



# Heterogeneous effect of high-tech industrial R&D spending on economic growth<sup>☆</sup>

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## ABSTRACT

Empirical evidence has suggested that R&D investment is positively related to economic growth. This paper extends prior research by further examining the heterogeneous effects of R&D expenditures in the high-tech sector on economic growth. This study adopts a quantile regression approach to explore the marginal effect of R&D expenditures in the high-tech sector across different quantiles of the conditional GDP distribution for 23 OECD countries and Taiwan during 1991–2006. Empirical evidences show that the impacts of R&D expenditures in the high-tech sector are heterogeneous across levels of per capita income. High-tech industrial R&D spending has a strong positive effect on GDP per capita at the highest quantile of the distribution. However, all sectors' R&D spending relative to GDP is subject to significant negative returns only when considering the middle income countries. The study provides a more comprehensive understanding of the correlation between R&D investment and economic growth.

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## 1. Introduction

R&D is a key measure of innovation activities and is an important source of productivity growth (Griliches, 1981; Stokey, 1995). An extensive literature (Aghion & Howitt, 1992; Cameron, 1996; Grossman & Helpman, 1991; Romer, 1990) supports the conclusion that investments in research and development (R&D) are crucial for economic growth. Jones and Williams (1998, 2000) find that socially optimal R&D investment greatly exceeds actual level. Accordingly, many governments have vastly increased their economic and policy commitments to innovation with significant impacts on levels of R&D expenditures of their countries (Furman & Hayes, 2004).

Although previous studies suggest a positive correlation between the level of investment in R&D and economic growth, Jones (1995, 1998) and Jones and Williams (2000) argue that the negative duplication externality from firms' competition and the creative destruction from the redistribution of innovators' rents may make the measured aggregate contribution of R&D to economic growth very uncertain. Pessoa (2010) shows that innovation policy has frequently relied on a 'linear model' of the impact of science and technology on economic development, which is often empirically supported on the positive correlation between R&D intensity and total factor productivity

(TFP) growth. However, a spurious, positive relationship may be found if some factors omitted in the typical regressions.

The problem of using the OLS regression analysis for the R&D based endogenous growth model is that the model implicitly assumes that the elasticity of output with respect to R&D is constant through time or across firms. Ulku (2004) shows that there is no evidence for constant returns to innovation in terms of R&D, implying that innovation does not lead to permanent increases in economic growth. This raises questions about the capacity of developed and developing countries to translate their technological innovations into productivity and economic growth. Economic development may become unsustainable in the long run as the innovation process is nonlinear and multidirectional (Dodgson, 2000; Pavitt, 2005; Rothwell, 1994).

Since the mid-90s, along with the information technology revolution, high-tech industry is playing a key role in promoting economic development. And, the innovation is regarded as a major force in developing the positive relationship between high-technology goods and economic growth (Lichtenberg, 1992). Griliches and Mairesse (1984), Nadiri (1993), Tsai and Wang (2004), and Ortega-Argilés, Piva, Potters, and Vivarelli (2010) suggest that R&D expenditures in the high-tech industries generate higher economic growth compared with R&D in other industries. Hill (2002) shows that the development of high-tech industry in the United States, Western Europe, Japan, and the newly industrialized economies (NIEs) of East Asia, including Taiwan, has contributed greatly to their national economic growth over the last decade.

Technological opportunities and appropriability conditions are so different across sectors and countries (Aghion & Howitt, 1996; Dosi, 1997; Greenhalgh, Longland, & Bosworth, 2001). This suggests the possibility of differences in the sector/country specific R&D productivity

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links. As an alternative to OLS regression, this study uses quantile regression to examine the heterogeneous effects of R&D spending in the high-tech sector on economic growth for the sample of OECD countries and Taiwan over the period 1991–2006. The quantile regression analysis allows researchers to estimate covariate effects at different points of the distribution. Therefore, the empirical and methodological contribution of this paper is to help determine whether the high-tech R&D elasticities are different across countries.

The remainder of the paper is organized as follows. Section 2 introduces the research methodology and the model. Section 3 presents the empirical results. Section 4 contains a discussion and conclusion.

## 2. Research methodology

In an insightful and influential paper, Mankiw, Romer, and Weil (1992) show that the augmented Solow model, including accumulation of human as well as physical capital, can account for around 80% of the variation in per capita income levels across countries. Nonneman and Vanhoudt (1996) extend Mankiw's model to include R&D capital also explain up to about 78% of the income variation across the OECD countries.

To investigate the effect of R&D specialization on economic growth, Falk (2007) incorporates the variable of high-tech R&D expenditures into the Nonneman and Vanhoudt (1996) extension and finds positive impact of the variable on GDP per capita. However, high-tech industries typically face dynamic challenges with shrinking product life cycles and demand for constant product innovation. Their competitive advantages in such a volatile business environment are not constant (Wu, 2007). Therefore, this study takes a further step by adopting quantile regression (QR) analysis on examining the heterogeneous effect of high-tech R&D expenditure determinants in Taiwan and the OECD countries.

