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Abstract

Recognising the nexus between growth and energy use, a fast growing country like India, is an ideal case for empirical assessment of increasing energy use in terms of consumption pattern driven by shifts in demand and technological changes. While the introduction of new technology contributes to lower energy use due to improved efficiency, the introduction of energy consuming machinery itself may cause an increase in energy use. Therefore, it is important to explore the sectoral dynamics of development. We study the relative contributions at the sector level in an economy-wide framework using the hybrid Input-Output model for structural decomposition analysis. Results for the overall economy show that changes in the production technology have been energy saving with a gradual response of non-energy inputs, as compared with energy inputs. Comparison of the changes in energy use highlights the need to reduce energy requirements from final demand expansion either through price corrections or along with a parallel improvement in technological performance.

Keywords: energy use; technological change; demand shifts; India; input-output.

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1. Introduction

The two-way causation in relationship between growth and structural change is well defined in economic theory. Structural change determines relative importance of various sectors of the economy in an inter-temporal context. The importance of structural change is well established through its impact in terms of change in output, income, labour, technology and use of inputs such as energy. The relative importance of sectors critically hinges upon changes in demand-side factors of the economy which act as major growth drivers in a true Keynesian sense. Changes in demand are further manifested through shifts in levels, distribution and sectoral composition. Another strand of literature on growth accounting attributes bulk of economic growth to the improvements in productivity achieved through technological changes (Solow, 1957). Thus, demand shifts and technological changes are the two important sources of economic growth. Regardless of its contributing factors, economic growth is accompanied by growing energy use. The environmental externalities arising from increasing energy use raise concerns on sustainability of the economic growth.

India's energy use more than doubled between 2000 and 2013 (British Petroleum, 2013). However, energy intensity of the overall economy declined. The lowering of energy intensity could be attributed due to the recovery in GDP growth along with relatively stable energy consumption (Deb and Appleby, 2015). The expansion of the energy sector is sensitive to growth of other sectors in terms of generating demand for energy resources as inputs into the production process. At the same time, energy sector stimulates production activities in other sectors due to input use from the upstream supply sectors (Ahmed and Tandon, 2014). This clearly brings to the fore the nexus between growth and energy use. The growing significance of energy use in non-energy sectors, such as the manufacturing through stronger intersectoral linkages, is also recognised. Therefore a fast growing country like India, qualifies as an ideal case for empirical assessment of increasing energy use in terms of consumption pattern driven by the shifts in demand and technological changes.

The importance of energy use due to growing intersectoral linkages; finite fossil resources, and environmental externalities, further adds significance to a study of energy induced technological change. The study is important for two reasons. Firstly, the contribution of technological change along with the shifts in the demand pattern is useful to examine the effectiveness of policy. Second, it is important to study the role of technological change in individual industries to understand the energy implications of economic growth.[1]

The energy induced technological change can be energy using, saving or neutral. Sustainability of economic growth is assessed in terms of energy intensity measured as the amount of energy used per unit output. Energy intensity represents the efficiency of energy use and is commonly used for comparisons between countries. From a domestic policy perspective also, it is important to compare the energy use across sectors of the economy. While the introduction of new technology contributes to lower energy use due to improved efficiency, the introduction of sophisticated energy consuming machinery may itself cause an increase in energy use. Although the same metric of energy intensity is useful for inter-industry comparisons, it becomes necessary to simultaneously consider change in sectoral demands. The change in energy intensity gets multiplied across each unit of output produced for final consumption. The sector-wise final demand shifts can either re-enforce or oppose changes in energy intensity making it difficult to predict the net effect *ex-ante*. Therefore, it is important to explore the sectoral dynamics of development. For instance, increasing economies of scale result in output expansion alongside changes from technological innovation. Thus, sector-wise changes in energy use are jointly determined from the corresponding changes in final demand shifts and energy intensity.

The energy intensity of a sector is fundamentally linked to production technology which refers to a choice of techniques used to produce unit output from a given quantity of inputs. Therefore, changing use of material inputs such as energy, measured in physical quantities which are independent of price, reflect a change in production technology of the sector. Thus, change in technology of production is recognised if the same amount of output is produced with a distinguished composition or level of inputs such as energy. Improvements in energy intensity of the relatively less intensive sectors may not be as effective when compared to improvements in the more intensive sectors. Similarly, changes in final demand will contribute to lowering energy use with a compositional shift towards the less intensive sectors or the improvement in efficiency of energy use. Hence, a study relating to the relative contribution of technical change and final demand to the changes in sector-wise energy use bears a critical importance for an in-depth analysis.

