

Key Concepts in Measuring Productivity and a Review of Estimation Techniques for India

Dr. Pooja Khanna, Associate Professor, Department of Economics, Daulat Ram College, University of Delhi, India

Abstract

Productivity measures relate an index of output to an index of inputs. Measuring total factor productivity (TFP), however, is a complex exercise. Because it is important to understand these complexities, this paper sets out some key concepts in defining and measuring productivity, together with the various methodologies that have been used in the literature to measure it. Further, since the estimation of TFP is itself a complex process, the paper presents an extensive review of the methodologies employed in estimating TFP. It emerges from the review that there is no clear-cut and straightforward way to measure productivity. While there is ambiguity relating to the labour measure, the perpetual inventory method is the most commonly used way of measuring capital. For firm-level studies, semi-parametric techniques emerge as the most popular techniques for estimating TFP.

Keywords: Review, Total Factor Productivity, estimation techniques

1. Introduction

A well-acknowledged fact is that economic growth is the result of higher and better resource and technical progress. It is believed by many scholars that improving productivity can lead to a higher standard of living, and hence to improved welfare, in the long run (Balakrishnan and Pushpangadan, 1998; Krugman, 1990). Measuring

productivity has therefore drawn a great deal of attention from researchers, yet the concept remains plagued with issues. This may be because of the existence of a multitude of methods and techniques for measuring productivity.

Given the complexities involved in measuring total factor productivity (TFP), this paper presents some key concepts in defining and measuring productivity and the various methodologies that have been used in the literature to measure it. The paper also presents an extensive review of the methodologies employed in estimating TFP, which has not been attempted in previous literature.

The remainder of the paper is organised as follows. Section 2 discusses the various productivity concepts. Section 3 sets out the alternative approaches and techniques for measuring TFP and TFP growth (TFPG). Section 4 reviews the methodologies used to estimate TFP and TFPG in India. Section 5 discusses the issues involved in measuring output and inputs and reviews the Indian literature on the measurement of these variables. Section 6 summarises the review and concludes.

2. Defining Productivity

2.1 Single Factor Productivity and Total Factor Productivity

Single factor productivity can be defined as an index of output over a single measure of input. Input can be labour- to measure Labour productivity or capital- to measure Capital Productivity. (Multi) Total factor productivity is defined as an aggregate index of output over an aggregate index of inputs. Productivity measures are further classified according to the output measure used, which may be Gross output or value added. Table 1 summarises the various measures of productivity.

The most frequently computed productivity measures are the value-added-based concept of labour productivity, K–L MFP and KLEMS (Krishna et al., 2018). Single or partial measures of productivity provide a powerful tool for measuring factor productivity, especially labour productivity within and across countries. They are, however, sometimes criticised for limitations arising from their sensitivity to changes in factor intensities and to economies of scale.

Table 1: Various Measures of Productivity

Inputs → Measure of output ↓	Labour (L)	Capital (K)	Capital and Labour (K, L)	Capital, Labour, Energy, Materials and Services (KLEMS)
Gross output (GO)	Labour productivity	Capital productivity	Capital-labour multifactor productivity, or K-L MFP	KLEMS multifactor productivity
Value added (VA)	Labour productivity	Capital productivity	Capital-labour multifactor productivity, or K-L MFP (VA)	–
	Single factor productivity measures		Multi (total) factor productivity measures	

Source: Schreyer and Pilat (2001)

Total factor productivity, seeks to overcome the problem of changing factor intensities by measuring productivity as an index of aggregate output over an index of inputs used in production. As stated in Kathuria et al., 2013, “TFP is a broader measure of productivity, as it decomposes changes in production into changes in the quantity of inputs used and changes in all other factors such as technology, quality of factors of production and capacity utilisation”.

Total factor productivity may be measured in levels and in growth terms. TFP is analysed as an increase in output which is not due to an increase in inputs. Similarly, total factor productivity growth (TFPG) can be analysed as growth in output that is not accounted for by growth in inputs.

