1 INTRODUCTION

1.1 Background

Sustained rise in per capita income and increasing urban population are fuelling rapid growth in the demand for animal food in India. Between 1980 and 2000, while the per capita consumption of foodgrains increased by 4 percent the per capita consumption of milk and meat increased by 50 percent and 25 percent respectively. In quantity the per capita milk consumption increased from 40 kg in 1980 to 66 kg in 2000, and meat consumption increased from 4 kg to 5 kg during this period. The total demand for meat increased from 2.7 million tonnes to 4.5 million tons during this period. Yet per capita consumption of animal food particularly meat is much below the consumption level of developed (77 kg) and developing countries (27 kg). The economic forces driving growth in meat demand have been quite robust in the recent past and are unlikely to subside in the near future. If these trends are to continue the demand for meat is expected to rise to 8 million tonnes in 2020 (Delgado et al, 1999).

The increase in demand has been accompanied by increase in production. Total meat production increased from 2.7 million tonnes in 1980 to 4.7 million tonnes in 2000 with annual growth of 3.41 percent. Cattle, buffalo, goat, sheep, pig and poultry are important meat species. While goat, sheep, pig and poultry are exclusive meat animals, cattle and buffalo provide meat as an adjunct to milk.
The structure of meat production however is undergoing a gradual shift from ruminant to non-ruminant (pig and poultry) meat production. The share of non-ruminant increased from 15 percent in 1980 to 23 percent in 1999.

Although most of the developing countries including India have never been major players in the world meat trade, trade liberalization is opening up opportunities for export of meat and meat products. Since the beginning of the process of trade liberalization in early 1990s, the share of developing countries in global meat exports increased from 14 percent in 1992 to 16 percent in 2000. The growth in meat exports from developing countries increased at double the rate than from the developed countries. India's share in world meat export increased from 0.24 percent to 0.54 percent during this period. In 2000 this constituted 4 percent of the total meat production, and 90 percent of livestock sector export earnings. Buffalo and sheep meats constitute bulk of the meat exports. There is a rising demand for buffalo meat in the East Asian countries, and India has sufficient potential to produce buffalo meat. Similarly, there is a prospective export market for goat and sheep meat in the Middle East countries.

These developments are expected to entail significant benefits for the poor, as bulk of the livestock resources in India are concentrated among the poor households comprising small landholders and the landless (Birthal and Parthasarathy, 2002). Nevertheless meat production in India is constrained by a number of economic and socio-cultural factors. The scale of production is small and meat yield is low. So is the marketed surplus. Local markets are thin and trading in distant markets is constrained by poor transport and market intelligence. Moreover live animal markets are dominated by a number of intermediaries.
Exports are constrained by protectionist policies and sanitary and phyto-sanitary standards. On the other hand, the meat industry is highly unorganized and only about one percent of meat output undergoes commercial processing. Traditional slaughter practices are still in vogue. Slaughterhouses are old, unhygienic and lack basic facilities like water, light, ventilation, drainage, waste disposal and effluent treatment. These contribute to poor meat quality and low recovery of various by-products such as hides, bloods, bonemeal, internal organs and trimmings.

In order to harness the emerging opportunities in domestic as well as export markets the Government of India has taken various initiatives to improve the efficiency of meat industry and export competitiveness. Some of these are financial assistance for the modernization of slaughterhouses in meat industry, creation of export processing zones, strengthening of vertical linkages, improvements in sanitary and phyto-sanitary standards etc.

