RESEARCH METHODOLOGY AND DATABASE

The present study is based on two digit level industries data of Punjab’s manufacturing sector. Productivity is used as an indicator of performance measurement. Various tools of performance measurement as discussed in literature are ratio analysis, growth rates, compound growth rates, efficiency measurement, productivity measurement etc. Among these, productivity is often considered as an important indicator of performance measurement in developing countries (Mitra, 1999). Since productive resources in these economies are scarce, so the high growth of industrial sector can be achieved only by using these limited resources efficiently, i.e. by improving the productivity growth (Chattopadhyay, 2004). Economists and policy makers also consider it as a major source of economic growth and welfare improvement (Fare et. al., 2001). Productivity growth means producing more of output either by using same or lesser level of inputs, which in turn results in lower prices for final product, and increased competitiveness of the industry. Thus, productivity growth affects the living standards of the nation by increasing real wages of the workforce (Sowlati and Vahid, 2006).

Since the overall objective of the present research work is to formulate growth strategy, so it seems necessary to begin with, to find out whether resources are efficiently utilised, and whether there is any technological advancement in the industrial groups. It can be done by measuring productivity. For this, DEA based Malmquist Productivity Index (MPI) has been used in this research work. Data on value added, capital and labour from 1980-81 to 2007-08 for 12 two digit industrial groups were compiled from Annual Survey of Industries published by the Economic and Political Weekly Research Foundation (EPWRF), India.

This chapter throws light on the reasons for using this database, dataset and methodology. It gives a detailed description of the data used, and construction of variables and methodology used. For this purpose, the chapter is divided into three broad sections. Section-1 unfolds the methodology used for empirical analysis. Section-2 discusses the various sources of data that has been used to measure
productivity. Section-3 defines the variables used. It also explains the construction of variables after going through deflation process.

3.1. Research Methodology

Productivity measures the relationship between output (the amount of goods and services) and inputs (the quantity of labour, capital and material resources) used to produce the outputs. In simple words, it is the ratio of output that it produces to the input that it uses.

\[
\text{Productivity} = \frac{\text{Output}}{\text{Input}} \quad (1)
\]

It is easy to solve above equation in case of single input and single output. But, if there are more than one input and output, then a choice is to be made among different methods for aggregating inputs/outputs into a single index of inputs/outputs to obtain a ratio of measure of productivity. These indices are discussed in the following sections of this chapter.

Productivity is often classified into partial productivity and total factor productivity. The basic difference between both is that while the former includes only a subset of all the outputs produced and inputs utilized by the production unit, the latter includes all outputs produced and inputs utilised by the production unit. Partial productivities are like labour productivity, capital productivity, fuel productivity in power stations, and land productivity (yield in farming). Partial productivity does not show a complete picture and thus provides a misleading indication of overall productivity when considered in isolation (Coelli and Rao, 2005). When the proportion in which the factors of production are combined (e.g. labour and capital) undergoes a change, partial measures of productivity provide a distorted view of the contribution made by these factors in changing the level of production (Kutharia et. al., 2011). In certain situations of capital intensity improvement, labour productivity may improve and capital productivity may fall. But these changes in labour productivity and capital productivity are because of rising capital labour ratio and not because of improvement in pure productivity (Majumdar, 2004; Ahluwalia, 1991). This problem is solved by analysing TFP
growth which encompasses the effect not only of technical progress but also of better utilisation of capacities, learning by doing and improved skills of labour (Ahluwalia, 1991). Similarly, improvements in labour productivity may also be due to capital substitution and changes in scale economies, both of which may be unrelated to the more efficient use of labour (Mahadevan, 2004).

Most commonly used partial productivity measure is labour productivity. Labour productivity is output per unit of labour or output per man hour. Labour productivity depends on other factors like capital, fuel and materials, land, that the labour has to work with, as well as the efficiency with which all the factors are used in production process, which is total factor productivity (TFP). Thus, TFP is best measure of productivity as it includes all the inputs and gives a complete picture of productivity (Kumar, 2001). Thus, on the whole, among these two measures of productivity i.e. partial productivity and TFPG, latter is superior to the former and gives exact measure of productivity.

Though TFP is superior to partial productivity, but we cannot ignore the estimation of partial productivity. Partial productivity like labour productivity is regarded as a crucial measure of society’s welfare. It measures the production per worker, and a country’s ability to improve its standard of living over time that depends on its ability to raise its output per worker (Kutharia et. al., 2011). Labour productivity is a measure of potential consumption, and a steady rise in the productivity of labour is necessary for a sustained increase in the standard of living of a population (Balakrishnan, 2004).

3.1.1. Approaches to the Measurement of Total Factor Productivity

There are different approaches to the measurement of productivity which are explained in Figure -3.1. This shows that there are parametric and non-parametric methods to productivity measurement. Parametric methods make a set of assumptions regarding the functional form and the distribution that it follows while no such assumptions are made in case of non-parametric models. Starting with the growth accounting approach, it examines how much of an observed rate of change
of an industry’s output can be explained by the rate of change of combined inputs. It is based on various assumptions, like production function that exhibits constant returns to scale, producers behave efficiently in that they attempt to maximise profits, and markets are perfectly competitive. Production function and DEA approaches do not have assumptions of constant returns to scale and perfect competition. But, in case of former i.e. in production functions approach, instead, assumptions about functional form and distribution are imposed while the latter is free from these assumptions. A detailed description of all these approaches is given below:

**Figure-3.1**

Source: Compiled from Table- 4.3 (p.-80) of Trivedi et. al. (2011)
3.1.1.1. Growth Accounting Approach (GAA)

The origin of GAA is traced to Tinbergen (1942) and Solow (1957) (Kutharia et. al., 2011). This method estimates TFP as a residual. In this method, factor shares in national income are used as weights in combining inputs for forming TFP index. GAA is based on the assumptions that the form of production function is known, constant returns to scale, neutral technical progress, and zero inefficiency (Fu, 2005).

The three main indices used in GAA are Kendrick Index (Kendrick, 1961), Solow Index (Solow, 1957), and Theil-Tornquist or Translog-Divisia Index. These indices are discussed in detail in the following section:

3.1.1.1.1. Kendrick Index

Kendrick Index of TFP is based on a linear production function which assumes infinite elasticity of substitution between factors of production. It assumes constant returns to scale, perfect competition, and factors are paid according to their marginal product (MP theory of distribution is assumed). Let there be a single output ($Q_t$) and two inputs i.e. labour ($L_t$) and capital ($K_t$). In this case, Kendrick index in year $t$ is given as:

$$P_t = \frac{Q_t}{w_0 L_t + r_0 K_t} \tag{2}$$

Where $w_0$ is factor reward of labour and $r_0$ is factor reward of capital

In case of more than two factors of production

$$P_t = \frac{q_t}{\sum_{i=1}^{k} R_{i,0} X_t} \tag{3}$$

Where $R_{i,0}$ refers to the reward of the input $i$ in the base year $0$.