2.2 Technical Change-Embodied and Disembodied

Defining and measuring TFP and TFPG have been subjects of extensive discussion and debate in the past. The terms technical change or efficiency and technological change or progress are often used to describe TFP and TFPG. Following Mahadevan (2003), TFP and TFPG can be defined as:

$$\begin{aligned}
 TFP / TFPG &= \text{technical or technological change (progress)} \\
 &= \text{embodied technical change} + \text{disembodied technical change} \\
 &= \text{technical efficiency} + \text{technological progress}
 \end{aligned}
 \tag{1}$$

Embodied technical change refers to the improvements in productivity that arises from the adoption of new technologies and efficient capital utilisation. This concept is considered endogenous because it is influenced by internal factors such as the following.

- **Learning by doing:** as producers gain experience, they become more proficient, leading to enhanced productivity.
- **Advances in applied technology:** innovations in technology can lead to better tools and processes, allowing for more efficient production methods.
- **Managerial efficiency:** improved management practices can optimise resource allocation and enhance productivity.
- **Industrial organisation:** changes in organisational structure can lead to better coordination and efficiency within production processes.

The primary outcome of embodied technical change is that it enables producers either to increase output with the same level of inputs or to maintain output while reducing the quantity of inputs required. This shift results in a movement towards the production frontier, which represents the maximum output achievable with a given set of resources. Embodied technical change is therefore crucial for economic growth and for enhancing competitiveness across industries.

Disembodied technical change, by contrast, is not embodied in factor inputs. It is exogenous and leads to an expansion of the production frontier itself, owing to technological progress arising from increases in knowledge in the art of production, which may occur through research, innovation and development (Mahadevan, 2003).

There was a debate in the earlier literature over whether total factor productivity should be defined as embodied or disembodied technological progress. While Tinbergen (1942) and Solow (1957) characterised total factor productivity as disembodied technical change, Solow (1960) interpreted TFP as embodied technical change.

2.3 Origins of the Concept

The origin of the concept of TFP goes back to the 1940s and was based on the circular income flow model. The growth accounting technique was largely used in the early literature to estimate some index of TFP (Stigler, 1947; Abramovitz, 1956). Solow, however, made the technique popular by linking it and index numbers with the production function.

3. Approaches to Measuring TFP and TFPG

There are two primary methods to measure TFP and TFPG: the frontier and the non-frontier method. Each is discussed in turn below.

3.1 The Frontier Method

The frontier method focuses on the best-performing firms or units, using them as a benchmark for efficiency. It identifies the production frontier and measures how far other firms lie from that frontier. The frontier measure of TFP or TFPG is therefore the sum of technological progress, represented by outward shifts of the production frontier, and technical efficiency, as reflected in movements towards the production frontier. Techniques used in the frontier method are as follows.

- **Parametric techniques.** These methods assume a specific functional form for the production function.
 - **Stochastic frontier analysis (SFA):** incorporates random errors as well as inefficiencies, allowing for statistical noise in the estimation.
 - **Deterministic frontier analysis:** assumes no statistical noise, focusing solely on inefficiencies.
- **Non-parametric techniques.** These methods do not assume a specific functional form.

- **Data envelopment analysis (DEA):** a linear programming approach which uses the input–output ratios to calculate the relative efficiency of decision-making units.

3.2 The Non-Frontier Approach

The non-frontier method does not focus solely on the best performers but instead examines average productivity and its changes over time. It assumes that firms are technically efficient and hence considers only shifts of the production frontier, or technological progress, as a measure of total factor productivity growth. Techniques used in non-frontier method are as follows.

- **Parametric techniques.** These methods also assume a specific functional form but do not focus on the frontier. Examples include the Cobb–Douglas production function and the translog production function.
- **Semi-parametric techniques.** These methods combine parametric and non-parametric approaches, allowing for greater flexibility. An example is the Levinsohn–Petrin (LP) methodology.
- **Non-parametric techniques.** These are similar to those used in the frontier approach but focus on average rather than best-practice productivity.