1.2 Objectives of the Study

In the light of the above observations, the importance of a study of growth and efficiency in meat processing cannot be overemphasized. Efficiency improvement of the processing industry is the key to sustained growth of meat production. This study examines the growth performance of meat industry and the contribution of technological changes to it. While the overall objective is to analyze the growth and efficiency in meat processing industry, the specific objectives of the study are:

a) To study the structure and trend in meat production in India
b) To analyze the performance and potential of meat industry in India
c) To assess the global competitiveness of Indian meat industry
1.3 Review of Literature

A number of studies have examined the Total Factor Productivity Growth (TFPG) in agriculture and manufacturing sector of India. Several studies have been carried out to estimate TFP growth in crop sector of India (Jha and Evension 1973; Rosegrant and Evension 1992; Kumar and Mruthyunjaya 1992; Kumar and Rosegrant 1994; Murgai 1997; Desai and Namboodiri 1998). Various empirical studies on productivity change in manufacturing sector that have also been done in India show quite varied results. These studies are basically concentrated on three digit industrial classification. Some of these are explained in brief as follows:

Goldar (1986) estimated the average annual growth rate of TFPG in Indian manufacturing by using Solow and Tranlog index for two periods i.e. 1951-65 and 1959-79. His estimates of productivity for these two periods reveal that TFP growth in Indian manufacturing during 1951-79 was rather sluggish and the relative contribution of TFP growth to output growth was quite small. He also observed significant rising trends in labour productivity and capital intensity and a significant declining trend in capital productivity.

Ahluwalia (1991) analysed the productivity growth in organized manufacturing sector for the period 1959-60 to 1985-86 using Translog Production Function. As per TFP estimate of whole manufacturing sector, it registered a negative growth of 0.4 percent per annum. She also estimated TFP growth
growth at three-digit level disaggregation of manufacturing sector. The TFP growth in food manufacturing except sugar was negative to the extent of 1.9 percent.

Mitra et al. (1998) analysed impact of availability of infrastructural facilities of Total Factor Productivity (TFP) and Technical Efficiency (TE) in Indian manufacturing. They estimated TFP and TE for 17 manufacturing industries from 1976 to 1992 across major states of India. The study shows that Indian manufacturing industries differ considerably in terms of productivity growth. The TFP growth in food processing industries shows positive growth during 1976-1992.

Mitra (1999) estimated TFPG and Technical Efficiency for 17 industry groups at two digit level using both the Cobb-Douglas and Translog production function during 1976-77 to 1992-93 across 15 major states. TFPG has improved in a large number of industries and across most of the states during 1985-1993. At the national level, there was hardly any growth in TFP during 1976-1984 (0.76%). However it improved to the extent of 5.57 percent in the subsequent years. Acquisition of technological capabilities and infrastructural development has possibly contributed to this change. The technological progress in food processing industry has been positive and impressive during this period.

Singh (2000) computed Total Factor Productivity for a sample set of 10 industries in Indian manufacturing (both registered and unregistered) sector for the period of 1973-1994. Solow’s unexplained residual is used as the measure of TFP. The result show that the TFP recorded improvements in all the sample industries except for the basic metal industry. The highest growth in TFP was observed in case of food processing industry, which recorded an annual growth of 2.68 percent during 1973-94.
Goldar and Kumari (2002) estimated TFP growth for Indian manufacturing and major industry group for the period of 1981-82 to 1997-98 to assess the effect of import liberalization on industrial productivity. In the post-reform period, there has been a notable decrease in the growth rate of total factor productivity (TFP) in Indian manufacturing. The TFP growth in food processing industries declined from 1.04 percent during 1981-90 to 0.03 percent during 1990-97. It has also highlighted that deceleration in productivity growth should not be attributed to import liberalization. Rather, the reduction in effective protection to industries appears to have had a favorable effect on productivity growth. The reason for the fall in growth rate of productivity lie partly in gestation lags in investment projects.

Trivedi et al. (2002) estimated TFP for five major industrial groups - textile, metals and metal products, machinery and transport equipment, chemicals and chemical products and leather and leather products for the period of 1973-74 to 1997-98. For textiles and chemicals, the TFP growth rate was lower in 1990s; for metal and leather it was higher in 1990s; for other groups there was no significant change.

Unel (2003) investigated productivity trends in India’s registered manufacturing during 1980s and 1990s using growth accounting method. He explained that labour and total factor productivity has picked up after 1991 reforms. He classified best and weakest performing sectors based on comparative TFP. TFP growth in food processing industry was 0.9 percent during this period.