The Kendrick Index of TFP growth rate from base year 0 to period 1 is expressed as:
\[
\frac{\Delta P}{P} = \left[ \frac{\left( \frac{Q_1}{Q_0} \right)}{\left( \frac{\sum_{i=1}^{n} R_{i,0} X_{i,0} \sum_{i=1}^{n} W_{i,0} X_{i,0}}{\sum_{i=1}^{n} W_{i,0} X_{i,0}} \right)} \right] - 1
\]  

(4)

Where \( \Delta P \) indicates change of TFP per period of time

Though easy to calculate and understand, it suffers from a major limitation that it is based on a linear production function and, therefore, does not allow for the diminishing marginal productivity of factors of production (Goldar, 1986).

3.1.1.1.2. Solow Index

Given by Solow, this index uses Cobb-Douglas production function with the assumption of constant returns to scale, autonomous Hicks neutral technical progress, payment to factors according to their marginal products and unit elasticity of substitution between the factors. The production function used is:

\[ Q = f(K, L; t) \]  

(5)

Where \( Q \) represents output; \( K \) and \( L \) represent capital and labour respectively, \( t \) represents time and it captures the technical change component.

Assuming neutral technical change, equation (5) can be written as:

\[ Q = A(\bar{t}). f(K,L) \]  

(6)

\( A(\bar{t}) \) measures the cumulated effects of shifts in the function.

Differentiating equation (6) w.r.t. time \( t \) and dividing by \( Q \), we get

\[ \frac{Q}{Q} = \frac{A}{\bar{A}} + A \cdot \frac{df}{dK} \cdot \frac{K}{Q} + A \cdot \frac{df}{dL} \cdot \frac{L}{Q} \]

\[ \frac{Q}{Q} = \frac{A}{\bar{A}} + \frac{w_k \cdot K}{K} + \frac{w_l \cdot L}{L} \]

Where \( w_k = \frac{dQ}{dK} \cdot \frac{K}{Q} \) and \( \frac{dQ}{dK} = A \cdot \frac{df}{dK} \)
\[ w_L = \frac{dQ}{dL} \cdot \frac{L}{Q} \left( \frac{dQ}{dL} = A \cdot \frac{dL}{dL} \right) \]

\[ \frac{A}{Q} = \frac{Q}{Q} - \left[ w_K \cdot \frac{K}{K} + w_L \cdot \frac{L}{L} \right] \]

Since \( w_K + w_L = 1 \), so

\[ \frac{A}{A} = \frac{Q}{Q} - \left[ w_K \cdot \frac{K}{K} + (1 - w_K) \cdot \frac{L}{L} \right] \]

(or)

\[ \frac{\Delta A}{A} = \frac{\Delta Q}{Q} - \left[ w_K \cdot \frac{\Delta K}{K} + (1 - w_K) \cdot \frac{\Delta L}{L} \right] \]  

(7)

From the time series of \( \frac{\Delta Q}{Q} \), \( w_k \), \( \frac{\Delta K}{K} \) and \( \frac{\Delta L}{L} \), we could calculate \( \frac{\Delta A}{A} \) and hence \( A(t) \) itself.

Continuing the assumption of marginal productivity theory of distribution and constant returns to scale yields the product exhaustion or the Euler’s theorem, which means the entire output is exhausted if factors of production are paid according to their marginal product. Thus, in the base year, \( A_0 \) will be equal to unity by definition.

Solow’s Index is obtained by using the following identity (taking \( A(0) \) as unity)

\[ A(t+1) = A(t) \left[ 1 + \frac{\Delta A}{A} \right] \]  

(8)

3.1.1.3. Divisia Index

Introduced by Christensen and Jorgenson (1970) and Jorgenson and Griliches (1972), Divisia index also known as translog index or Tornquist Index is superior to Kendrick Index and Solow Index. Translog Index numbers are symmetric in data of different time periods and also satisfy the Factor Reversal test appropriately (Goldar, 1986). It can be applied to discrete data points (Ahluwalia, 1991). Tornquist Index is based on translog production function. It assumes constant
returns to scale, variable elasticity of substitution, perfect competition and profit maximisation. Unlike Solow Index, it is free from Hicks neutrality assumption.

Consider an aggregate production function with two factors of production

\[ Q = f(K,L,t) \]

Where \( Q \) is aggregate output, \( K \) is aggregate capital, \( L \) is aggregate labour and \( t \) is time.

The Translog index of technological change is based on a translog production function given as:

\[
\ln Q_i = \alpha_0 + \alpha_K \ln K_i + \alpha_L \ln L_i + \alpha_T T + \frac{1}{2} \beta_{kk} (\ln K_i)^2 + \beta_{kl} (\ln K_i) (\ln L_i) + \frac{1}{2} \beta_{ll} (\ln L_i)^2 + \beta_{kt} (\ln K_i) T + \beta_{lt} (\ln L_i) T + \frac{1}{2} \beta_{tt} T^2 + \varepsilon_i
\] (9)

Divisia Translog Index takes the form:

\[
\Delta \ln TFP (t) = \Delta \ln Q (t) - \left[ \frac{SL(t) + SL(t-1)}{2} \right] \times \Delta \ln L (t) - \left[ \frac{SK(t) + SK(t-1)}{2} \right] \times \ln \Delta K (t)
\] (10)

Where \( SL \) and \( SK \) are respectively the share of labour and capital in output. \( SL \) and \( SK \) add up to unity.

\( \Delta TFP (t) \) is the rate of technological change or rate of growth of TFP.

Translog index suffers from the problem of multicollinearity due to the presence of large number of parameters. The major limitation of this index and all other indices of growth accounting approach is that it does not take into consideration technical efficiency and assumes that the units are fully efficient. Moreover, GAA is based on many assumptions like constant returns to scale, perfect competition, factors are paid according to marginal products etc. Violation of any of these assumptions may result in biased estimates of the cumulative effects of technical change (Fare. et. al., 1994). However the production functions approach overcomes this limitation.
3.1.1.2. Production Functions Approach

This approach involves the specification of the functional form and then estimates it using appropriate econometric technique. Moreover, the parameters of production function like returns to scale, elasticity of substitution between inputs, elasticity of inputs etc. can be estimated along with technical progress term by using econometric approach (Kumar, 2001). It captures TFP growth as a shift in the production function. Like GAA, it also assumes that there is no technical inefficiency in production. In case of single output and two inputs, aggregate production function with disembodied technical progress is given as:

\[ Q = F (K, L, t) \]

Where Q is output and; K and L are capital and labour inputs. t is a time variable which acts as a proxy for technical progress.

