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An Empirical Note on R&D Growth Models with Regional Implications

James W. Saunoris# and James E. Payne*
University of Kentucky#, University of South Florida Polytechnic – USA*

Abstract. Using U.S. data from 1960 to 2007 this empirical note re-examines the semi-endogenous and Schumpeterian R&D growth models presented by Ha and Howitt (2007) and Madsen (2008). The empirical results support the Schumpeterian R&D growth model. Specifically, in the long-run increases in R&D expenditures are necessary to counteract lower R&D productivity due to the presence of product proliferation. Furthermore, the study provides a framework for further investigation of R&D growth models at the regional level.

1. Introduction

The role of research and development (R&D) in the economic growth process has been a topic of continued interest by researchers [see, e.g, Jaffe, 1986; Coe and Helpman, 1995; Park, 1995; Lichtenberg and de la Potterie, 1998; Engelbrecht, 1997; Guellec and de la Potterie, 2004; Del Barrio-Castro et al., 2002; Keller, 2002]. Earlier R&D based growth models predicted that more R&D labor should induce a proportional increase in total factor productivity (TFP); however, the empirical evidence revealed an upward trend in R&D labor, but no trend in TFP growth (Jones, 1995a). In response, a second generation of R&D-based growth models, the semi-endogenous and Schumpeterian growth models, has been advanced to rectify this inconsistency.

The semi-endogenous growth models developed by Jones (1995b), Kortum (1997) and Segerstrom (1998) replaces the assumption of constant returns to knowledge with diminishing returns. Thus, in order to maintain a given rate of TFP growth it is necessary for sustained growth in R&D labor, which implies that long-run TFP growth, and hence total growth per capita, depends on the rate of population growth. On the other hand, Schumpeterian growth models of Aghion and Howitt (1998), Dinopoulos and Thompson (1998), Peretto (1998), and Howitt (1999) maintain the assumption of constant returns to knowledge; however, as the economy grows the proliferation of product varieties reduces the effectiveness of R&D. The long-run implication of this theory is that an increase in R&D expenditures is necessary to counteract lower R&D productivity due to product proliferation.

The purpose of this empirical note is to re-examine the semi-endogenous and Schumpeterian R&D growth models within the context of a nested model which parallels Ha and Howitt (2007) and Madsen (2008). This empirical note provides the framework for future work with respect to differentiating between semi-endogenous and Schumpeterian R&D growth models in the case of regional economies along with the policy implications associated with economic development initiatives.

Section 2 provides a brief overview of the literature on second generation R&D based growth models. Section 3 presents the theoretical underpinnings of the semi-endogenous and Schumpeterian growth models and testable hypotheses. Section 4 discusses the data, methodology, and results. Concluding remarks are given in Section 5.

2. Brief review of semi-endogenous and Schumpeterian growth models

The literature on second generation R&D based growth models has only recently emerged in the growth literature. Zachariadis (2003) finds support for the Schumpeterian growth model using a panel of U.S. industries over the period 1963-88. He finds that the share of output devoted to R&D positively affects patenting and productivity growth. In a related study, Zachariadis (2004) examines the relationship between TFP growth and the share of output devoted to R&D expenditures for a panel of 10 OECD countries from 1971-1995 to provide further confirmation of the Schumpeterian growth model. Using R&D personnel per establishment as a proxy for R&D per product line over the period 1964-2001, Laincz and Peretto (2004) show that the amount of R&D per product line and fluctuations in output are related to the fluctuations in employment per product line and R&D per product line, consistent with the Schumpeterian growth model. In another panel study of 41 countries for the period 1981-1997, Ulku (2005) provides evidence that the degree of returns to the stock of knowledge in R&D is almost equal to unity, a value predicted by the Schumpeterian growth model.

Ha and Howitt (2007) was one of the first studies to discriminate between semi-endogenous and Schumpeterian growth theories. Using U.S. data from 1953-2000, Ha and Howitt (2007) finds strong empirical support for Schumpeterian theory, but fail to find any support for semi-endogenous theory. A more recent study by Madsen (2008) uses relatively long historical data on patents, trademarks, and R&D expenditures for 21 OECD countries to examine the ability of second-generation growth models to explain TFP growth over time and across countries. Although the time series evidence tends to favor Schumpeterian theory with little support for semi-endogenous theory, the cross country evidence is less favorable for Schumpeterian theory. As further support of the Schumpeterian theory, Madsen (2008) finds significant spillover effects based on the channels for imports of intermediate goods and geographical proximity as well as through channels independent of trade and geography.