Pattnayak and Thangavelu (2003) analyzed production structure in terms of biased technical change and economies of scale using Translog cost function of Indian manufacturing industries. They have taken a panel of 121 Indian manufacturing industries from 1982 to 1998. Most of the industries
revealed bias technology change and majority of the industries have experienced capital using technological change. They also observed TFP improvements for most of the industries after the reform initiatives.

The studies on Total Factor Productivity growth and efficiency at disaggregate three-digit level in Indian manufacturing in general and food processing in particular are limited in the country. Productivity analysis at disaggregate level is essential for various kinds of decision making as the nature of individual industry varies widely. There are few studies where TFP and efficiency have been estimated for Indian dairy industry but no such study on meat processing industry has been done separately in India till date.

Singh et al. (2000a) estimated effect of private sector competition on productivity growth in dairy processing plants in Punjab, Haryana and India. Fisher index number method was used to analyse the effect of these changes upon Total Factor Productivity (TFP) during 1987-88 to 1994-95. Empirical results indicate that there is no TFP growth in Indian dairy processing since liberalization. But there is significant scope to improve productivity at unit level. Punjab shows a 7 percent increase in productivity while Haryana shows an 8 percent decline in productivity over the study period.

Singh et al. (2000b) analysed the performance of dairy plants in the cooperative and private sector in terms of Technical, Allocative and Cost Efficiency using Stochastic Frontier Analysis (SFA) and Data Envelopment Analysis (DEA) models. The panel data sample of 23 plants, comprising 13 cooperative plants and 10 private plants were taken into account between 1992-93 to 1996-97. The SFA results indicate that: (i) cooperative plants are more cost efficient than private plants; (ii) the cost efficiency of cooperative plants has not improved since market liberalization in 1991; and (iii) capital and material have
been over utilized relative to labour and other inputs. The DEA results also suggest that there is scope to increase efficiency level both in cooperative and private plants and mean cost could be reduced by 42 percent and 33 percent respectively. This implies that the private plants are more cost efficient, contrary to SFA findings.

Singh et al. (2000c) measured technical and allocative efficiency of Indian dairy processing plants during 1992-93 to 1996-97. In this paper cost-efficiency decomposition has been done with stochastic input distance function. The average cost efficiency for cooperative dairy plants is observed to be 0.788, which indicates that an average cost saving of 21.2 percent is achievable among cooperative plants. The cost efficiency score for private plants is 0.720. These results suggest that private plants are not as cost efficient as their cooperative counterparts.

Birthal et al. (2004) analysed the effect of trade liberalization on the efficiency of Indian dairy industry during 1980-81 to 1999-2000. This study employs input oriented variable returns to scale (VRS) DEA to measure technical and scale efficiency using DEAP Software (version 2.1) developed by Coelli (1996). The efficiency score has improved during the reform period. This implies that trade reforms have helped to improve the performance of Indian dairy industry.

1.4 Data and Methodology

1.4.1 Data and Variables

The study is based on secondary data for the period 1980-81 to 1999-2000. The information on inputs and output related to meat industry were compiled from Annual Survey of Industries published by the Central Statistical
Organisation, Ministry of Statistics and Programme Planning, Government of India. The ASI data on inputs and output were converted into 1980-81 prices using commodity specific deflators.

The data on meat production, consumption and trade were taken from FAOSTAT. The data on livestock population was collected from Livestock Census, Ministry of Agriculture, Government of India. The data of Gross Domestic Products (GDP), Gross Domestic Products from Agriculture Sector (AgGDP), Gross Domestic Products from Livestock Sector (LivGDP) and Value of crops and livestock output have been compiled from National Accounts Statistics, Central Statistical Organization (CSO), Government of India. The data on domestic wholesale prices for different species of meat has been compiled from Agricultural Prices in India, Directorate of Economics and Statistics, Ministry of Agriculture, New Delhi. The border prices/ international reference prices have been worked out under exportable hypothesis as value of export divided by quantity of export of different meat for different continents and the world as a whole.