There are different types of production functions used for measuring TFP growth as discussed in the literature. These are Cobb-Douglas (CD) Production Function, Constant Elasticity of Substitution (CES) production function, and Translog (TL) production function.

3.1.1.2.1. Cobb-Douglas Production Function

This form of production function is restrictive in nature and assumes that the elasticity of substitution is unity. Under the assumptions of constant returns to scale and competitive equilibrium, this implies constant factor shares (Goldar, 1986). This is given as:

\[ Q_t = A_t K_t^\alpha L_t^\beta \]  \hspace{1cm} (11)

\( A_t \) represents technology and causes a shift of production function. \( \alpha \) and \( \beta \) are output elasticities with respect to capital and labour inputs.

The technology parameter, \( A_t \), is given as:

\[ A_t = A_0 e^{\lambda t} \]  \hspace{1cm} (12)
It implies that technology grows at a constant exponential rate of $\lambda$.

Thus, assuming that Cobb-Douglas production function is Hicks neutral and grows at a constant exponential rate, equation (12) can be written as:

$$Q_t = A_0 e^{\lambda t} K_t^\alpha L_t^\beta$$  \hspace{1cm} (13)

Taking logarithms on both sides of equation (13), we get:

$$\ln Q_t = \ln A_0 + \lambda t + \alpha \ln K_t + \beta \ln L_t + \epsilon_t$$  \hspace{1cm} (14)

The sum of coefficients of labour and capital provides the measure of returns to scale. If the sum of $\alpha$ and $\beta$ is equal to unity, then there are constant returns to scale. If sum of $\alpha$ and $\beta$ is greater than unity, it implies increasing returns to scale. And if their sum is less than one, it implies decreasing returns to scale. The flexible form of Cobb-Douglas production function can be given by re-writing equation (14):

$$\ln Q_t = \beta_0 + \beta_1 t + \beta_2 \ln K_t + \beta_3 \ln L_t + \epsilon_t$$  \hspace{1cm} (15)

Given the time series of output, capital and labour, one can work out the output elasticities ($\beta_2$ and $\beta_3$) and the technology coefficient ($\beta_1$) by applying OLS technique. An alternative version of equation (15) can be derived by subtracting $\ln L_t$ from both sides of the equation which is given as under:

$$\ln Q_t - \ln L_t = \beta_0 + \beta_1 t + \beta_2 \ln K_t + \beta_3 \ln L_t - \ln L_t + \epsilon_t$$

$$\ln Q_t - \ln L_t = \beta_0 + \beta_1 t + \beta_2 \ln K_t + \beta_3 \ln L_t - \ln L_t + \beta_2 \ln L_t - \beta_2 \ln L_t + \epsilon_t$$

$$\ln Q_t - \ln L_t = \beta_0 + \beta_1 t + \beta_2 \ln K_t - \beta_2 \ln L_t + \beta_2 \ln L_t + \beta_3 \ln L_t - \ln L_t + \epsilon_t$$

$$\ln \left(\frac{Q_t}{L_t}\right) = \beta_0 + \beta_1 t + \beta_2 \ln \left(\frac{K_t}{L_t}\right) + (\beta_2 + \beta_3 -1) \ln L_t + \epsilon_t$$  \hspace{1cm} (16)

Under the assumption of constant returns to scale, equation (16) is given as:

$$\ln \left(\frac{Q_t}{L_t}\right) = \beta_0 + \beta_1 t + \beta_2 \ln \left(\frac{K_t}{L_t}\right) + \epsilon_t$$  \hspace{1cm} (17)

where $\beta_2$ is the output elasticity of capital.
One of the major limitations of this production function is that returns to scale is assumed to be same at all levels of output and for all factor proportions (Goldar, 1986).

3.1.1.2.2. Constant Elasticity of Substitution (CES) Production Function

Unlike Cobb-Douglas production function, CES production function assumes elasticity of substitution to be constant but not necessarily equal to one. Thus, former is a special case of CES production function. CES production function with exponential Hick-neutral technical progress and non-constant returns to scale is given as:

\[
Q_t = A_0 e^{\lambda t} \left[ \delta L_t^\rho + (1- \delta) K_t^\rho \right]^{\nu/\rho} \tag{18}
\]

Where \( Q_t \) is output, \( L_t \) is labour, \( K_t \) is capital, \( t \) is time, \( \delta \) is distribution parameter, \( \nu \) is scale parameter, \( \lambda \) is Hicks-neutral disembodied technical change, \( \rho \) is substitution parameter and related to elasticity of substitution (\( \sigma \)).

\[
\sigma = 1/(1- \rho)
\]

When \( \rho = 0 \) (elasticity of substitution equal to one), CES production function reduces to Cobb-Douglas production function which is its special case.

Taking natural log of equation (18), we get

\[
\ln Q_t = \ln A_0 + \lambda t - (\nu/\rho) \ln \left[ \delta L_t^\rho + (1- \delta) K_t^\rho \right] \tag{19}
\]

Since equation (19) is non-linear in nature, so OLS cannot be used for calculating the parameters of CES production function. Various methods used to work out the parameters of this non-linear production function include Kmenta’s approximation procedure, maximum likelihood method or Bayesian estimation technique, ACMS procedure, Bairam’s method etc. Another alternate is to convert the model to linear form through Taylor expansion process and then find its parameters.
3.1.1.2.3. Transcendental Logarithmic (TL) Production Function

TL model was developed by Christensen, Jorgenson and Lau (1971, 1973). It is more flexible than the Cobb-Douglas and CES production functions as it imposes fewer a priori assumptions. Unlike CD and CES production functions, it assumes variable elasticity of substitution, variable scale elasticity and non-neutral technical progress. With single output and two inputs i.e. labour and capital, TL model takes the form:

\[
\ln Q_i = \alpha_0 + \alpha_K \ln K_i + \alpha_L \ln L_i + \alpha_T T + \frac{1}{2} \beta_{KK} (\ln K_i)^2 + \beta_{KL} (\ln K_i)(\ln L_i) + \frac{1}{2} \beta_{LL} (\ln L_i)^2 + \beta_{KT} (\ln K_i) T + \beta_{LT} (\ln L_i) T + \frac{1}{2} \beta_{TT} T^2 + \varepsilon_i
\]  

(20)

One major limitation of this model is that it has very few degrees of freedom due to which it is not often used for empirical estimation of TFPG in a time series framework. Moreover, just like GAA, CD and CES production functions assume that all observations represents efficient production or that input and output levels are unaffected by shocks which is not true. Stochastic Production Frontier Approach (SPF) and Malmquist Index (MI) overcome this limitation and decompose TFP into technical efficiency change (TECH) and technical change (TC).