3. Semi-endogenous and Schumpeterian growth models

Following Ha and Howitt (2007) and Madsen (2008), let us begin with a homogenous Cobb-Douglas production function:

$$Y = K^{\alpha}\left(AHL\right)^{1-\alpha} \qquad (1)$$

where Y is output, A is knowledge, H is the level of human capital per worker, K is capital stock, and L is labor. The growth in knowledge is given by the following:

$$g_a = \frac{\dot{A}}{A} = \lambda\left(\frac{X}{Q}\right)^{\sigma} A^{\phi-1},\ 0 < \sigma \le 1,\ \phi \le 1 \qquad (2)$$

where Q is $Q \propto L^{\beta}$ in steady state for product variety, ϕ represents the returns to scale in knowledge, σ is the duplication parameter which is zero if all innovations are duplications and one in the absence of duplicating innovations, β is the coefficient for product proliferation, λ is the research productivity parameter, L is employment, and X represents R&D inputs. Q is a measure of product variety, measured by productivity-adjusted real GDP (Y/A), human capital augmented labor (HL), and unadjusted labor (L).[1] Real GDP scaled by productivity is considered since the propensity to enter the market with new products depends on the productivity-adjusted measure of output. The ratio between X and Q is considered research intensity.

As noted by Madsen (2008), first generation growth models predict constant returns to scale (ϕ = 1) and absence of product proliferation (β = 0), Schumpeterian growth models maintain the assumption of constant returns to scale but complete product proliferation (β = 1), and the semi-endogenous growth models predict diminishing returns to knowledge (ϕ < 1) and the absence of product proliferation. The log-linearized stochastic version of equation (2), as in Ha and Howitt (2007) and Madsen (2008), can be written as follows:

$$\Delta \ln A_t = \ln \lambda + \sigma\left[\ln X_t - \ln Q_t + \left(\frac{\phi-1}{\sigma}\right)\ln A_t\right] + u_t \qquad (3)$$

[1] Q can be any measure that grows at the same rate as the population in the long run.

where $u_t \sim i.i.d.(0,\sigma^2)$. Provided that $\Delta\ln A_t$ is stationary, as in Zacharadis (2003), Ha and Howitt (2007), and Madsen (2008), then the variables in brackets should form a cointegration relationship between A, X, and Q. The second-generation growth models imply the following equations are stationary:

semi-endogenous growth model:

$$\nu_t = \ln X_t + \left(\frac{\phi - 1}{\sigma}\right)\ln A_t \quad (4)$$

Schumpeterian growth model:

$$\zeta_t = \ln X_t + \ln Q_t . \quad (5)$$

The cointegrating model specified in (6) nests both models:

$$\ln X_t = \eta \ln Q_t + \theta \ln A_t + \varepsilon_t \quad (6)$$

where $\theta = \left(\frac{1-\phi}{\sigma}\right)$. The semi-endogenous growth model hypothesizes that $\eta = 0$ and $\theta > 0$ whereas the Schumpeterian growth model hypothesizes that $\eta = 1$ and $\theta = 0$.

4. Data, methodology, and results

Annual data on the U.S. from 1960 to 2007 were collected from a variety of sources. X is measured by real R&D expenditures (R) collected from National Science Foundation, Division of Science Resources Statistics, *National Patterns of R&D Resources*. Measures of product variety, Q, include productivity-adjusted real gross domestic product (Y/A), human capital augmented labor (HL), and unadjusted labor (L). Real GDP (Y) and total employment (L) were collected from the U.S. Bureau of Economic Analysis and the U.S. Bureau of Labor Statistics, respectively.

The level of human capital per worker (H) is calculated following Ha and Howitt (2007) using the Mincerian approach:[2]

$$H_t = e^{\theta s_t} \quad (7)$$

where θ is the returns to one additional year of schooling and is assumed to be 0.07. s_t is the average educational attainment for US workers, calculated using a weighted average for employed workers including various age-sex subgroups (males and females age 25-34, 35-54, and 55 and over):

$$s_t = \sum_i \frac{s_{it} L_{it}}{L_t} \quad (8)$$

where i represents each subgroup and L is total employment.