The frontier method was used for industry- and firm-level studies, whereas the non-frontier method was used to measure productivity at the economy level in the early literature. However, as disaggregated data have become available, non-frontier techniques are increasingly being used for sectoral and industrial studies. Indian studies have mainly used growth accounting techniques for productivity estimation in the past, with the recent focus now shifting to semi-parametric techniques (Mahadevan, 2003).

3.3 Explaining the Three techniques of Estimation

Both the frontier and the non-frontier approaches allow for parametric as well as non-parametric estimation. The parametric technique estimates a specific model econometrically and, because it assumes underlying statistical properties of the parameters, it permits statistical testing of the selected model. Choosing correct functional model is therefore important in parametric estimation, as model mis-specification can lead to errors in the findings.

Parametric estimations technique require that the in OLS regressions, variables on the right containing the inputs be exogenously determined, that is, not dependent on the productivity level of the firm. Inputs however, are not independently determined, as they are generally chosen by producers on the basis of the firm's level of productivity. This leads to the problem of simultaneity bias, which arises from the endogeneity between productivity (unobserved productivity shocks) and the choice of inputs by producers.

Traditional methods like fixed effects and instrumental variable estimation help solve the endogeneity issue. Both these techniques have, however, been plagued with problems such as finding appropriate instruments (Van Beveren, 2012). As an alternative, Olley and Pakes (1996) introduced the semi-parametric technique. It was subsequently modified by Levinsohn and Petrin (2003) and Akerberg, Caves and Frazer (2006) and Wooldridge (2009). LP estimation involves two stages: first, identifying the labour coefficient; and second, identifying the capital and materials coefficients. This technique removes the simultaneity bias by introducing a proxy variable to substitute for unobserved productivity (Van Beveren, 2012). Wooldridge introduces a modification to the LP estimator (W-LP) that addresses collinearity through joint generalised method of moments (GMM) estimation. This approach allows for efficient estimation of the parameters of variable inputs such as labour, and for the handling of Auto-correlation and heteroscedasticity of error terms, improving the robustness of the estimates.

Non-parametric methods like DEA and growth accounting techniques have a significant advantage of not imposing any functional form on the model. At the same time they also have the disadvantage that they cannot be validated by statistical tests. More recently, some newer techniques to estimate stochastic frontiers have been developed. These

include techniques such as stochastic DEA and the Bayesian approach that can help overcome a few of the issues relating to statistical testing. The use of these techniques requires extensive computational and programming skills, and hence they have been confined largely to operations research rather than to estimating productivity or productivity growth (Mahadevan, 2003). A few studies have employed the DEA technique for TFP estimation in India, like Raj (2011) and Ray (2002) for the manufacturing sector; Sahoo (2013) for the services (software) sector.

Among the non-frontier techniques, the growth accounting approach is sometimes referred to as the deterministic approach, as the estimator obtained from it does not contain a stochastic term. Statistical estimation of this model is therefore not possible, and usual econometrics techniques cannot be used for the growth accounting model. The non-frontier parametric techniques constitute the econometric approach to measuring productivity. The commonality between the two is that both use a production function as their starting point (Mahadevan, 2003).

3.4 Sensitivity of Estimates to Technique and Data

Despite the multitude of estimators and estimation techniques available for computing productivity, the literature remains inconclusive regarding the best choice of TFP or TFPG measure. There is no single measure that is appropriate or best suited to all situations, and TFP estimates can be sensitive to model specification and measurement error.

Van Biesebroeck (2004), using Monte Carlo simulations, compares the sensitivity of commonly used parametric, semi-parametric and non-parametric techniques for measuring firm productivity to measurement and specification errors. Results show that the GMM estimator is robust in the presence of some technological heterogeneity and high measurement error. With low measurement error, however, the GMM estimator can yield downwardly biased input coefficients. He finds techniques such as DEA and index numbers (non parametric) are robust in the presence of small measurement error, heterogeneous technology and non-constant returns to scale. Van Beveren (2012), in a study of the Belgian food and beverages sector, finds that semi-parametric estimators

perform better than parametric ones, though she also supports the view that the choice of TFP estimator is data sensitive.