3.1.1.2.4. Stochastic Production Frontier Approach:

The parametric frontier approach was developed by Aigner, Lovell, Schmidt (1977) and by Meeusen and Broeck (1977) which analyses cross sectional data. Further, various models to account for panel data (assuming time invariant technical inefficiency) were introduced by Pitt and Lee (1981), Cornwell et. al. (1990), Kumbhakar (1990). These models were extended by Battese and Coelli (1992) in which the technical inefficiency is time variant. (Peris and Garchia, 2012). The generic form of this frontier production function is given by:

\[
Y_{it} = f(X_{it}, \beta, t). \exp(V_{it} - U_{it})
\]

(21)

Where \(i = 1,2,\ldots,I\) firms or industries; \(t = 1,2,\ldots,T\) time periods

\(Y_{it}\) denotes output level of industry \(i\) at time \(t\);
$X_i$ is a vector of inputs of industry $i$ at time $t$;

$\beta$ is vector of unknown parameters to be estimated;

$V_i$ is a symmetric random error term, independently and identically distributed as $N(0, \sigma_v^2)$, intended to capture random variation in output level due to external shocks;

$U_i$ is intended to capture technical inefficiency of industry $i$ at time $t$. A higher value for $U$ implies an increase in technical inefficiency of industry $i$. A value of $U$ close to zero implies that industry $i$ is perfectly technically efficient.

$f (X_{it}, \beta, t). \exp(V_{it})$ in equation (21) is the deterministic stochastic production frontier with the technology parameter vector to be estimated.

To estimate the stochastic production frontier, an appropriate functional form is assumed (i.e. Cobb-Douglas, CES, or Translog Production function). Further, after selecting the production function, one has to select whether to measure it using OLS or MLE. Assumptions regarding the inefficiency error term is also made i.e. whether error term follows normal distribution, half normal distribution or truncated normal distribution. Assuming different assumptions will produce different results when applied on the same data. Thus, this approach has serious limitations; that is wrong selection of production function will produce inaccurate results. It being based on many such assumptions is not a reliable method of calculating TFPG. DEA based Malmquist Index is one such approach that does not require any assumptions of production function, distributional assumptions, perfect competition assumption, elasticity of substitution assumption etc. Thus, this non-parametric approach is considered superior to both GAA and econometric approaches. It is discussed in detail in the following section.

3.1.1.3. **DEA based Malmquist Productivity Index (MPI):**

The Malmquist Index was first introduced in two papers by Caves, Christensen and Diewert (1982). Fare, et. al. (1994) decomposed the Malmquist Total Factor Productivity change into various components, including technical change and efficiency change (Coelli and Rao 2005). The MPI can be calculated using the distance functions. Distance functions allow for the representation of a multiple-input-multiple-output technology without assuming any behavioural
assumptions such as cost minimisation or profit maximisation. Distance functions are input-oriented and output-oriented in nature. Assuming a production technology \( P(x) \) which produces a vector of outputs, \( y_t \in \mathbb{R}^M_+ \), by using a vector of inputs, \( x_t \in \mathbb{R}^N_+ \), for each time period \( t = 1, 2, \ldots, T \).

\[
P(x) = \{(x_t, y_t): x_t \text{ can produce } y_t\} \quad (22)
\]

The output-oriented distance function is given as:

\[
D_0 (x_t, y_t) = \min \{\varphi: (y_t / \varphi) \in P(x)\} \quad (23)
\]

In the above equation, output is proportionally increased (through dividing \( y_t \) by \( \varphi \)) so that the resulting \( y_t / \varphi \) still belongs to the output set. Therefore, \( \varphi \) has a value between 0 and 1. The closer the unit to the frontier, the larger the \( \varphi \). A value of 1 means that, given a fixed input, output cannot be increased any more, i.e. \( (x_t, y_t) \) belongs to the production frontier and the unit is fully efficient.

The Malmquist Total Factor Productivity Index measures the Total Factor Productivity Change between two data points by calculating the ratio of the distances of each point relative to a common technology. Using period \( t+1 \) technology as a reference technology, the Output-Oriented Malmquist index between period \( t \) (base year) and period \( t+1 \) is:

\[
M_{o}^{t+1}(y_t, x_t, y_{t+1}, x_{t+1}) = \frac{d_{o}^{t+1}(y_{t+1}, x_{t+1})}{d_{o}^{t+1}(y_t, x_t)} \quad (24)
\]

Where distance function, \( d(.) \) measures the distance of a unit from the efficient frontier. The subscript ‘o’ denotes output-oriented function and the superscript \( t+1 \) states that the frontier of period \( t+1 \) is being considered.

\[
d_{o}^{t+1}(y_{t+1}, x_{t+1}) = \text{The efficiency measure using the observation at period } t+1 \text{ relative to the frontier technology at period } t+1.
\]

\[
d_{o}^{t+1}(y_t, x_t) = \text{The efficiency measure using the observation at period } t \text{ relative to the frontier technology at period } t+1.
\]
Equation (24) measures the change in the distance of a unit from period t to t+1 relative to the frontier of period t+1.

Using period t technology as a reference technology, the output oriented Malmquist Productivity Index between period t and t+1 is:

\[
M_0^t (y_t, x_t, y_{t+1}, x_{t+1}) = \frac{d_0^t(y_{t+1}, x_{t+1})}{d_0^t(y_t, x_t)}
\]  
(25)

\(d_0^t(y_{t+1}, x_{t+1})\) = It indicates the efficiency measure using the observation at period t+1 relative to the frontier technology at period t.

\(d_0^t(y_t, x_t)\) = It indicates the efficiency measure using the observation at period t relative to the frontier technology at period t.

Equation (25) measures the change in the distance of a unit from period t to t+1 relative to the frontier of period t. In order to avoid choosing arbitrary benchmark frontiers, the malmquist index is usually defined as a geometric mean of two indices of two adjacent periods as follows:

\[
M_0(y_t, x_t, y_{t+1}, x_{t+1}) = \sqrt{M_0^t * M_0^{t+1}}
\]

\[
M_0(y_t, x_t, y_{t+1}, x_{t+1}) = \left[ \frac{d_0^t(y_{t+1}, x_{t+1})}{d_0^t(y_t, x_t)} * \frac{d_0^{t+1}(y_{t+1}, x_{t+1})}{d_0^{t+1}(y_t, x_t)} \right]^{1/2}
\]  
(26)

Equation (26) represents the productivity of production point \((y_{t+1}, x_{t+1})\) relative to the production point \((y_t, x_t)\).

