0.21	0.17	0.50	−0.58***	0.00	Yes
				(0.19)	(2.34)	(1.39)	(0.20)	[0.99]	
	Y	72.72***		0.02	2.54	1.81	−0.61***	0.68	Yes
				(0.18)	(2.11)	(1.31)	(0.21)	[0.41]	
	WH	73.94***		0.22	−1.00	1.15	−0.57***	0.24	Yes
				(0.17)	(1.94)	(1.35)	(0.20)	[0.62]	
Machinery	L	97.27***		0.57***	2.00	0.05	−1.13***	1.04	Yes
				(0.12)	(1.32)	(0.72)	(0.19)	[0.31]	
	Y	$r > 1$							
	WH	$r > 1$							
Elec.	L	$r > 1$							
	Y	$r > 1$							
	WH	95.49***		0.13	−1.79**	1.37***	−0.60***	2.07	Yes
				(0.17)	(0.89)	(0.16)	(0.21)	[0.15]	
Trapsp.	L	$r > 1$							
	Y	$r > 1$							
	WH	$r > 1$							

Table 15: Italy VECM Time Series Results

Results for: $\ln \left(\overset{\bullet}{A}\right) = \ln\delta + \sigma_X \ln X - \sigma_Q \ln Q + \phi \ln A$									
Sector	Prod.	Cointegration		lnX	lnQ	lnA	ecm	$\sigma_X = \sigma_Q$	Stable
		λ		σ	$(-1)*\widehat{\sigma_Q}$	ϕ			
Food	L	86.00***		0.38*** (0.13)	0.27 (1.69)	1.59*** (0.63)	−0.65*** (0.22)	0.00 [0.96]	Yes
	Y	$r > 1$							
	WH	87.73***		0.38*** (0.10)	0.65 (1.56)	1.53** (0.70)	−0.64*** (0.22)	0.02 [0.89]	Yes
Textiles	L	70.36***		0.03 (0.10)	−1.32 (1.52)	2.63 (1.90)	−0.76*** (0.24)	0.69 [0.41]	Yes
	Y	71.41***		−0.05 (0.11)	−1.69 (1.95)	1.78* (1.03)	−0.75*** (0.25)	0.61 [0.44]	Yes
	WH	73.28***		0.01 (0.10)	−1.41 (1.40)	3.23 (2.08)	−0.76*** (0.24)	0.83 [0.36]	Yes
Paper	L	57.94***		0.24 (0.34)	−0.99 (2.04)	2.98 (2.12)	−0.97*** (0.24)	0.39 [0.54]	Yes
	Y	59.71***		0.61 (9.42)	1.26 (2.19)	3.20 (2.12)	−0.98*** (0.24)	0.11 [0.73]	Yes
	WH	59.96***		0.16 (0.31)	−2.72 (2.42)	4.12* (2.37)	−0.97*** (0.24)	1.35 [0.24]	Yes
Chem.	L	67.49***		0.10 (0.29)	−3.41 (2.86)	1.55 (1.03)	−0.75*** (0.23)	1.13 [0.29]	Yes
	Y	$r > 1$							
	WH	$r > 1$							
Rubber	L	72.82***		1.42** (0.60)	0.92 (2.01)	−0.92 (2.01)	−1.07*** (0.20)	0.11 [0.74]	Yes
	Y	$r > 1$							
	WH	73.74***		1.25** (0.53)	0.64 (1.65)	−1.92 (1.88)	−1.07*** (0.20)	0.20 [0.65]	Yes
NMM	L	67.64***		0.41 (0.68)	0.71 (1.35)	−1.47 (1.89)	−1.09*** (0.20)	0.06 [0.80]	Yes
	Y	$r > 1$							
	WH	71.01***		0.15 (0.64)	0.40 (1.13)	−1.14 (1.89)	−1.08*** (0.21)	0.05 [0.83]	Yes
B&F.Met.	L	$r > 1$							
	Y	$r > 1$							
	WH	$r > 1$							
Machinery	L	65.19***		0.43 (0.31)	0.58 (1.03)	−0.21 (1.18)	−1.12*** (0.22)	0.02 [0.89]	Yes
	Y	$r > 1$							
	WH	$r > 1$							
Elec.	L	$r > 1$							
	Y	$r > 1$							
	WH	$r > 1$							
Trapsp.	L	66.32***		0.20 (0.92)	−7.31*** (2.41)	−1.96 (1.78)	−1.04*** (0.22)	6.55** [0.01]	Yes
	Y	69.46***		−0.12 (0.99)	−5.36*** (1.82)	−8.39*** (2.65)	−0.97*** (0.21)	5.73** [0.02]	Yes
	WH	66.47***		0.43 (0.95)	−6.49*** (2.10)	−2.10 (1.87)	−1.00*** (0.22)	6.48** [0.01]	Yes