1.4.1.1 Raw Materials

Raw material is the major input used in meat processing. Raw materials include meat, spices, edible oils, vegetables, chemicals, ice and packing materials. In the meat processing industry raw meat constitutes the major share of raw materials. The weighted price index of meat (beef, mutton, pork and poultry meat) has been used to deflate value of raw materials.

1.4.1.2 Labour

Labour is measured in terms of number of persons employed (either permanently or on casual basis) or simply the total cost of labour. The Annual Survey of Industry provides two categories of labour employment in meat
industry i.e. employees and workers. The data is available in three forms - number of employees and workers, mandays employment and total payments to both employees and workers. The index number of industrial labour has been used to deflate the value payments to labour and employees.

1.4.1.3 Capital

Capital is the most difficult input to measure. It can be measured either in physical or in value terms. Various studies have used an index of capital stock calculated by the perpetual inventory method for productivity measurement (Goldar, 1986; Sarma and Rao, 1990; Campbell, 1997; Kumar, 2000). Capital can also be measured as user cost of capital, i.e. depreciation (Kumbhakar and Heshmati, 1996). In the present study, the perpetual inventory method has been used to estimate gross capital stock for meat processing industry. As per the perpetual inventory method, the real capital stock \( K(t) \) in period \( t \) is given by

\[
K(t) = K(0) + \sum_{i=1}^{n} I(t_i)
\]

A machinery price index has been used to deflate the current value of capital at 1980-81 prices.

1.4.1.4 Fuel Consumed

Fuel is measured in values/ costs or preferably in quantities disaggregated into different types of energy. Fuel consumed in meat processing industry mainly includes electricity, diesel and petrol, which accounts for more than 85 percent of total energy used. The price index of fuel is used to deflate cost of fuel consumed.

1.4.2 Output

The Annual Survey of Industry provides two kinds of output data i.e. gross output and net output. Gross Output is defined as ex-factory value of
products and by-products manufactured during the accounting year. It also includes the receipts for non-industrial services rendered to others, the receipt for work done for others on materials supplied by them, value of electricity produced and sold and net balance of goods sold in the same condition as purchased. Net Value Added is the increment to the value of goods and services that is contributed by the factory and is obtained by deducting the value of total input and depreciation from value of output. In the present study, gross output has been used.

1.5 Analytical Approach

1.5.1 Growth Rate

The performance of the industry was assessed in terms of growth rates of various input and output indicators. The decadal growth rates were calculated for the periods 1980-90 (pre-reform period) and 1990-1999 (post reform period) using the following regression equation.

\[ \ln Y_t = b_0 + b_1 t \]  

(2)

Then, annual compound growth rate \( r \) was worked out as:

\[ r = \left[ \exp(b_1) - 1 \right] \times 100 \]  

(3)

1.5.2 Competitiveness

There are four methods for measuring global competitiveness - namely, Nominal Protection Coefficient (NPC), Effective Protection Coefficient (EPC), Effective Subsidy Coefficient (ESC) and Domestic Resource Cost (DRC). These are estimated as ratio of domestic and border prices. NPC is the simplest method for calculating competitiveness. Measurement of EPC, ESC and DRC requires distinction between tradable and non-tradable inputs. As these distinctions in
available data for meat industry is lacking in India, the NPC has been adopted for calculating competitiveness for export. The data on domestic wholesale prices for different species of meat has been compiled from Agricultural Prices in India. The border prices/ international reference prices have been worked out under exportable hypothesis as value of export divided by quantity of export of different meat for different continents and world as a whole.

NPC is defined as the ratio of domestic prices $P_{i}^d$ to border prices $P_{i}^b$ of $i^\text{th}$ commodity. Symbolically,

$$NPC_i = \frac{P_{i}^d}{P_{i}^b} \quad (4)$$

NPC was calculated for T.E. 1980-82, 1990-92 and 1997-99 to analyze trend in competitiveness. Meat prices have been converted in terms of US dollars to stabilize the exchange rate fluctuation.