Rearranging equation (26) shows that Malmquist Productivity Index is the product of technical efficiency change and technical change.

\[
M_0(y_t, x_t, y_{t+1}, x_{t+1}) = \frac{d_0^{t+1}(y_{t+1}, x_{t+1})}{d_0^t(y_t, x_t)} \left[ \frac{d_0^t(y_{t+1}, x_{t+1})}{d_0^{t+1}(y_{t+1}, x_{t+1})} * \frac{d_0^t(y_t, x_t)}{d_0^{t+1}(y_t, x_t)} \right]^{1/2}
\]  
(27)

Where \(\frac{d_0^{t+1}(y_{t+1}, x_{t+1})}{d_0^t(y_t, x_t)}\) is technical efficiency change. It measures change in overall technical efficiency from period t to t+1, i.e. moving closer to the frontier or
catching up effect. Technical efficiency change is further decomposed into pure technical efficiency change and scale efficiency change.

\[ \left( \frac{d_0^T(y_{t+1}, x_{t+1})}{d_0^T(y_{t+1}, x_{t+1})} \right)^{1/2} \] is technical change. It represents changes in technology, i.e. a shift in the frontier from period \( t \) to period \( t+1 \). It is the geometric mean of two terms, one comparing period \( t \) technology to \( t+1 \) technology from the perspective of period \( t+1 \) data, and other comparing the two technologies from the perspective of period \( t \) data.

Value greater than one indicates positive total factor productivity growth in period \( t+1 \) and value less than one shows that productivity has deteriorated over time. A value one indicates that no change has occurred in the level of productivity. Similarly the same concept applies to the components of the index TECH and TCH. If TECH and TCH are greater than one, it implies progress in the components, and the regress is associated with the values less than unity. As an example TFPG (positive MPI) can be on account of following:

<table>
<thead>
<tr>
<th>Case</th>
<th>TFPG</th>
<th>TECH</th>
<th>TCH</th>
<th>Which of the two accounted for TFPG?</th>
</tr>
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<tbody>
<tr>
<td>I</td>
<td>1.05</td>
<td>1.01</td>
<td>1.04</td>
<td>Both TECH and TCH</td>
</tr>
<tr>
<td>II</td>
<td>1.05</td>
<td>1.07</td>
<td>0.983</td>
<td>TECH</td>
</tr>
<tr>
<td>II</td>
<td>1.05</td>
<td>0.995</td>
<td>1.055</td>
<td>TCH</td>
</tr>
</tbody>
</table>

In all the three cases, TFP grows by five percent per annum. But different factors account for TFPG in the three cases. In the first case, since both TECH and TCH are positive, so both catching up effect and frontier shift resulted in TFPG. In the second case, it is due to technical efficiency improvement, while in the third case, technological progress results in TFP growth. Similarly, one can explain about TFP regress.

In order to calculate productivity growth and to decompose it as shown in equations (26) and (27), we need to solve four different distance functions i.e. 

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\(d_0^t(x_t, y_t), d_0^{t+1}(x_{t+1}, y_{t+1}), d_0^t(x_t, y_t), d_0^{t+1}(x_{t+1}, y_{t+1})\) for each industry. It involves calculating four Linear Programming problems. Assuming \(k=1,2,\ldots,K\) industries and \(t = 1,2,\ldots,T\) time period. \(n=1,2,\ldots,N\) inputs \(x_{n,k,t}\) are used to produce \(m=1,2,\ldots,M\) outputs \(y_{m,k,t}\). Following are the four linear programming problems which need to be solved for each industrial group.

\[
[d_0^t(x_t, y_t)]^{-1} = \max_{\varphi, \lambda} \varphi \\
\text{St} \\
-\varphi y_{i,t} + Y_t \lambda \geq 0, \quad \text{(Output constraint)} \\
x_{i,t} - X_t \lambda \geq 0, \quad \text{(Input constraint)} \\
\lambda \geq 0 \quad \text{(Variable returns to scale constraint)}
\]

\[
[d_0^{t+1}(x_{t+1}, y_{t+1})]^{-1} = \max_{\varphi, \lambda} \varphi \\
\text{St} \\
-\varphi y_{i,t+1} + Y_{t+1} \lambda \geq 0, \\
x_{i,t+1} - X_{t+1} \lambda \geq 0, \\
\lambda \geq 0
\]

\[
[d_0^t(x_{t+1}, y_{t+1})]^{-1} = \max_{\varphi, \lambda} \varphi \\
\text{St} \\
-\varphi y_{i,t} + Y_{t+1} \lambda \geq 0, \\
x_{i,t} - X_{t+1} \lambda \geq 0, \\
\lambda \geq 0
\]

\[
[d_0^{t+1}(x_t, y_{t})]^{-1} = \max_{\varphi, \lambda} \varphi \\
\text{St} \\
-\varphi y_{i,t} + Y_{t+1} \lambda \geq 0, \\
x_{i,t} - X_{t+1} \lambda \geq 0, \\
\lambda \geq 0
\]

where \(\varphi\) is a scalar and \(\lambda\) is \(n*1\) vector of constants.

\(y_{i,t}\) is the output vector of \(i^{th}\) industry in the \(t^{th}\) time period.
\(x_{i,t}\) is the input vector of \(i^{th}\) industry in the \(t^{th}\) time period.
\(Y_t\) is the output matrix which consists of output vectors of all the industries in the \(t^{th}\) time period.
X_t is the input matrix which consists of input vectors of all the industries in the t^{th} time period.

Total number of linear programming models for calculating Malmquist Index of K industries during T periods is 4K(T-1). Since in our study, there are 12 industries and 28 time periods, so total number of linear programming models to be solved will be 4*12(28-1)=1296. It is done with the help of DEAP Version 2.1 developed by T.J. Coelli. Diagrammatically it is given as:

If there is technical progress, production frontier will shift from OS^t to OS^{t+1}. The industry produces at point N in period t by using x_t input and it produces at point M in period t+1 by using x_{t+1} input. In each period, the industry is operating below the technology for that period.