Table 16: Spain VECM Time Series Evidence

Results for: $\ln\left(\dot{A}\right) = \ln\delta + \sigma_X \ln X - \sigma_Q \ln Q + \phi \ln A$									
Sector	Prod.	Cointegration		lnX	lnQ	lnA	ecm	$\sigma_X = \sigma_Q$	Stable
		λ		σ	$(-1)*\widehat{\sigma_Q}$	ϕ			
Food	L	$r>1$							
	Y	$r>1$							
	WH	75.04^{***}		0.17 (0.37)	4.76 (3.75)	1.90 (1.33)	-1.01^{***} (0.24)	1.02 $[0.31]$	Yes
Textiles	L	$r>1$							
	Y	83.23^{***}		0.83^{**} (0.36)	4.25^{***} (1.36)	1.43^{*} (0.75)	-0.77^{***} (0.20)	2.64^{*} $[0.10]$	Yes
	WH	$r>1$							
Paper	L	$r>1$							
	Y	$r>1$							
	WH	$r>1$							
Chem.	L	$r>1$							
	Y	$r>1$							
	WH	84.94^{***}		-12.63 (7.43)	-13.91^{**} (5.87)	0.69 (0.81)	-1.08^{***} (0.19)	0.14 $[0.71]$	Yes
Rubber	L	81.86^{***}		2.37^{***} (0.41)	3.95^{**} (1.53)	3.26^{***} (0.91)	-1.51^{***} (0.18)	0.53 $[0.47]$	Yes
	Y	$r>1$							
	WH	77.52^{***}		2.29^{***} (0.44)	2.47^{*} (1.45)	2.51^{***} (0.94)	-1.51^{***} (0.18)	0.01 $[0.94]$	Yes
NMM	L	46.50^{*}		20.93^{*} (11.12)	-270.69^{***} (59.83)	204.62^{***} (34.52)	0.04^{***} (0.01)	5.46^{**} $[0.02]$	No
	Y	48.88^{**}		-2.08^{**} (1.24)	19.34^{***} (5.74)	4.35 (7.45)	-0.33^{***} (0.09)	5.71^{**} $[0.02]$	Yes
	WH	46.58^{*}		-37.01 (52.94)	1216.90^{***} (275.33)	-559.12^{***} (137.17)	-0.01^{***} $(2.8e{-}3)$	3.28^{*} $[0.07]$	Yes
B&F Met.	L	79.11^{***}		0.57 (0.52)	0.23 (0.82)	2.14^{***} (0.61)	-0.99^{***} (0.25)	0.13 $[0.72]$	Yes
	Y	77.93^{***}		0.61 (0.52)	0.38 (1.00)	2.54^{**} (1.24)	-0.99^{***} (0.25)	0.04 $[0.84]$	Yes
	WH	76.72^{***}		0.56 (0.50)	0.32 (0.86)	2.17^{***} (0.58)	-0.99^{***} (0.25)	0.05 $[0.82]$	Yes
Machinery	L	65.94^{***}		0.29 (0.95)	0.11 (1.45)	0.99^{***} (0.34)	-0.95^{***} (0.24)	0.01 $[0.92]$	Yes
	Y	66.44^{***}		0.59 (0.92)	1.03 (2.19)	2.39 (2.81)	-0.99^{***} (0.24)	0.04 $[0.85]$	Yes
	WH	68.29^{***}		0.44 (0.82)	0.16 (1.48)	1.09^{***} (0.36)	-0.98^{***} (0.24)	0.02 $[0.88]$	Yes
Elec.	L	81.09^{***}		0.25 (0.66)	1.31 (1.40)	0.85^{**} (0.37)	-0.82^{***} (0.28)	0.77 $[0.38]$	Yes
	Y	81.62^{***}		-0.38 (0.76)	-0.37 (2.00)	0.14 (2.66)	-0.79^{***} (0.29)	0.00 $[1.00]$	Yes
	WH	82.92^{***}		-0.35 (0.68)	-0.29 (1.48)	0.59 (0.40)	-0.79^{***} (0.29)	0.00 $[0.96]$	Yes
Transp.	L	69.05^{***}		0.00 (0.69)	2.16 (2.05)	3.22^{***} (0.83)	-0.85^{***} (0.27)	1.12 $[0.29]$	Yes
	Y	72.46^{***}		-0.64 (0.58)	-2.00 (1.68)	-0.05 (2.28)	-0.82^{***} (0.24)	0.33 $[0.56]$	Yes
	WH	69.08^{***}		-0.43 (0.66)	0.58 (2.09)	2.93^{***} (0.90)	-0.86^{***} (0.26)	0.16 $[0.69]$	Yes