4. Review of Methods Used in Estimating Productivity in India

Measuring productivity broadly involves two categories of issue: the methodology used to estimate productivity, and the measurement of output and inputs. The former pertains to selecting a suitable estimation technique. First, the researcher has a choice between frontier and non-frontier techniques. Second, there is a choice between the production function (stochastic frontier or econometric) approach, the non-parametric (deterministic) approach involving the traditional techniques of growth accounting and data envelopment analysis, and the more recent semi-parametric approach. Each technique is itself associated with issues such as sensitivity to measurement error, sample size and the functional form of the production function chosen.¹

Further, parametric techniques are associated with simultaneity bias, and growth accounting techniques rest on the strong assumptions discussed in the previous section. The existence of a multitude of techniques is perhaps the reason behind the inconclusive empirical evidence on productivity estimates. This section reviews the methodologies used to estimate TFP and TFPG in India; Section 5 discusses the issues involved in measuring outputs and inputs and presents a brief review of the Indian studies in this context.

4.1 Methodologies Used in Measuring TFP and TFPG

Productivity in India has been measured extensively at the industry and plant level as well as at the firm level. Typically, the former category of studies has used the Annual Survey of Industries (ASI) database, whereas the latter has used the Prowess database of the Centre for Monitoring Indian Economy (CMIE). A commonly used technique for measuring productivity at the industrial level has been the traditional growth accounting

¹ Kathuria et al. (2011) provide a comparison of the sensitivity of parametric, semi-parametric and non-parametric techniques to these problems.

approach, using index numbers such as the Törnqvist–Theil index (Balakrishnan and Pushpangadan, 2000; Goldar and Kumari, 2003; Tata Services Limited, 2003; Unel, 2003; Das, 2004; Goldar, 2004). Many studies have also applied the DEA approach using the Malmquist index at the industrial and firm level (Ray, 2002; Raj, 2011; Sahoo, 2013).

More recently, the semi-parametric LP approach has been used by many studies at the industrial as well as the firm level, owing to its ability to overcome simultaneity bias and its suitability for panel data estimation (Sivadasan, 2006; Kathuria et al., 2010; Nagraj, 2014; Topalova and Khandelwal, 2011; Kathuria et al., 2013; Goldar et al., 2020, among others). The stochastic frontier approach, though suitable for cross-sectional data, has been modified by Battese and Coelli (1992, 1995) for panel data estimation. Kathuria (2001), Goldar et al. (2004) and Kathuria et al. (2013) apply the stochastic frontier approach to estimate productivity using panel data.

Largely, the focus of these studies has been the formal manufacturing sector, though some recent studies have measured productivity in the informal manufacturing sector (Kathuria et al., 2010, 2013; Raj, 2011; Krishna et al., 2018). Very few studies have attempted to measure productivity for the services sector (Bhattacharya et al., 2012; Sahoo, 2013; Chawla, 2017; Goswami and Narayanan, 2022), employing different methodologies such as the Levinsohn–Petrin method used by Goswami and Narayanan (2022), the DEA technique used by Sahoo (2013) and the stochastic frontier technique used by Bhattacharya et al. (2012).

5. Issues in Measuring TFP and TFPG

Issues pertaining to the measurement of TFP and TFPG fall broadly into two categories: the measurement of output and the measurement of inputs.

5.1 Measurement of Output

Measuring productivity involves creating an index of output. This can be done following two approaches: the gross output approach and the value-added approach. Further, if the

output measure is value added, it needs to be deflated by price indices, which can also be done in two ways: single deflation and double deflation.

5.1.1 Gross Output versus Value Added

Two approaches may be used to derive the output measure: gross-output approach and the value-added approach. The total goods and services produced within a production unit (firm, industry, sector or the entire economy) available for final use are called gross output. Gross output includes the sum of total sales and net additions to inventories.

From the gross output value, if we deduct the value of intermediate inputs purchased, we derive the value added measure. The concept of separability in production functions is crucial for this measure when estimating productivity (Balakrishnan and Pushpangadan, 1998).