Efficiency in period t = OF/OE and in period t+1 = OB/OA

Efficiency Change = \frac{d_0^{t+1}(y_{t+1},x_{t+1})}{d_0(y_t,x_t)} = \frac{OB/OA}{OF/OE}
Technical Change = \[ \left[ \frac{d_0^{t}(y_{t+1},x_{t+1})}{d_0^{t+1}(y_{t+1},x_{t+1})} \times \frac{d_0^{t}(y_{t},x_{t})}{d_0^{t+1}(y_{t},x_{t})} \right]^{1/2} \]

\[ d_0^{t}(y_{t+1},x_{t+1}) = \frac{OB}{OD} \]

\[ d_0^{t+1}(y_{t+1},x_{t+1}) = \frac{OB}{OA} \]

\[ d_0^{t}(y_{t},x_{t}) = \frac{OF}{OE} \]

\[ d_0^{t+1}(y_{t},x_{t}) = \frac{OF}{OC} \]

\[ \frac{d_0^{t}(y_{t+1},x_{t+1})}{d_0^{t+1}(y_{t+1},x_{t+1})} = \frac{OB}{OD} \times \frac{OA}{OB} = \frac{OA}{OD} \]

\[ \frac{d_0^{t}(y_{t},x_{t})}{d_0^{t+1}(y_{t},x_{t})} = \frac{OF}{OE} \times \frac{OC}{OF} = \frac{OC}{OE} \]

Technical Change = \[ \left[ \frac{OA}{OD} \times \frac{OC}{OE} \right]^{1/2} \]

Malmquist TFP Change = TECH \* TCH

\[ = \left[ \frac{OB/OA}{OF/OE} \times \frac{OA}{OD} \times \frac{OC}{OE} \right]^{1/2} \] \quad \text{(28)}

Having discussed the pros and cons of different approaches, we now focus on the selection of an appropriate method for measuring TFPG in this study. Among all the methods discussed above, DEA based Malmquist productivity index has several advantages over other methods which are as follows:

1. Unlike GAA, it does not require any assumptions regarding market structure, profit maximisation, cost minimisation objectives of the firm, elasticity of substitution between factors, marginal productivity assumptions.

2. Unlike GAA and econometric approaches, it does not assume that units are technically efficient and TFPG is accounted for by technical change only. Rather, DEA allows the decomposition of TFPG into technical efficiency change component (catching up effect) and technical change (frontier shift).
3. Unlike econometric approaches and SFA, DEA envelopes observed input-output data without requiring a-priori specification of the functional forms. Different specifications of production functions provide different results and this is a serious methodological problem. Hence, these approaches do not produce reliable results of TFP measurement.

4. It requires no information on factor prices and factor shares.

5. DEA can handle multiple inputs and outputs simultaneously.

Since, DEA Malmquist Productivity Index (MPI) requires lesser a-priori assumptions and allows the policy makers to know as to which of the two i.e. technical efficiency change or technical change results in TFPG, so it has been considered as an appropriate index for this study.

3.2. Database

Manufacturing sector in India and at state level is subdivided into two broad sectors:

1. Registered Manufacturing: It covers all factories registered under Section 2m (i) and 2 m (ii) of the Indian factories Act of 1948. This section includes all factories:
   (a) where ten or more workers are working, or were working on any day of the preceding twelve months, and in any part of which a manufacturing process is being carried on with the aid of power, or is ordinarily so carried on
   (b) wherein twenty or more workers are working or were working on any day of the preceding twelve months and in any part of which a manufacturing process is being carried on without the aid of power, or is ordinarily so carried on.

2. Unregistered Manufacturing: This sector includes
   (a) Household enterprise where members of family work in their own house with marginal employment of non-family members.
   (b) The residual category of non-factory, non-factory household units which employ 9 persons or less with use of power and 19 persons or less without use of power.
There are mainly five sources from which the data on these categories of manufacturing units can be culled out. These are:

1. National Accounts Statistics (NAS)
2. Annual Survey of Industries (ASI)
3. Unit level data at Central Statistical Organisation (CSO)
4. Prowess database of Centre for Monitoring Indian Economy (CMIE)
5. National Sample Survey Organisation (NSSO)

NAS includes both registered and unregistered manufacturing factories; ASI includes only registered manufacturing; CSO and CMIE compile unit level data; and NSSO deals with only unorganised manufacturing sector. ASI database is preferred to other sources and has been used in the present study as others suffer from certain limitations which are detailed below:

1. Though NAS includes both registered and unregistered manufacturing, but employment series on an annual basis is not available for registered manufacturing sector in this data source.
2. In the CSO dataset, the permanent serial numbers or identification codes for the units included in the sample are not available which resulted in under-utilisation of data. Moreover, the estimates of capital stock for earlier years are not available.
3. As regards PROWESS database of CMIE, it does not include labour input. Employment series developed in the previous studies using this database are based on interpolation/extrapolation using various assumptions. Moreover, financial statements are issued only for listed companies which results in underestimation of the whole dataset.
4. NSSO data source is available only for few years and some of these datasets are not comparable across the different surveys (Trivedi et. al., 2011).

The above limitations prevented us from using any of these data sources, namely, NAS, CSO, CMIE and NSSO. On the other hand, the ASI data of registered manufacturing covers all the primary and non-primary inputs both at industry as well as at state levels. Also, this data source has been widely used for measuring the