Table 17: USA VECM Time Series Results

Canada					
	$\phi < 0$	$\phi = 0$	$0 < \phi < 1$	$\phi = 1$	$\phi > 1$
$\sigma < 0$		Food Elec. (Y)			Textiles Chem. Elec. (L,WH)
$\sigma = 0$			Transport (Y)		Machinery Transport (L,WH)
$\sigma > 0$		Paper NMM (L)			NMM (Y,WH)
r>1	Rubber	B&FMet			
Finland					
	$\phi < 0$	$\phi = 0$	$0 < \phi < 1$	$\phi = 1$	$\phi > 1$
$\sigma < 0$		Textiles (L)	Transport (Y)		
$\sigma = 0$	NMM (L,WH)	Textiles (Y,WH) NMM (Y) Rubber (WH) Machinery			
$\sigma > 0$	Paper (L,WH) Rubber (Y) Chem (WH) Transport (L,WH)	Food Rubber (L) Elec.			Paper (Y) Chem (L,Y)
r>1	B&FMet.				
France					
	$\phi < 0$	$\phi = 0$	$0 < \phi < 1$	$\phi = 1$	$\phi > 1$
$\sigma < 0$	Textiles (σ_X) (WH) Paper (σ_X) (L,WH)	Machinery (σ_X) (L) Elec. (Y)			
$\sigma = 0$	Food	Chem (Y) NMM Elec. (WH)			
$\sigma > 0$	Textiles (L) Textiles (σ_Q) (WH) Paper (σ_Q) (L,WH)	Textiles (Y) Paper (Y) Chem (L) Machinery (σ_Q) (L) Machinery (WH)			Chem (WH) Machinery (Y)
r>1	Rubber	B&FMet	Transport		

Y,L,WH indicate estimation under GDP, Employment and Working Hours product variety.

Results are consistent where no product variety proxy (Y,L,WH) is indicated.

σ_X, σ_Q indicates elasticity parameter under R&D input and product variety respectively.

Results are consistent where neither elasticity parameter (σ_X, σ_Q) is indicated.

