The evolution of high-tech industries in modern times has been profoundly affected by innovations in different forms such as new product designs and new software developments. Research and development (R&D) spending capture the key elements of the dynamic innovation process. Several features of R&D investment by firms are important in the dynamic evolution of an industry. First of all, R&D spending not only generate new knowledge about technical processes and products but also enhance the firm’s capability to improve the stock of existing “knowledge capital.” This is the process of learning that has cumulative impact on industry growth. Second, growth of R&D spending helps in expanding the growth of sales or demand through new product variety and quality improvements. This has often been called economies of scale in demand in the modern theory of hyper-competition analyzed by Sengupta (2004). Third, the R&D investment within a firm has a spillover effect in the industry as a whole. This is because R&D spending yields externalities in the sense that knowledge acquired by one firm spills over to other firms and very often knowledge spread in this way finds new applications both locally and globally and thereby stimulates further innovative activity and R&D intensity in other firms.

Our objective here is two-fold. One is to incorporate R&D investment into the Data envelopment analysis (DEA) efficiency models and thereby show its impact on market demand and efficiency. Second, we apply these efficiency models in two modern industries: computers and pharmaceuticals. These empirical applications apply a two-stage approach to economic efficiency. In the first stage the efficient levels of R&D inputs are determined for the DEA efficiency firms and in the second stage we
estimate by a regression model the role of R&D spending in total sales. This type of analysis is especially important for the pharmaceutical industry, since the share of R&D spending in total cost is much higher here, since the development of new medicines requires substantial spending on research.

### 3.1 Efficiency models in R&D

Three types of R&D models are developed here for empirical and theoretical applications. One emphasizes the cost reducing impact of R&D inputs. This may be related to the learning by doing implications of knowledge capital. Second, the impact on output growth through increases in R&D spending is formalized through a growth efficiency model. Here a distinction is drawn between *level* and *growth* efficiency, where the former specifies a static production frontier and the latter a dynamic frontier. Finally, the market structure implications of R&D spending are analyzed in a Cournot-type industry, where R&D spending is used as a marketing strategy just like advertisement.

Denote average cost by $c_j/y_j$ where total cost $c_j$ excludes R&D costs denoted by $r_j$. Then we set up the DEA model with radial efficiency scores $\theta$ of firm $h$.

$$\text{Min } \theta$$

s.t. $\sum_{j=1}^{n} c_j \lambda_j \leq \theta c_h$, $\sum_{j=1}^{n} r_j \lambda_j \leq r_h$,

$$\sum_{j=1}^{n} r_j^2 \lambda_j = r_h^2$$

$\sum_{j=1}^{n} y_j \lambda_j \geq y_h$,

$$\sum_{j=1}^{n} \lambda_j = 1, \quad \lambda_j \geq 0, \quad j \in I_n = (1, 2, \ldots, n) \quad (3.1)$$

On using dual variables $\beta_1, \beta_2, \beta_3, \alpha, \beta_0$ and solving the linear programming (LP) model (3.1), we obtain for an efficient firm $h, \theta^* = 1.0$ and all slacks zero the following average cost frontier

$$c_h^* = \beta_0^* - \beta_2^* r_h + \beta_3^* r_h^2 + \alpha^* y_h$$

(3.2)

since $\beta_1^* = 1.0$ if $\theta^* > 0$. Thus if R&D spending $r_h$ rises, average cost $c_h$ falls if $2\beta_3^* r_h < \beta_2^*$. If we replace $r_h$ by cumulative R&D knowledge capital