The present study takes into consideration the time period spanning from 1980-81 to 2007-08 which is further sub-divided into pre-reform period i.e. from 1980-81 to 1990-91 and post-reform period i.e. from 1991-92 to 2007-08. The choice of the initial year is governed by the availability of data for the earliest year (1980-81) and for the terminating year (2007-08), as the new classification i.e. NIC-2008 came into being in 2008. Further, considering this classification, the concordance table for the subsequent period has not yet been prepared by CSO. The two digit industrial classification has been considered for the present study. As National Industrial Classification changed according to changes in the International Standard Industrial Classification (ISIC), so till today NIC-1962, NIC-1970, NIC-1987, NIC-1998, NIC-2004 and NIC-2008 have came into being. For analysis of time series data, concordance needs to be met between NIC-1970, NIC-1987 and NIC-1998. The concordance tables released by the CSO for this purpose has been used.
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacture of food products (20-21) + Inedible Oils (315)</td>
<td>Manufacture of food products (20-21)</td>
<td>Production, processing and preservation of meat, fish, fruit vegetables, oils and Fats (151)+ Manufacture of dairy product (152)+ Manufacture of grain mill products, starches and starch products, and prepared animal feeds (153)+ Manufacture of other food products (154)</td>
</tr>
<tr>
<td>Manufacture of beverages, tobacco and related products (22)</td>
<td>Manufacture of beverages, tobacco and related products (22)</td>
<td>Manufacture of beverages (155)+ Manufacture of Tobacco Products (16)</td>
</tr>
<tr>
<td>Manufacture of cotton textiles (23)+ Manufacture of wool silk and man-made fibre textiles (24)- Manufacture of Wool Products n.e.c. (244)+ Manufacture of jute and other vegetable fibre textiles (except cotton)25</td>
<td>Manufacture of cotton textiles (23)+ Manufacture of wool silk and man-made fibre textiles (24)+ Manufacture of jute and other vegetable fibre textiles (except cotton)25</td>
<td>Spinning, weaving and finishing of textiles (171)</td>
</tr>
<tr>
<td>Manufacture of textile products (including wearing apparel) (26) + Manufacture of Wool Products n.e.c. (244)</td>
<td>Manufacture of textile products (including wearing apparel) (26)</td>
<td>Manufacture of other textiles (172)+ Manufacture of knitted and crocheted fabrics and articles (173)+ Manufacture of wearing apparel, except fur apparel [this class includes manufacture of wearing apparel made of material not made in the same unit. Both regular and contract activities are</td>
</tr>
<tr>
<td>Sector</td>
<td>Description</td>
<td>Included</td>
</tr>
<tr>
<td>-----------------------------------------------------------------------</td>
<td>-----------------------------------------------------------------------------</td>
<td>----------</td>
</tr>
<tr>
<td>Manufacture of wood and wood products; furniture and fixtures (27)</td>
<td>Manufacture of wood and wood products; furniture and fixtures (27)</td>
<td></td>
</tr>
<tr>
<td>Manufacture of paper and paper products and printing publishing &amp; allied industries (28)</td>
<td>Manufacture of paper and paper products and printing publishing &amp; allied industries (28)</td>
<td></td>
</tr>
<tr>
<td>Manufacture of leather and products of leather, fur &amp; substitutes of leather (29)</td>
<td>Manufacture of leather and products of leather, fur &amp; substitutes of leather (29)</td>
<td></td>
</tr>
<tr>
<td>Manufacture of chemicals and chemical products (except products of petroleum and coal) (31)</td>
<td>Manufacture of basic chemicals and chemical products (except products of petroleum and coal) (30)</td>
<td></td>
</tr>
<tr>
<td>Manufacture of rubber, plastic, petroleum and coal products (30) + Processing of nuclear Fuels (319)</td>
<td>Manufacture of rubber, plastic, petroleum and coal products; processing of nuclear fuels (31)</td>
<td></td>
</tr>
<tr>
<td>Manufacture of non-metallic mineral products (32)</td>
<td>Manufacture of non-metallic mineral products (32)</td>
<td></td>
</tr>
<tr>
<td>Basic metal and alloys industries (33) + Manufacture of metal products and parts except machinery transport equipment (34)</td>
<td>Metal and metal products (33-34)</td>
<td></td>
</tr>
</tbody>
</table>

Manufacture of Wood and of Products of Wood and Cork, except Furniture; Manufacture of Articles of Straw and Plating Materials (20)+ Manufacture of furniture (361)
<p>| Manufacture of machinery | Manufacture of Machinery and transport equipment (35-36, 37) | Manufacture of general purpose Machinery (291) + Manufacture of special purpose machinery (292) + Manufacture of domestic appliances, n.e.c.(293) + Manufacture of office, accounting and computing machinery (300) + Manufacture of electric motors, generators and transformer (311) + Manufacture of electricity distribution and control apparatus, etc. (312) + Manufacture of insulated wire and cable, etc. (313) + Manufacture of accumulators, primary cells and primary batteries (314) + Manufacture of electric lamps and lighting equipment (315) + Manufacture of other electrical equipment n.e.c (319) + Manufacture of electronic valves and tubes and other electronic component (321) + Manufacture of television and radio transmitters and apparatus for line telephony and line telegraphy (322) + Manufacture of television and radio receivers, sound or video recording or reproducing apparatus, and associated good (323) + Manufacture of medical appliances and instruments and appliances for measuring, checking, testing, navigating and other purposes except optical instruments |
| machine tools and parts except electrical machinery + Manufacture of electrical machinery, apparatus, appliances and supplies, and parts-366. (electronic control instruments) + Manufacture of transport equipment and parts (37) | generators (281) + Manufacture of other fabricated metal products; metal working service activities (289) |</p>
<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>(331)</td>
<td>Manufacture of optical instruments and photographic equipment</td>
</tr>
<tr>
<td>(332)</td>
<td>+ Manufacture of watches and clock</td>
</tr>
<tr>
<td>(333)</td>
<td>+ Manufacture of motor vehicle</td>
</tr>
<tr>
<td>(341)</td>
<td>+ Manufacture of bodies (coach work) for motor vehicles</td>
</tr>
<tr>
<td>(342)</td>
<td>+ Manufacture of trailers and semi-trailer</td>
</tr>
<tr>
<td>(343)</td>
<td>+ Manufacture of parts and accessories for motor vehicles and their engines</td>
</tr>
<tr>
<td>(351)</td>
<td>+ Building and repair of ships &amp; boat</td>
</tr>
<tr>
<td>(352)</td>
<td>+ Manufacture of railway and tramway locomotives and rolling stock</td>
</tr>
<tr>
<td>(353)</td>
<td>+ Manufacture of aircraft and spacecraft</td>
</tr>
<tr>
<td>(359)</td>
<td>+ Manufacture of transport equipment n.e.c.</td>
</tr>
<tr>
<td>(38)</td>
<td>Other manufacturing industries</td>
</tr>
<tr>
<td>(39)</td>
<td>Repair of capital goods</td>
</tr>
<tr>
<td>(725)</td>
<td>Maintenance and repair of office, accounting and computing machinery</td>
</tr>
</tbody>
</table>

Source: Ministry of Statistics and Programme Implementation (MOSPI), Government of India and Trivedi et al. (2011)
Having confirmed from EPWRF, data on industrial groups 725 and 16 under NIC-1998 have not been provided by the CSO. Keeping into consideration the above constraints, the present study limits its analysis to only 12 out of the total 14 industrial manufacturing groups mentioned in Table 3.1. These 12 industrial groups are Food Products (20-21), Cotton, Wool and Jute textile (23+24+25), Manufacture of Textile products (26), manufacture of Wood and Wood products (27), manufacture of Paper and paper products (28), manufacture of Leather and Leather products (29), manufacture of Chemical and chemical products (30), manufacture of rubber, plastic, petroleum, coal products and processing of nuclear fuels (31), Manufacture of non-metallic mineral products (32), manufacture of Metal and Metal products (33-34), manufacture of Machinery and Transport Equipment (35-36,37), and manufacture of other Manufacturing products (38).