Table 18: OECD Sector Classification I

Italy					
	$\phi < 0$	$\phi = 0$	$0 < \phi < 1$	$\phi = 1$	$\phi > 1$
$\sigma < 0$	Paper (L,Y)				Elec.
$\sigma = 0$		Rubber NMM (WH) B&F Met			NMM (L,Y)
$\sigma > 0$	Food (L,WH) Paper (WH)	Food (Y) Machinery			
r>1	Textiles	Chem.	Transport		
Spain					
	$\phi < 0$	$\phi = 0$	$0 < \phi < 1$	$\phi = 1$	$\phi > 1$
$\sigma < 0$	Transport (Y)	Transport (L,WH)			
$\sigma = 0$		Textiles (L,WH) Paper (L,Y) Chem. NMM Machinery			Textiles (Y) Paper (WH)
$\sigma > 0$		Rubber			Food
r>1	B&F Met.	Elec.			
USA					
	$\phi < 0$	$\phi = 0$	$0 < \phi < 1$	$\phi = 1$	$\phi > 1$
$\sigma < 0$		Chem. NMM (σ_X) (Y)			NMM (σ_Q) (L)
$\sigma = 0$		Food Machinery (Y) Elec. (Y,WH) Transport (Y)	Elec. (L)	Machinery (L,WH)	B&F Met. Transport (L,WH)
$\sigma > 0$	NMM (WH)	NMM (σ_Q) (Y)			Textiles Rubber NMM (σ_X) (L)
r>1	Paper				

Y,L,WH indicate estimation under GDP, Employment and Working Hours product variety.

Results are consistent where no product variety proxy (Y,L,WH) is indicated.

σ_X, σ_Q indicates elasticity parameter under R&D input and product variety respectively.

Results are consistent where neither elasticity parameter (σ_X, σ_Q) is indicated.

Table 19: OECD Sector Classification II

a range of alternative specifications of the test as well as to a range of alternative estimators (OLS, FE, GMM, PMG and MG). Our results from the panel data estimation are thus not conclusive, with evidence for both Schumpeterian and semi-endogenous growth theory emerging. It is surprising that the Schumpeterian case is strongest for the data set that includes developing countries, and the middle-income case of South Africa, and weakest for the set of six developed OECD economies.

One of the more nuanced findings from the panel data is that there is evidence of sector heterogeneity, such that panel data estimation may hide significant sector differences (with the partial exception of PMG and MG estimators).

For this reason, we also considered time series evidence for the South African and OECD data, for which a sufficient number of observations are available to render time series estimation feasible. The results are consistent with the existence of considerable sectoral heterogeneity.

The first implication of the South African time series findings is confirmation of the inference that we drew from the panel data evidence: there is no guarantee that sectors are homogenous in terms of the characteristics of their productivity growth. Only six sectors of the South African manufacturing sector appear to follow a Schumpeterian productivity growth regime in the strict sense of satisfying all the requirements of the theory, although a further six sectors follow Schumpeterian productivity growth weakly in the sense that they meet some of the restrictions on parameter space (a high rate of return on knowledge, but insignificant elasticity on R&D and product variety proxy).

Nonetheless, the second implication of the South African time series evidence is that Schumpeterian productivity growth is favoured with greater preponderance (in the strict sense) than semi-endogenous productivity growth for South African manufacturing - consistent with the panel data findings.

Third, we note that Schumpeterian growth in South African manufacturing appears to be concentrated in the Chemicals and related sectors, Machinery and Transport equipment, and Basic iron and steel.

While there is thus some prospect for sustained productivity growth in South African manufacturing, such prospects are also narrowly focussed amongst South African manufacturing sectors. For the majority of South African manufacturing sectors, the inference is instead that productivity growth will not be sustained, and will instead be constrained by the natural rate of growth of the sector. For an economy in need of strong and sustained growth performance, this is not good news.