Value-added method is preferred over gross output as it prevents double counting of intermediate inputs, and, particularly for inter-industry studies, the estimates obtained from this approach are meaningful indicators of the value added by industries to productivity growth (Schreyer and Pilat, 2001). In addition, inter-firm comparison becomes meaningful in the case of firms using heterogeneous raw materials (Griliches and Ringstad, 1971).

On the other hand, the implicitly maintained hypothesis of separability of the production function has been questioned by many scholars stressing on the meaningfulness of a production function only if material inputs could be separated from the primary ones; their studies employ gross output as the index of output (Balakrishnan and Pushpangadan, 2000; Ray, 2002). Moreover, productivity growth estimates obtained from the value-added measure tend to be higher than those obtained from the gross output approach, as dropping intermediate inputs creates an upward bias.

5.1.2 Single and Double Deflation of Value Added

Value added as the measure of output will be credible only if we can define and derive a measure of real value added. There are two ways of obtaining the same. First when output price index is used to deflate both nominal output and nominal inputs. This is the single deflation method. Alternatively, when output price index is used to deflate the nominal

output while input price index is used as a deflator for nominal inputs, it gives the double deflation method.

The study by Balakrishnan and Pushpangadan (1994) highlighted the importance of, the double deflation method on account of changing relative prices for the Indian manufacturing sector. Since then, many studies have used the double deflation method (Dougherty et al., 2009; Sharma, 2010; Goldar et al., 2020). Owing to the difficulty of compiling a material inputs price deflator index, however, many studies have employed the single deflation method (Unel, 2003; Kathuria et al., 2013).

5.1.3 Measuring Output in the Services Sector

Measuring output for the services sector poses a further challenge to the researcher. Since this sector includes highly diversified services and activities, the nature of its output is not easy to characterise. The problem of simultaneity in production and consumption in services sector, leads to difficulties in measuring output. The issue of measuring output in services thus remains contested (Griliches, 1992). For most Indian studies on the services sector, gross output has been used for measuring TFP (Bhattacharya et al., 2012; Sahoo, 2013; Goswami and Narayanan, 2022).

5.2 Measurement of Inputs

Labour and capital are the two inputs to be estimated. The estimation of both, however, is far from straightforward.

5.2.1 Labour

There are two commonly used methods of measuring labour input. It can be measured in two ways- as the quality-adjusted number of hours actually worked or as a head count of jobs or employees. The former method is deemed the more appropriate measure of labour input, as it accounts for differences in the quality of labour by incorporating characteristics such as sex, education and employment status. One of the major limitations in obtaining this measure is the lack of accurate and consistent data on labour

employment in India.² Krishna et al. (2018) is one of the few studies to classify labour on the basis of education in order to estimate TFPG.

The second measure, the number of employees, has mostly been used in studies of productivity in India, even though it has been criticised on the grounds that it does not include changes in average working time for an employee, self-employment and the quality of labour. The main data source for these studies has been the Annual Survey of Industries (ASI), processed by the Labour Bureau, which provides data on working days, person-days worked, person-hours worked, absenteeism, earnings and social security benefits. However, as the primary unit of enumeration in the survey is the factory (for manufacturing industries) it cannot be used directly for firm-level studies in the absence of firm-level identifiers.

Company-level databases such as Prowess, developed by the Centre for Monitoring Indian Economy, also do not give complete data on the number of employees in a firm. Since disclosure of employment figures is not mandatory for companies in this database, the percentage of companies reporting their number of employees is extremely low; Chawla (2012) reports it to be about 10 per cent. Research on firm-level productivity therefore uses one of three approaches to impute labour: the ASI/CMIE-based approach, the compensation-to-employees approach, and the more recent Lancheros and Girma (2009) approach (Chawla, 2012). As a direct measure of employment is not available for firms, these approaches only suggest substitutes for it. The three measures, as discussed in Chawla (2012), are as follows.