For the year 2007, the sampled data accounts for 67.17 percent of total GVA and 96.05 percent of numbers of workers employed of Punjab’s manufacturing sector. The contribution made by each of the sampled industrial groups in GVA and employment is given in Table-3.2. It reveals that among all the selected industrial groups, Manufacture of Machinery and Transport Equipment (35-36, 37), followed by Cotton, Wool and Jute textile (23+24+25), Manufacture of Metal and Metal products (33-34) and Food Products (20-21) contributed most to GVA of Punjab’s manufacturing sector. These four together accounted for 42.60 percent of total GVA. Considering employment, it was found that Manufacture of Machinery and Transport Equipment (35-36, 37), followed by Food Products (20-21), Manufacture of Metal and Metal products (33-34) and Manufacture of non-metallic mineral products (32) absorbed highest amount of labour force of Punjab’s manufacturing. These four together employed 61.29 percent of total labour force of Punjab’s manufacturing. Wood and Wood Products (27), followed by Leather and Leather products (29) and Other Manufacturing Industries (38) contributed less than one percent to total GVA and employment.
### Table-3.2

**Percentage Share of Selected Industrial Groups in Total GVA and Employment**

<table>
<thead>
<tr>
<th>Industrial Group</th>
<th>GVA</th>
<th>Number of Workers</th>
</tr>
</thead>
<tbody>
<tr>
<td>20-21</td>
<td>8.57 %</td>
<td>17.41 %</td>
</tr>
<tr>
<td>23+24+25</td>
<td>11.96 %</td>
<td>12.63 %</td>
</tr>
<tr>
<td>26</td>
<td>7.79 %</td>
<td>10.65 %</td>
</tr>
<tr>
<td>27</td>
<td>0.12 %</td>
<td>0.02 %</td>
</tr>
<tr>
<td>28</td>
<td>4.49 %</td>
<td>2.84 %</td>
</tr>
<tr>
<td>29</td>
<td>0.38 %</td>
<td>0.84 %</td>
</tr>
<tr>
<td>30</td>
<td>6.47 %</td>
<td>3.18 %</td>
</tr>
<tr>
<td>31</td>
<td>2.11 %</td>
<td>3.75 %</td>
</tr>
<tr>
<td>32</td>
<td>2.58 %</td>
<td>13.04 %</td>
</tr>
<tr>
<td>33-34</td>
<td>8.86 %</td>
<td>13.22 %</td>
</tr>
<tr>
<td>35-36,37</td>
<td>13.31 %</td>
<td>17.46 %</td>
</tr>
<tr>
<td>38</td>
<td>0.53 %</td>
<td>1.00 %</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>67.17 %</strong></td>
<td><strong>96.05 %</strong></td>
</tr>
</tbody>
</table>

*Source: Annual Survey of Industries*

In addition, data has also been taken from Handbook of Statistics on Indian Economy, Reserve Bank of India Bulletin, Statistical Abstract(s) of Punjab, CMIE, Ministry of Industry, Government of India and other sources.

### 3.3. Variables Used

For calculating productivity, one output i.e. Gross Value Added and two inputs i.e. fixed capital and total number of persons employed have been taken.

#### 3.3.1. Output

Industry specific output is measured by its **Gross Value Added**. For deflating real value added, there are two approaches:

1. Single Deflation Method wherein nominal value added is deflated by an index of the price of gross output.
2. Double Deflation Method wherein gross output is deflated by output price index, and material input by the input price index. The difference is treated as real value added. (Balakrishnan, 2004)
Some studies have used single deflation method (Fare et. al. (2001), Jajri and Ismail (2006), Madheswaran et. al. (2007), Mahadevan (2000), Mahadevan (2002), Majumdar (1996), Unni et. al.(2001)). Some others have used double deflation method (Goldar (2004), Goldar and Kumari (2002), Pradhan and Barik (1999), Sowlati and Vahid (2006), Tan (2006), Yean (1997), Zamorano et. al. (2004)).

Double deflation method suffers from certain limitations:

1. It is highly sensitive to the set of weights used to derive the input price index and hence is more prone to errors.
2. Double deflation provides different answers for different base years for constant prices whereas the single deflation method gives a unique answer (Dholakia and Dholakia, 1994).

So, single deflation method is preferred over double deflation method for deflating Gross Value Added. It is deflated by industry specific wholesale price index (Base 2004-05=100) collected from the Office of Economic Advisor, Ministry of Industry

### 3.3.2. Inputs

For the purpose of analysis, two inputs have been taken i.e. labour and capital

#### 3.3.2.1. Labour

Total persons employed have been taken as a measure of labour force. Total persons employed includes the employees engaged in any manufacturing process or in cleaning any part of the machinery or premises used for manufacturing process or in any other kind of work connected with the manufacturing process. It also includes those holding supervisory or managerial positions engaged in administrative office, store keeping section and welfare section, sales department as also those engaged in purchase of raw materials etc or purchase of fixed assets for the factory and watch and ward staff as defined above. Apart from it, it includes all working proprietors and their family members who are actively engaged in the work of the factory even without any pay and the unpaid members of the co-operative societies who worked in or for the factory in any direct and productive capacity.
3.3.2.2. Capital

Capital stock deflated at 2004-05 prices is taken as a measure of capital input. The estimates are based on ‘Perpetual Inventory Method’. This method requires an estimate of the capital stock for a benchmark year and estimates of investment in the subsequent periods. In the present study, the value of finished equipment of a balanced age composition is assumed to be exactly half the value of equipment when it was new. Thus, twice the book value of the base year has been taken as an estimate of fixed capital for the benchmark year. This approach is followed by Banerji (1975), Chattopadhyay (2004), Goldar (1986), Kumar (2001), Raj and Mahapatra (2009), Ray (2012), Roychaudhury (1977), Samra and Rao (1990), Saputra (2011), Sehgal and Sharma (2011), Sharma and Upadhyay (2003), and Singh and Ajit (1995).

The investment figures were obtained using the formula:

\[ I_t = \frac{(B_t - B_{t-1} + D_t)}{P_t} \] \hspace{1cm} (29)

Where 'B' is the book value of the fixed capital, 'D' is depreciation, and 'P' is an appropriate deflator for fixed capital. For 'P', we have used the deflator of Gross Fixed Capital Formation of registered manufacturing (base 2004-05=100).

The capital stock in any year is then calculated as:

\[ K_t = K_{t-1} + I_t + d.K_{t-1} \] \hspace{1cm} (30)

Where \( d \) = Annual rate of discard of capital.

Following Burange (2000), Burange (2004), Goldar (1986); we have taken 2 percent annual rate of discard of capital.

Thus, this study will concentrate on measuring the performance (productivity) of Punjab’s manufacturing sector by considering 12 two digit industrial groups for the years 1980-81 to 2007-08. Variables used for this purpose are GVA as output; and labour and capital as inputs.