For the OECD time series results, three distinct implications follow. First, as for the South African data, the findings confirm sector heterogeneity in terms of the characteristics of their productivity growth. An additional form of heterogeneity in the OECD countries is that the results are very sensitive to the proxy of product variety. For the OECD sample most of the sectors align with semi-endogenous productivity growth, although Schumpeterian productivity growth is also supported for a number of OECD manufacturing sectors. While the time series evidence is thus broadly consistent with the panel data evidence, the sector-specific findings also show considerable variation across the precise magnitude of the σ and the ϕ parameters, which may explain why the panel data evidence have been inconsistent across previous studies. Here too, then, prospects for sustained Schumpeterian productivity growth are narrowly concentrated in a few sectors.

Results for the OECD sectors indicate that the two North American economies (Canada and the US) have more sectors identified as Schumpeterian than the European economies included in the study (Finland, France, Italy and Spain). Finland has the most sectors identified with a positive *R&D* elasticity towards productivity growth. More specifically, each of the two North American economies has six sectors that satisfy the $\phi \geq 1$ requirement of Schumpeterian growth under all or some of the proxies for product variety, whereas each of the four European economies has only two (Finland, France and Italy) or three (Spain). Such findings predict that the North American economies have stronger potential for unbounded productivity growth across more sectors. On the other hand, for each of the six OECD

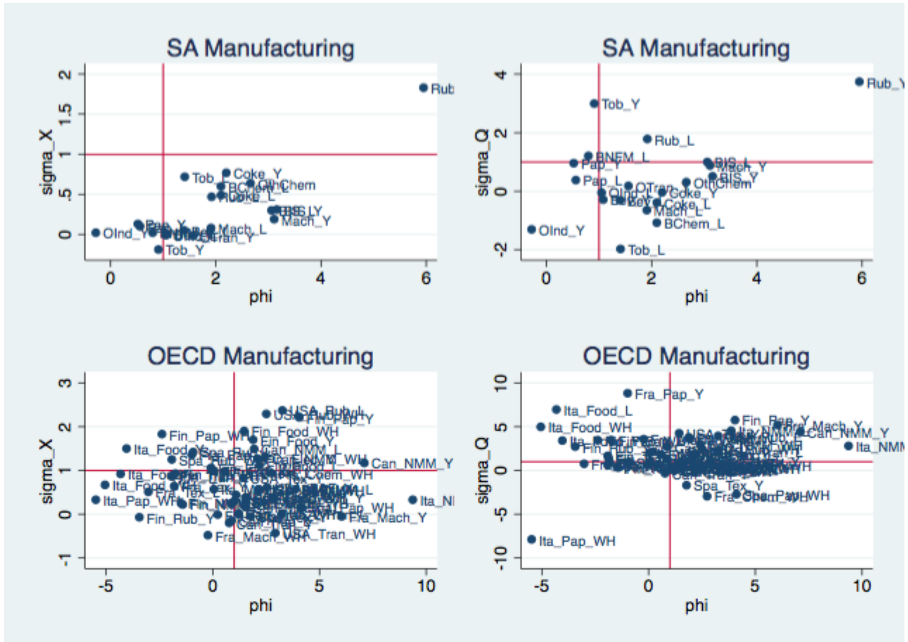

Figure 1: Association between σ and ϕ for both Schumpeterian and Semi-endogenous sectors. sigma_X denotes σ obtained from $\ln X$, sigma_Q denotes σ obtained from $\ln Q$.

economies, at least half of the ten sectors included in the study are more readily classifiable as subject to semi-endogenous than Schumpeterian productivity growth (5 for Canada, 6 for Italy and the US, 7 for France and Spain, and 9 for Finland). This finding is consistent with those reported by Barcenilla-Visús et al (2014).

Given the sectoral heterogeneity that emerges from the time series evidence, we note that sector-specific time series modelling may be preferable to panel data analysis.