1.5.3 Total Factor Productivity (TFP) Change

The simplest indicators of productivity are partial productivity measures derived by dividing the output by the relevant input. The most commonly used measures are labour productivity i.e. the output/ labour ratio and capital productivity i.e. the output/ capital ratio. However, these ratios can be misleading, as improvement in productivity cannot be attributed to any single factor input individually. Therefore, an integrated model for measuring productivity is desirable which considers all the factor input in aggregate and explains interacting economic relationship.

The TFP index interprets the change in output, which is not accounted for change in input, but is due to change in efficiency, or technology, or returns to scale or a combination of these three factors. Thus, Total Factor Productivity (TFP) is an index of aggregate output to an index of aggregate input. The growth
in TFP occurs when output grows without an increase in input or the use of input decreases without decline in output level. The changes in TFP can be decomposed into three components: (i) technological change, (ii) changes in technical efficiency, and (iii) changes in scale efficiency.

There are several methods to measure Total Factor Productivity based on econometrics and statistical approach. In the present study, Malmquist TFP index is used to measure productivity change in Indian meat processing industry. Malmquist productivity index is defined as the ratio of two output distance function (Caves et al., 1982). Distance functions are functional representations of multiple-output and multiple-input technology which requires data only on input and output quantities. Malmquist index has several advantages over Fisher and Tranquist index as it does not require assumptions regarding market structure and economic behaviour.

Malmquist TFP index decomposes productivity change into technical change and technical efficiency change. Fare et al (1994) specifies an output based Malmquist productivity change index as:

\[ M_0(y_{it1}, x_{it1}, y_{it}, x_{it}) = \left[ \frac{d^+_0(x_{it1}, y_{it1})}{d^+_0(x_{it}, y_{it})} \times \frac{d^{t+1}_0(x_{it1}, y_{it1})}{d^{t+1}_0(x_{it}, y_{it})} \right]^{1/2} \]  \hspace{1cm} (5)

This represents the productivity of the production point \((x_{it1}, y_{it1})\) relative to the production point \((x_{it}, y_{it})\). A value greater than one will indicate positive TFP growth from period \(t\) to \(t+1\). This index is the geometric mean of two output based Malmquist TFP indices. The input thus employs distance functions from two different periods or technologies, \(d^+_0(x_{it}, y_{it})\) and \(d^{t+1}_0(x_{it1}, y_{it1})\); and two pairs of input-output vectors, \((x_{it}, y_{it})\) and \((x_{it1}, y_{it1})\). Caves et al. (1982) assume that
implies that own-period observations are technically efficient in the sense of Farrell (1957).

The Malmquist index can be decomposed into two components namely technical efficiency change (EFFCH) and technical change (TECHCH), defined as:

\[
M_0 (y_{t+1}, x_{t+1}, y_t, x_t) = \frac{d_0^t (x_{t+1}, y_{t+1})}{d_0^t (x_t, y_t)} \times \left[ \frac{d_0^t (x_{t+1}, y_{t+1})}{d_0^{t+1} (x_{t+1}, y_{t+1})} \times \frac{d_0^t (x_t, y_t)}{d_0^{t+1} (x_t, y_t)} \right]^{1/2}
\]  

(6)

where the ratio of outside the square bracket measures the change in relative efficiency between \( t \) and \( t+1 \). The geometric mean of the two ratios inside the square bracket captures the shift in technology between the two periods. These may be given as:

\[
EFFCH = \frac{d_0^t (x_{t+1}, y_{t+1})}{d_0^t (x_t, y_t)}
\]  

(7)

\[
TECHCH = \left[ \frac{d_0^t (x_{t+1}, y_{t+1})}{d_0^{t+1} (x_{t+1}, y_{t+1})} \times \frac{d_0^t (x_t, y_t)}{d_0^{t+1} (x_t, y_t)} \right]^{1/2}
\]  

(8)