(a) ASI/CMIE-based approach. Obtaining this measure involves two computational steps. First, data on total emoluments and total persons engaged for the relevant year or years at the appropriate two-digit or three-digit level of industry classification are taken from the ASI database, and an average wage rate is computed as emoluments per employee. Second, each firm-year observation on the total wage bill obtained from the

² The India KLEMS research project is a significant initiative aimed at enhancing understanding of the Indian economy through detailed data collection and analysis. The project is supported financially by the Reserve Bank of India and focuses on gathering comprehensive data related to various aspects of labour and productivity, including employment by education level, the wage share in GDP with estimates for self-employed workers, and indicators of labour productivity growth and total factor productivity growth. The data are available for 27 industries of the Indian economy over the period 1980–2011 (Krishna et al., 2018). However, a major gap still exists in employment statistics for firm-level studies in India.

company database is divided by the average wage calculated above to obtain a measure of the firm's employment (the ASI measure). A drawback of this approach is that it cannot be applied to the services industry, as the ASI database is restricted to registered manufacturing industries. Following Chawla (2012), a further measure, referred to here as the CMIE measure, is suggested for the computation of labour; its advantage is that it can be employed to measure labour in the services sector. It also involves two steps. First, compensation to employees is divided by the number of employees for those firms that report them, and an average wage rate is computed from the firm-specific wage rates so obtained. Second, a measure of labour is derived for the remaining firms by dividing compensation to employees by this computed average wage rate.

(b) Compensation-to-employees approach. This approach does not yield the number of employees. Real values of compensation to employees, a measure of labour productivity or quality, are used as a proxy for labour input. Firms' wages and salaries are divided by the respective industries' price index (WPI or CPI). This gives real values which are used as a proxy for labour input (the CPE measure).

(c) Lancheros–Girma approach. A relatively new technique has been proposed by Lancheros and Girma (2009). The elasticity of employment with respect to total assets is calculated by regressing the logarithm of employment on the logarithm of total assets for those firms in Prowess that report the number of employees. This elasticity is then used to estimate employment (the LG measure) for firms that do not report the data. The applicability of this approach is, however, limited in the literature.

Most studies at the industry level use the number of employees from the ASI data. For firm-level studies, both the ASI measure and the CPE measure are employed to impute labour. Prominent studies using the CPE measure include Topalova and Khandelwal (2011), Dougherty et al. (2009) and Topalova (2004). Studies that employ the ASI measure include Balakrishnan and Pushpangadan (2000), Hasan (2002) and Goldar et al. (2020). Nagraj (2014) is one of the few studies to have employed both.

The ASI measure, though the most popular, has the disadvantage that it cannot be applied to the services sector. The CPE measure can be used for both manufacturing and services, but it is at best a substitute measure of labour, reflecting its productivity. Similarly, the

LG measure is an approximation of labour based on the elasticity of employment. Given the advantages and disadvantages of all three measures, none can be considered superior or inferior to the others. Chawla (2012) reviews the ASI, CMIE and LG measures but remains inconclusive as to the best measure for imputing labour.

5.2.2 Capital

Measuring capital is a complex challenge for researchers, primarily because of the nature of capital goods and their services. Capital goods, whether purchased or rented, provide services that contribute to production. However, these services do not always correspond to observable market transactions. When capital goods provide services to their owners, no direct market transaction is recorded, and this lack of market data complicates the estimation of the value of capital services.

To measure capital services, researchers must assign prices to these implicit transactions. Since the actual flows of services are not directly observable, researchers often approximate them which can introduce inaccuracies.

The challenges of measuring capital in the services sector, particularly in relation to intangible capital for which data on depreciation are rare, also present unique difficulties for researchers (Goswami and Narayanan, 2022).

Measuring capital remains one of the most complex issues in productivity analysis, and there is no single universally acceptable way of estimating it. Researchers have applied different techniques to estimate the capital stock. One of the most popular measures is the perpetual inventory method (PIM), which accumulates past capital formation and deducts the value of assets (“scrapping”) that have reached the end of their service lives³. Many studies, including Balakrishnan and Pushpangadan (2000), Goldar et al. (2004) and Goldar et al. (2020), apply PIM to estimate the capital stock.