Finally, we also illustrate the association between the σ-parameter estimates and the estimates of the ϕ-parameter from our estimations. We do so in Figure 1 for both Schumpeterian and semi-endogenous sectors, including both sectors that strictly and weakly meet the theoretical requirements. Figure 2 repeats for the Schumpeterian sectors and Figure 3 for the semi-endogenous sectors, in both instances under the strict interpretation of the theory only.

The evidence of Figure 1 suggests that, for South African manufacturing there is a positive association between σ and ϕ, while this association is absent for OECD manufacturing.

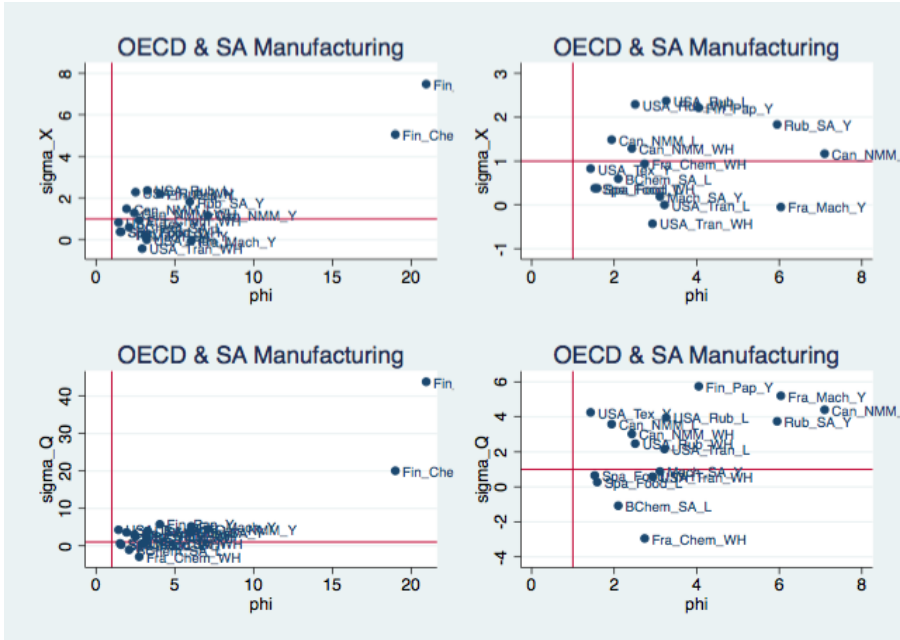

Figure 2: Association between σ and ϕ for Schumpeterian sectors. sigma_X denotes σ obtained from $\ln X$, sigma_Q denotes σ obtained from $\ln Q$.