The Malmquist index can further be explained in diagrammatic form (Figure 1.1). In the figure \( S_t \) and \( S_{t+1} \) denotes the technologies in period \( t \) and \( t+1 \) respectively. The input-output vectors \((x_t, y_t)\) and \((x_{t+1}, y_{t+1})\) are feasible in their own periods, but \((x_{t+1}, y_{t+1})\) does not belong to \( S_t \). In the figure, \( d_0^t (x_{t+1}, y_{t+1}) = Oa/Ob \) and \( d_0^t (x_t, y_t) = Od/Oe \). Thus the term outside the square bracket in equation 5 equals:
Similarly, the term inside the square bracket in equation 6 is given as:

\[ EFFCH = \frac{O_a O_e}{O_b O_d} \]  \hspace{1cm} (9)

\[ TECHCH = \left[ \frac{O_a O_b O_d O_f}{O_c O_a O_e O_d} \right]^{1/2} = \left[ \frac{O_b O_f}{O_c O_e} \right]^{1/2} \]  \hspace{1cm} (10)

Figure 1.1: Malmquist Output - Based TFP Index

The last expression shows that the ratio of term inside the square bracket in equation 6 measures shift in technology at input levels \( x_t \) and \( x_{t+1} \) respectively. This indicates technical change as the geometric mean of two shifts, which is of the same form as Fisher Ideal Index (Hossain and Bhuyan, 2002).
1.5.4 Technical and Scale Efficiency

Frontiers in economics have been estimated by two approaches namely, parametric and non-parametric approaches. The former follows econometric procedure, while the latter is a mathematical programming approach. The disadvantage of parametric approach is that it assumes a particular functional form for a technology. The estimates of the parameters are sensitive to the probability distributions specified for the disturbance terms. On the other hand, the non-parametric approach introduced as Data Envelopment Analysis (DEA) by Charnes, Cooper and Rhodes (1978) is a method of measuring efficiency of a firm (the firm is referred to as the Decision Making Unit (DMU) in the DEA literature) through mathematical programming. The DEA does not assume any functional form and the efficiency of a DMU is measured relative to all other DMUs with the simple restriction that all DMUs lie on or below the efficient frontier.

The DEA is a methodology directed to frontiers rather than central tendencies (Seiford and Thrall, 1990). The DEA is also capable of handling multiple outputs. This study employs input oriented variable returns to scale (VRS) DEA to measure technical and scale efficiency in Indian meat processing industry DEAP software (version 2.1) developed by Coelli (1996). The input-output variables used include capital, labour, raw materials consumed fuel consumed, and gross value of output. A brief outline of the method is given below.

The original model developed by Charnes, Cooper and Rhodes (CCR model) was applicable when technologies characterized by constant returns to scale (CRS). It is assumed that there are ‘N’ DMUs with K inputs and S outputs on each DMU. That is, $\text{DMU}_j (j = 0, 1, \ldots, N)$ consumes $x_{ji}$ amount of input $i$
and produces \( y \) amount of output \( r \), where \( x^i \geq 0 \) and \( y^j \geq 0 \). The essential characteristic of the CCR construction is the reduction of the multiple outputs or multiple inputs to that of a “single virtual output” and “single virtual input” for each DMU (Seiford and Thrall, 1990). For a particular DMU ratio of single virtual output to single virtual input such as \( \frac{u_r y_0}{v_i x_0} \), gives a measure of efficiency, where \( u_r \) and \( v_i \) are output weights and input weights, respectively. The mathematical programming involves the selection of optimal weights that maximizes the objective function of the ratio of outputs to inputs for each DMU being evaluated. Mathematically, for DMU_0 it can be expressed as follows.

\[
\max_{u_r, v_i} \left( \frac{\sum_{j=1}^{s} u_r y_j}{\sum_{i=1}^{K} v_i x_i} \right) \\
\text{subject to} \\
\frac{\sum_{j=1}^{s} u_r y_j}{\sum_{i=1}^{K} v_i x_i} \leq 1 \quad j = (0, 1, 2, \ldots, N) \\
u_r \geq 0 \quad r = (1, \ldots, S) \\
v_i \geq 0 \quad i = (1, \ldots, K)
\]