Knowledge, A, is measured as the residual from the Cobb-Douglas production function detailed in equation (1), where the variables include the ones mentioned above along with a capital stock measure created using chain-type quantity indices for net stock of fixed assets and consumer durable goods, specifically the quantity indices for nonresidential private and government fixed assets.[3]

Thus, for research intensity, $\left(\frac{X}{Q}\right)$, the following normalizations are used: $\left(\frac{R}{Y}\right)$, $\left(\frac{R}{A \cdot HL}\right)$, and $\left(\frac{R}{A \cdot L}\right)$, where Q is productivity-augmented ($A \cdot Q$), in the case of Schumpeterian growth models, to allow for decreasing returns to R&D due to the increasing complexity of innovations.[4]

The analysis begins by testing the stationarity properties of $\Delta\ln A_t$ using the augmented Dickey Fuller (ADF, 1979) and Phillips-Perron (PP, 1988) unit root tests. Table 1 displays the results of the unit root tests which indicate that $\ln A_t$ is stationary in first differences. This finding supports both theories in that $\Delta\ln A_t$ is stationary, which in turn implies the existence of a cointegrating relationship among the bracketed terms in equation (2). Indeed, if the bracketed terms represent a cointegration relationship, the variables must be integrated of the same order, in this case I(1). Table 1 also provides the results from the stationarity test for all the X and Q variables under consideration. The results from the ADF and PP unit root tests indicate that all the variables are stationary in first differences. In sum, the unit root tests are consistent with the predictions of both theories with $\ln A_t$, $\ln X_t$, and $\ln Q_t$, integrated

[2] See Appendix A of Ha and Howitt for details on calculations and variable descriptions.

[3] These can be accessed at www.bea.doc.gov/bea/dn/faweb/AllFATables.asp, Table 1.2.

[4] The first normalization follows Zachariadis (2003, 2004), Ha and Howitt (2007), and Madsen (2008); the second follows Ha and Howitt (2007); and the third follows Ha and Howitt (2007) and Madsen (2008).

of the same order and therefore consistent with a cointegrating relationship.

Table 1. Unit root rests, 1960-2007.

A Variable:		
(A)	**ADF**	**PP**
$\ln A_t$	-1.236	-1.257
$\Delta \ln A_t$	-3.593[a]	-5.903[a]
X Variable:		
(R)	**ADF**	**PP**
$\ln X$	-0.38	-0.54
$\Delta \ln X$	-3.15[b]	-3.18[b]
Q Variables:		
(Y)	**ADF**	**PP**
$\ln Q$	-1.61	-1.80
$\Delta \ln Q$	-3.78[a]	-5.21[a]
(AHL)	**ADF**	**PP**
$\ln Q$	-0.89	-1.89
$\Delta \ln Q$	-3.83[a]	-5.53[a]
(AL)	**ADF**	**PP**
$\ln Q$	-1.82	-2.05
$\Delta \ln Q$	-4.27[a]	-4.91[a]

Notes: ADF is the Augmented Dickey-Fuller (1979) test and PP is the Phillips-Perron (1988) test. Proper lag length for each test was chosen by AIC for ADF test and 4 lags used for PP test. Significance at the 1% is denoted by "a".

Given that the respective variables are integrated of order one, the Engle-Yoo (1987) cointegration procedure is employed to estimate equation (6). For each specification a cointegrating relationship exists with the η coefficient statistically insignificantly different from one (Table 2). This finding lends support for complete product proliferation predicted by the Schumpeterian growth model. The coefficient associated with ln A_t is negative and statistically insignificant, which is counter to the positive sign associated with diminishing returns to knowledge ($\theta > 0$), instead favoring constant returns to knowledge consistent with the Schumpeterian growth model. Both of these findings lend further support for the predictions associated with the Schumpeterian growth model.[5]

Table 2. Engle-Yoo cointegration tests, nested growth models, 1960-2007.