Alternative method of estimating capital as a stock is by taking book value of fixed assets. However, the book value may not accurately represent the actual physical stock of capital (machines and other equipment). Ray (2002) employs this technique to measure capital,

³ Capital formation and scrapping of assets are re-valued either at current-year prices or at constant prices (OECD, 2001).

acknowledging its imperfections. A summary of the review is presented in Tables 2 and 3.

6. Summary and Conclusion

It emerges from the above review that there is no clear-cut and straightforward way to measure productivity. Both parametric and non-parametric approaches have their own advantages and disadvantages as estimation techniques. Whereas parametric techniques impose a functional form on the model and face the simultaneity issue, non-parametric techniques do not assume underlying statistical properties for the model; unlike parametric techniques, however, non-parametric estimates cannot be validated by statistical testing. TFP estimates are also found to be data sensitive.

In the Indian case, industry-level studies have mainly used the traditional growth accounting techniques based on index numbers, along with DEA and LP techniques. For firm-level studies, semi-parametric techniques, and LP in particular, have emerged as the most popular, which may be due to their advantage in resolving the simultaneity bias between unobserved productivity shocks and input levels that other techniques lack.

Both gross output and value added have been used as measures of output for the Gross output measure scores over the value-added measure as it does not require the assumption of separability of the production function and is hence a more effective measure of output (Balakrishnan and Pushpangadan, 2000).

For estimating labour, industry-level studies have used ASI data, whereas firm-level studies have used both the CPE and the ASI methods. As ASI is a database for industry, it is more suitable for industry and aggregate-level studies, while CPE may be considered the preferred measure of labour for firm-level studies. The perpetual inventory method is used most widely in the literature and is a more robust way of estimating the capital input than the book value of fixed assets.

Table 2: Literature Summary on the Estimation of TFP for India – Industry- and State-Level Studies

Study	Output index	Method to estimate capital	Measure of labour	Estimation approach	Period of study	Sector
Balakrishnan and Pushpangadan (1994)	VA (SD & DD)	PIM	No. of employees (ASI)	GAA (TLI)	1970–89	Formal Mfg
Ray (2002)	GO	BVFA	No. of employees (ASI)	DEA (TLI, MI)	1991–2001	Formal Mfg
Goldar and Kumari (2003)	GO	PIM	No. of employees (ASI)	GAA (TLI)	1981–98	Formal Mfg
Unel (2003)	VA (SD)	PIM	No. of employees (ASI)	GAA (TLI); PFA	1979–98	Formal Mfg
TSL (2003)	GO	PIM	No. of employees (ASI)	GAA (TLI)	1981–2000	Formal Mfg
Goldar (2004)	GO, VA (DD)	PIM	No. of employees (ASI)	GAA (TLI); PFA	1979–2000	Formal Mfg
Das (2004)	GO	PIM	No. of employees (ASI)	GAA (TLI)	1980–2000	Formal Mfg
Sivadasan (2006)	VA (DD)	PIM	No. of employees (ASI)	LP	1986–87 to 1994–95	Formal Mfg
Banga and Goldar (2007)	GO	PIM	No. of employees (ASI)	PFA	1980–81 to 1999–2000 (agg.); 1980–81 to 1997–98 (disagg.)	Formal Mfg
Kathuria et al. (2010)	VA (SD)	Total fixed assets (ASI & NSSO)	No. of employees (ASI & NSSO)	LP	2000–01 to 2004–05	Formal & informal Mfg
Kathuria et al. (2013)	VA (SD)	Total fixed assets (ASI & NSSO)	No. of employees (ASI & NSSO)	SFA; GAA (TLI); LP	1994–95 to 2001–05	Formal & informal Mfg
Raj (2011)	VA (SD)	BVFA	No. of employees (NSSO)	DEA (MI)	1978–2001	Informal Mfg
Goldar (2015)	GO	PIM	No. of employees (ASI)	LP	1999–2000 to 2011–12	Formal Mfg
Krishna et al. (2018)	GO, VA (SD, DD, TI)	PIM	No. of employees (ASI & NSSO)	GAA (TLI)	1980–2011	Formal & informal Mfg