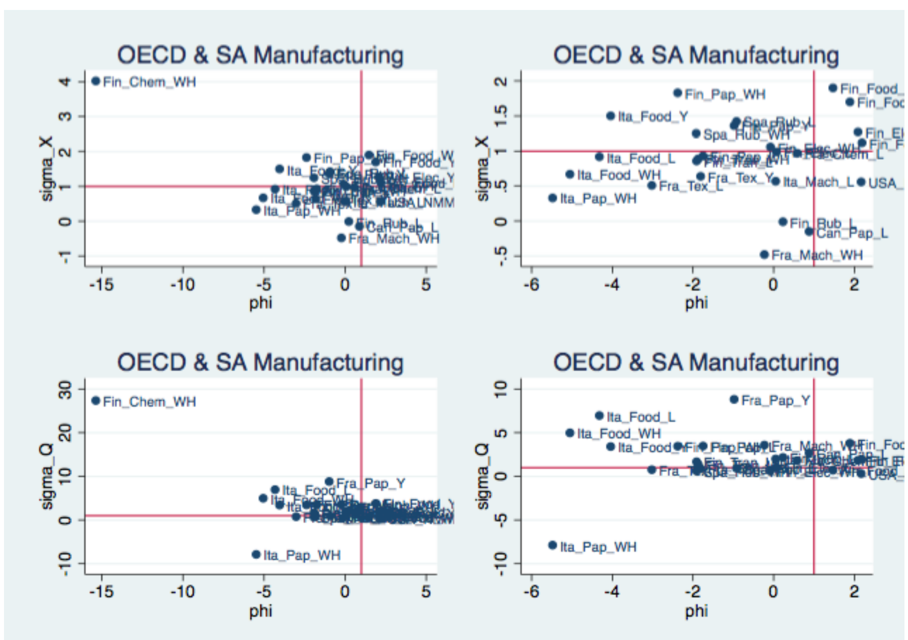

Figure 3: Association between σ and ϕ for Semi-endogenous sectors. sigma_X denotes σ obtained from $\ln X$, sigma_Q denotes σ obtained from $\ln Q$.

However, recall that the OECD results incorporate both Schumpeterian and semi-endogenous productivity growth model consistent results. On separating the two types of sectors, note that in Figure 2 for the Schumpeterian sectors the positive association is again present, while for the semi-endogenous sectors of Figure 3 it is not. This finding is reassuring, since it suggests that, in the presence of strong returns to knowledge, the rate of return to the factor of production that generates technological growth mirrors the high returns to knowledge creation.

We also note that relative to their OECD competitors, the South African manufacturing sectors show relatively moderate returns to knowledge (ϕ) and the factor of production driving knowledge creation (σ), consistent with South Africa's middle-income country status.

However, all countries that are considered in this study appear to have a relatively narrow Schumpeterian base in their productivity growth.

REFERENCES

Abramovitz, M., (1956), Resource and Output Trends in the united States since 1870, *American Economic Review*, 46(2), 5-23.

Abramovitz, M., (1993), The Search for the Sources of Growth: Areas of Ignorance, Old and New, *Journal of Economic History*, 53(2), 217-43.

Aghion, P. and Howitt, P., (1992), A Model of Growth through Creative Destruction, *Econometrica*, 60(2), 323-351.

Arora, V., (2005), Economic Growth in Post-Apartheid South Africa: A Growth-Accounting Analysis, in M. Novak and L.A. Ricci (eds.) *Post-Apartheid South Africa: The First Ten Years*, Washington: International Monetary Fund.

Barcenilla-Visús, S., López-Pueyo, C., and Sanaú-Villaroya, J., (2014), Semi-Endogenous versus Fully Endogenous Growth Theory: A Sectoral Approach, *Journal of Applied Economics*, 17(1), 1-30.

Du Plessis, S., and Smit, B., (2009), Accounting for South Africa's Growth Revival after 1994, in J. Aron, B. Khan, and G. Kingdon (eds.) *South African Economic Policy under Democracy*, Oxford: University Press, 28-57.

Fagerberg, J., (1994), Technology and International Differences in Growth Rates, *Journal of Economic Literature*, 32(3), 1147-75.

Fedderke, J.W., (2002), The Structure of Growth in the South African Economy: Factor Accumulation and Total Factor Productivity Growth 1970-97, *South African Journal of Economics*, 70(4), 611-46.

Fedderke, J.W., (2006), Technology, Human Capital and Growth: evidence from a middle income country case study applying dynamic heterogeneous panel analysis, in South African Reserve Bank, Banco de Mexico and The People's Bank of China (eds.) *Economic Growth, Proceedings of a G20 seminar held in Pretoria, South Africa, on 4-5 August 2005.*

Greenslade, J., Hall, S.G., and Henry, S.G.B., (1999), On the Practical Identification of Cointegrated Systems with an application to UK Wage and Price Setting, Paper presented at the African Econometrics Society Conference 1999.

Ha, J.Y., and Howitt, P., (2007), Accounting for Trends in Productivity and R&D: A Schumpeterian Critique of Semi-Endogenous Growth Theory, *Journal of Money, Credit and Banking*, 39(4), 733-74.