$\ln R_t = 1.12 \ln Y_t - 0.52 \ln A_t$ ADF = -5.67[a]

(0.32)[a] (1.19)

Null Hypothesis: $\eta = 1$	t-stat= 0.393
Null Hypothesis: $\theta = 0$	t-stat= -0.441
Jarque-Bera test: 0.159 [0.924]	
Adj. R-squared: 0.974	
F(6,38): 241.17 [0.000]	

$\ln R_t = 1.10 \ln A \cdot HL_t - 0.62 \ln A_t$ ADF = -5.33[a]

(0.29)[a] (1.14)

Null Hypothesis: $\eta = 1$	t-stat= 0.336
Null Hypothesis: $\theta = 0$	t-stat= -0.545
Jarque-Bera test: 0.222 [0.895]	
Adj. R-squared: 0.978	
F(6,38): 281.732 [0.000]	

$\ln R_t = 1.29 \ln A \cdot L_t - 0.78 \ln A_t$ ADF = -5.80[a]

(0.52)[a] (1.72)

Null Hypothesis: $\eta = 1$	t-stat= 0.561
Null Hypothesis: $\theta = 0$	t-stat= -0.449
Jarque-Bera test: 1.70 [0.428]	
Adj. R-squared: 0.963	
F(6, 38): 165.702 [0.000]	

Notes: The dynamic ordinary least squares estimates include as additional variables one-period leads and lags of the explanatory variables and a constant term. Standard errors are given in parentheses and adjusted for long-run variance. Probability values are given in brackets. ADF is the value for Engle-Yoo test for cointegration where the null hypothesis is no cointegration. The number of auxiliary regressors in the ADF tests was chosen using the Bayesian and Hannan–Quinn information criteria. Critical values for the ADF test (Engle-Yoo, 1987) are as follows: [a](1%) -4.32, [b](5%) -3.67, and [c](10%) -3.28.

[5] These results also provide evidence against the "hybrid" semi-endogenous model (Jones, 1999) which incorporates partial product proliferation.

5. Concluding remarks

This empirical note differentiates between the semi-endogenous and Schumpeterian R&D growth models using U.S. annual data from 1960 to 2007. The policy implications corresponding to each growth model are strikingly different. Semi-endogenous growth models predict that R&D expenditures will equal the growth rate of the population along a balanced growth path, irrespective of what fraction of resources are devoted to knowledge creation. Consequently, any policy that would increase R&D expenditures would only have transitory effects on total factor productivity growth. On the other hand, the Schumpeterian growth model asserts that long-run growth depends on policies that impact the long-run level of R&D expenditures. Therefore, any policy that increases the fraction of resources devoted to R&D will likely increase long-run total factor productivity growth.

This empirical note provides additional confirmation for the Schumpeterian R&D growth model in which increases in R&D expenditures are necessary in the long-run to counteract lower R&D productivity due to the presence of product proliferation. In the case of the U.S. there have been a number of advances that have effectively enhanced R&D expenditures over time. The personal computer revolution of the early 1980s essentially lowered both the barriers to entry and the cost of performing R&D, particularly for small firms. As discussed by Chandler (1994) and Hunt and Nakamura (2007), the introduction of the personal computer enabled small firms to compete in new product markets by accelerating the automation of information processing which allowed smaller firms to quickly transact large volumes of new products. In turn, the lower entry barriers and cost resulted in greater product proliferation and R&D competition leading to significant increases in R&D intensity.

Also, governmental policies during this time enabled firms to allocate more resources towards R&D investment. According to Hall (1993) and Hall et al. (1993), among others, the Research and Experimentation Tax Credit, introduced in the Economic Recovery Tax Act (ETRA) of 1981, contributed to the increase in R&D spending of U.S. corporations.[6] The reduction in corporate tax rates also dramatically reduced the cost of R&D expenditures relative to other types of capital investments.[7]

Furthermore, this empirical note provides a framework to analyze the role of R&D expenditures in total factor productivity and growth for regional economies. It is conceivable that decreasing returns to knowledge plays a much larger role at the regional level than at the national level. For example, more remote, rural areas probably experience much more difficulty in attracting and retaining sufficient R&D inputs necessary to increase TFP and enhance economic growth. Many studies have shown that labor mobility with respect to R&D staff positively affects patent applications through the transfer of knowledge (see, e.g., Almeida and Kogut, 1999; Kim and Marchke, 2005; Simonen and McCann, 2008). Given the advancements in spatial econometrics, the above model could easily be extended to incorporate spatial dynamics between regions to examine such knowledge spillovers. Thus, the differentiation between the semi-endogenous and Schumpeterian R&D growth models may serve as a basis for the design of regional development policies with respect to R&D expenditures.

[6] See also Eisner et al. (1984), Mansfield (1986), Altshuler (1988) and the GAO Report (1989) for information regarding the impact of the Research and Experimentation Tax Credit on R&D expenditures in the early 1980s.

[7] According to Hall et al. (1993) the R&D tax credit was responsible for a 200 basis point reduction in the cost of capital.

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