Source: Compiled by the authors. Notes: VA – value added; SD – single deflated value added; DD – double deflated value added; GO – gross output; PFA – production function approach ; GAA – growth accounting approach;; LP – Levinsohn and Petrin methodology; W-LP – Wooldridge-modified LP methodology; TLI – Theil–Törnqvist (translog-Divisia) index; MI – Malmquist index; TI – Törnqvist index; BVFA – book value of fixed assets; PIM – perpetual inventory method; SFA – stochastic frontier analysis; DEA – data envelopment analysis; GMM – generalised method of moments. ASI, CPE, CMIE and LG are methods of imputing labour described in Section 5.2.1.

Table 3: Literature Summary on the Estimation of TFP for India – Firm-Level Studies

Study	Output index	Method to estimate capital	Measure of labour	Estimation approach	Period of study	Sector
Krishna and Mitra (1998)	GO	Net fixed assets	CPE (public sector employee wage rate)	PFA	1986–93	Formal Mfg
Balakrishnan et al. (2000)	GO	PIM	ASI	PFA	1988–98	Formal Mfg
Kathuria (2001)	VA (SD)	PIM	ASI	SFA	1975–76 to 1988–89	Formal Mfg
Hasan (2002)	GO	PIM	ASI	PFA (GMM)	1975–76 to 1986–87	Formal Mfg
Goldar et al. (2004)	VA (SD)	PIM	ASI	SFA	1990–91 to 2000–01	Formal – engineering
Topalova (2004)	GO	PIM	CPE (WPI)	LP	1989–2001	Formal Mfg
Dougherty et al. (2009)	VA (DD)	BVFA	CPE (CPI)	PFA	2004–05	Formal Mfg
Kato (2009)	VA (SD)	PIM	ASI	PFA	1991–92 to 2001–02	Formal Mfg
Lancheros and Girma (2009)	GO	BVFA	LG	LP	1997–2007	Software services & pharmaceutical firms
Sharma (2010)	VA (DD)	PIM	Labour employed	LP	2000–09	Formal Mfg
Das (2011)	GO	Capital employed	Labour employed	LP	2000–08	Formal Mfg
Topalova and Khandelwal (2011)	GO	Capital employed	CPE (WPI)	LP	1987–2001	Formal Mfg
Bhattacharya et al. (2012)	GO	Gross fixed assets net of land and building assets	CPE	SFA	2000–08	Services – software
Das (2013)	GO	PIM	No. of employees (Prowess)	LP; PFA	2008–09 to 2011–12	Formal Mfg
Sahoo (2013)	GO	Expenditure on computer and electronics + operating expenses	LG	DEA (MI)	1999–2000 to 2007–08	Services – software
Nagraj (2014)	GO, VA	PIM	ASI, CPE (CPI)	LP	1989–2008	Formal Mfg
Chawla (2017)	GO (LP), VA (DD, W–LP)	PIM	ASI/CMIE	LP; W–LP	1995–2012	Formal Mfg; services (information & communication); mining and construction
Goldar et al. (2020)	GO, VA (DD)	PIM	ASI	LP	1995–2010	Formal Mfg
Goswami and Narayanan (2022)	GO	PIM	CMIE	LP	2000–14	Services – information technology

Source: Compiled by the authors. Notes: VA – value added; SD – single deflated value added; DD – double deflated value added; GO – gross output; PFA – production function approach; GAA – growth accounting approach; LP – Levinsohn and Petrin methodology; W–LP – Wooldridge-modified LP methodology; TLI – Theil–Törnqvist (translog-Divisia) index; MI – Malmquist index; TI – Törnqvist index; BVFA – book value of fixed assets; PIM – perpetual inventory method; SFA – stochastic frontier analysis; DEA – data envelopment analysis; GMM – generalised method of moments. ASI, CPE, CMIE and LG are methods of imputing labour described in Section 5.2.1.

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