(11)

Here, the efficiency measure of DMU_0 is maximized with the constraint that the efficiency measure of every DMU be less than or equal to unity. However, the above formulation gives infinite number of solutions. That is, if \((u^*, v^*)\) is an optimal solution, then \((a u^*, a v^*)\) is also an optimal solution. Thus, to overcome this problem, the constraint \( \sum_{i=1}^{K} v_i x_i = 1 \) can be imposed. The
account for technologies that show variable returns to scale (VRS). The Banker, Charnes and Cooper (BCC model) can be developed by adding the convexity constraint to the constant returns to scale (CRS) linear programming problem.

\[ \sum_{j=1}^{N} \lambda_j = 1 \]
\[ \lambda \geq 0 \]

The CRS technical efficiency scores can be decomposed into pure technical efficiency and scale efficiency. This can be done by applying both CRS and VRS DEA on the same model. The difference between CCR model and BCC model can be illustrated as follows. We shall assume one input and one output situation. The CRS and VRS frontiers have been drawn in the following figure 1.2.

The inefficient DMU is represented by the point P. Under input orientation measure, the technical inefficiency of DMU 'P' is \( mp \) in CRS and \( bp \) in VRS. The difference between these two measures is expressed as scale inefficiency (SE). In ratio form, technical efficiency in CRS is \( \frac{qm}{qp} \) and in VRS it is \( \frac{qb}{qp} \). Scale efficiency is \( \frac{qm}{qb} \). Further, \( \frac{TE_{CRS}}{SE} = \frac{TE_{VRS}}{SE} \). Thus, technical efficiency (TE) obtained from CRS can be decomposed into 'pure' technical efficiency and scale efficiency. The point such as 'c' on the frontier is scale efficient.

The concept of scale efficiency constitutes two technologies i.e. constant return to scale (CRS) and variable return to scale (VRS). The VRS technology in the figure 1.2 is presented by the single input-single output production function. The scale efficiency measure corresponding to input \( X_t \) is given by:
Scale Efficiency = \( \frac{(Oq / Or)}{(Oq / Os)} = \frac{Os}{Or} \) \hspace{1cm} (14)

Figure 1.2: CRS, VRS and Scale Efficiency

We can include scale efficiency for period \( t \) and \( t+1 \) in the measure of efficiency change as follows:

\[
EFFCH \ = \ \frac{S'_0(x_{i,t}, y_{i,t})}{S'_{0+1}(x_{i,t+1}, y_{i,t+1})} \cdot \frac{D'_0(x_{i,t}, y_{i,t} / VRS)}{D'_{0+1}(x_{i,t}, y_{i,t+1} / VRS)}, \quad \text{where}
\]

\[
(15)
\]

We can include scale efficiency for period \( t \) and \( t+1 \) in the measure of efficiency change as follows:

\[
EFFCH = \frac{S'_0(x_{i,t}, y_{i,t})}{S'_{0+1}(x_{i,t+1}, y_{i,t+1})} \cdot \frac{D'_0(x_{i,t}, y_{i,t} / VRS)}{D'_{0+1}(x_{i,t}, y_{i,t+1} / VRS)}, \quad \text{where}
\]

\[
(15)
\]

Scale Efficiency Change = \( SCCH = \frac{S'_0(x_{i,t}, y_{i,t})}{S'_{0+1}(x_{i,t+1}, y_{i,t+1})} \), and
Pure Efficiency Change (PECH) = \[ \frac{D^*_0(x_{ij}, y_{ij}, VRS)}{D'_0(x_{ij}, y_{ij}, VRS)} \]

So, the enhanced decomposition of Malmquist TFP index explained by Hossain and Bhuyan (2002) can be written as:

\[ Malmquist \_ \text{Index} = EFFCH \times TECHH = SCCH \times PECH \times TECHCH \]  
(16)