Hausman, J.A., (1978), Specification tests in economics, *Econometrica*, 46, 1251-70.

Johansen, S., (1991), Estimation and Hypothesis Testing of Cointegration Vectors in Gaussian Vector Autoregressive Models, *Econometrica*, 59(6), 1551-80.

Johansen, S., and Juselius, K., (1990), Maximum Likelyhood Estimation and Inference on Cointegration - with applications to the demand for money, *Oxford Bulletin of Economics and Statistics*, 52(2), 169-210.

Johansen, S., and Juselius, K., (1992), Testing structural hypotheses in a multivariate cointegrating analysis of the PPP and the UIP for UK, *Journal of Econometrics*, 53, 211-44.

Jones, C.I., (1995a), Time Series Tests of Endogenous Growth Models, *Quarterly Journal of Economics*, 110(2), 495-525.

Jones, C.I., (1995b), R & D-Based Models of Economic Growth, *Journal of Political Economy*, 103(4), 759-84.

Kortum, S.S., (1997), Research, Patenting, and Technological Change, *Econometrica*, 65(6), 1389-1419.

Lim, D., (1994), Explaining the Growth Performance of Asian Developing Economies, *Economic Development and Cultural Change*, 42(4), 829-44.

Madsen, J.B., (2008), Semi-endogenous versus Schumpeterian growth models: testing the knowledge production function using international data, *Journal of Economic Gro*wth, 13, 1-26.

Perron, P., (1989), The Great Crash, the oil shock and the unit root hypothessis, *Econometrica*, 57, 1361-402.

Perron, P., (1990), Testing for a unit root in a time series with a changing mean, *Journal of Econometrics*, 33, 311-40.

Pesaran, M.H., and Y. Shin, (1995a), Long Run Structural Modelling, Mimeo, University of Cambridge.

Pesaran, M.H., and Y. Shin, (1995b), An Autoregressive Distributed Lag Modelling Approach to Cointegration Analysis, *DAE Working Paper no 9514*, Department of Applied Economics, University of Cambridge.

Pesaran, M.H., Y. Shin, and R.J. Smith, (1996), Testing for the Existence of a Long Run Relationship, *DAE Working Paper No.9622*, Department of Applied Economics, University of Cambridge.

Pesaran M.H., Shin, Y., and Smith, R.P., (1999), Pooled Mean Group Estimation of Dynamic Heterogenous Panels, *Journal of the American Statistical Association*, 94, pp. 621-634.

Pesaran, M.H. and Smith, R.P., (1995), Estimating Long-Run Relationships from Dynamic Heterogeneous Panels, *Journal of Econometrics*, 68, 79-113.

Romer, P.M., (1986), Increasing Returns and Long-Run Growth, *Journal of Political Economy*, 94(5), 1002-37.

Romer, P.M., (1990), Endogenous Technological Change, *Journal of Political Economy*, 98(5), S71-S102.

Romer, P.M., (1992), Two Strategies for Economic Development: Using Ideas vs. Producing Ideas, Paper prepared for the World Bank's *Annual Conference on Development Economics*.

Romer, P.M., (1994), The Origins of Endogenous Growth, *Journal of Economic Perspectives*, 8(1), 3-22.

Solow, R.M., (1956), A Contribution to the Theory of Economic Growth, *Quarterly Journal of Economic Growth*, 70(1), 65-94.

Solow, R.M., (1957), Technical Change and the Aggregate Production Function, *Review of Economics and Statistics*, 39, 312-20.

Swan, T.W., (1956), Economic Growth and Capital Accumulation, *Economic Record*, 32, 334-61.

Wickens, M.R., (1996), Interpreting cointegrating vectors and common stochastic trends, *Journal of Econometrics*, 74, 255-71.

Young, A., (1998), Growth Without Scale Effects, *Journal of Political Economy*, 106(1), 41–63.