To meet the research objective, this paper adopts the following model to investigate the heterogeneous impact of high-tech R&D investment on economic growth.

$$GDPPC = \beta_{\theta 0} + \beta_{\theta 1}BERDHT_i + \beta_{\theta 2}BERDXGDP_i + \beta_{\theta 3}TEA_i + \beta_{\theta 4}UR_i \quad (1)$$

where  $GDPPC$  is GDP per capita.  $\theta_i$  represents the  $i$ -th quantile of the distribution. The set of independent variables includes the share of business enterprise R&D expenditures performed in the high-tech sector ( $BERDHT$ ), the ratio of business enterprise R&D expenditures to GDP ( $BERDXGDP$ ), the tertiary education graduation rates ( $TEA$ ), and the unemployment rates ( $UR$ ).

Koenker and Bassett (1978) propose the quantile regression (QR) methods to infer the results of the conditional functions for different quantiles. For policy purposes, researchers may be interested in something happening at the bottom or top of a distribution, which will not be captured by modeling the conditional mean. In these cases, it can be useful to look instead at “quantiles”. Quantile regression is about looking at conditional quantiles of which modeling quantiles of the conditional distribution of the response variable expressed as functions of observed covariate. Quantile regression, unlike pooled regression, does not pool information across quantile level or spatial location.

The two most commonly used regression techniques are the ordinary least squares (OLS) method, which is the method used to minimize the sum of the squares of the errors, and the least absolute deviations (LAD) method, which is the method used to minimize the absolute values of the errors. And, QR is based on a weighted version of the LAD approach to estimate regression parameters. The model for a median linear regression is:

$$y_i = \beta_{\theta}x_i + \varepsilon_{\theta i} \quad (2)$$

where the assumption is median ( $\varepsilon_{\theta i} | x_i$ ) = 0 (in other words, half of errors are positive and half are negative, but they need not average

zero as in linear regression). This concept can be expanded to any quantile – the 75th percentile, 95th percentile, etc. The estimate is defined by minimizing the sum of asymmetrically weighted residuals.

$$\min_{\beta} \left[ \sum_{t|y_t \geq x_t \beta} \alpha |y_t - x_t \beta| + \sum_{t|y_t < x_t \beta} (1-\alpha) |y_t - x_t \beta| \right] \quad (3)$$

where  $\alpha$  is a parameter ( $0 < \alpha < 1$ ) that represents the size of the quantile, and is also the quantile  $\alpha$  of the explained variable that one may wish to examine in the quantile regression. When  $\alpha = 0.5$ , the quantile regression is the median regression. Since on this occasion the values of  $\alpha$  and  $(1 - \alpha)$  are both 0.5, then the above equation changes to  $\sum_y |y_t - x_t \beta|$ , indicating that the observed values above and below the median values are given the same weights.

Bao, Lee, and Saltoğlu (2006) indicate that the main advantage of quantile regression is that better statistics could be obtained by means of the empirical quantiles. Quantile regression can help “complete the picture” when trying to understand the relationship between variables for which effects may vary with outcome levels. Quantile regression is more forgiving than OLS in the sense that the model is relatively insensitive to outliers and can avoid censoring problems (Conley & Galenson, 1998). As Bassett and Koenke (1982) extend the median so that it could be applied to the calculation of the various quantiles, their quantile regression models do not make any distribution assumptions regarding the population, and the parameters estimated could also be done nonparametrically.

## 3. Empirical results

Prior literature (Aghion & Howitt, 1996; Dosi, 1997; Greenhalgh et al., 2001) has indicated that technological opportunities and appropriability conditions are unequal across sectors and countries. This observation raises the question of whether the capacity of developed and developing countries to translate their technological innovations into economic growth varies. For this reason, we use data of Taiwan and 23 OECD countries which including developed and Eastern European member countries and for the period 1991 through 2006.

The International Monetary Fund (IMF) is a major data source of GDP per capita. The data source for the independent variables of the study is the OECD's Analytical Business Enterprise Research and Development (ANBERD) and Main Science, Technology Indicators (MSTI), Education at a Glance (EAG), and Labour Market Statistics (LMS) databases.

Table 1 reports results from OLS and QR estimation. The high-tech R&D elasticity lies in between  $-31.93$  and  $143.50$ . The OLS result shows that high-tech R&D spending has no impact on economic growth. And, the quantile estimates of high-tech R&D, except in the highest income quantile, are similar to those obtained from the OLS model. The results may be explained by Jones and Williams (2000) and Kafouros (2008) who suggest that although the potential for innovation is greater in high-tech industry, intense R&D competition prevents technologically dynamic firms from enjoying high returns to R&D. However, this paper finds that high-tech R&D expenditures have a statistically significant positive and highest effect on the countries with the highest income per capita.

The F-statistics (data not shown) for testing the equality of the high-tech R&D coefficient at the 95th quantile are significantly different from other quantiles. The finding implies that the high-tech R&D investment cannot bring benefits to countries with lower income levels. Fig. 1 contains a graphical representation of the results. It can be seen that the impact of high-tech R&D spending ( $BERDHT$ ) on income exhibits an upward trend between negative and positive shocks across the quantiles.

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