The discussion raises some key research issues: how has India's energy use pattern changed over time; what are the main contributing factors; what has been the relative direction of the changes – whether they support or cancel out the effects of individual factors, and what has been the behavior at the sector level. The answer to these queries will have direct bearing on the realisation of Sustainable Development Goals (SDGs) which integrate economic; social, and environmental dimensions into sustainable development. Against this backdrop, we propose to study the relative contributions of sector-wise technological change and final demand shifts in changing the energy use at the sector level. The present paper is based on the Keynesian theory of economic development. The analysis is performed in an economy-wide framework using the hybrid Input-Output (I-O) model for Structural Decomposition Analysis (SDA) (Miller and Blair 2009; Lin and Polenske 1995). We also compute real transaction flows to highlight the change in energy use measured in physical terms. To ensure consistency of energy induced technological change, we also compare the estimates from both direct and indirect changes vis-a-vis the change in corresponding energy intensity. The analysis primarily contributes to the development literature with oblique inputs for innovation theory and factor productivity.

The present paper re-visits the earlier work of the authors in the two following ways (Tandon and Ahmed, 2016). Firstly, the study contributes by disaggregating the composite electricity sector into primary (non-thermal) and secondary generation sources (thermal). The improvement is important in view of the increasing emphasis on renewable sources for generation of primary electricity. Secondly, the study complements the earlier work of changes in production technology by further bringing in the analysis of final demand shifts at sector level.

Rest of the paper is organised into the following sections. Section 2 presents a review of the literature followed by Section 3 with the details of methodology and database. The results are discussed in Section 4. Section 5 concludes the discussion.

2. Review of Literature

The literature on growth models is broadly divided under two streams. On one hand, the Keynesian (1964) model of growth is based on the assertion that aggregate demand is the most important driving force which can pull the economy above or below the full employment levels. Although Keynesian models of growth are important tools in the literature on development economics, they ignore the long-run growth effects of investment on productive capacity. This gap was filled by Harrod (1939) and Domar (1946) by emphasising the dual role of investment through income effect (through increasing demand) and productive capacity of the economy. On the other hand, Nobel laureate Solow (1957) ascribed growth to the supply side factors; acknowledged growth due to addition of labour and capital inputs, and also to new ideas and technology. In fact, Solow emphasised on the contribution of technological change as an exogenous variable over the use of capital. The problem of exogeneity was improved in the endogenous growth models that followed. For instance Schumpeter (1943) explained economic growth due to endogenous technological change. The Schumpeter-ians believe that economic development is the result of a discontinuous change substantially driven by innovation. The study of relationship between innovation and growth constitutes the subject of evolutionary economics which emphasises the role of technology and institutions. Innovation, in a broad sense, is realised in the form of – introduction of a new product; introduction of new methods of products; opening of a new market; access to a new raw material, and new organisational structure (Archibugi, 1988).

The economic growth is the process of transformation of economic output. Output growth is *extensive* if achieved only by increasing the use of inputs and *intensive* if accompanied by efficiency change of the inputs. Resource efficiency attains importance in view of the fact that extensive growth may not be sustainable though feasible (Mongia and Sathaye, 1998). While efficiency is important for all factors and inputs, energy efficiency is particularly important due to its universal use – directly or indirectly; related emissions, and the finite nature of fossil reserves. The energy efficiency refers to output production with lesser amount of energy used as input. This in turn may be due to the introduction of a new technology, output elasticity or a relative change in prices which have a substitution effect (Rezagholi, 2006). In addition, the benefits from improved economies of scale also change the input used per unit of output.

Thus, technological effect in a production system is the net effect of the above forces. In a time series analysis, the production function is used to attribute the output change to – the changes in input use, increasing returns of scale and technical progress (Korres and Drakopoulus, 2009). Productivity or efficiency of the economy is measured as a difference between the observed growth rate and the predicted growth rates of the factors (Chenery and Syrquin, 1986); which is a function of technology. However, the validity of results is sensitive to the underlying assumptions of the estimation procedure. In a cross-section study, technology of production is regarded as given. Productivity is measured as the difference between efficiency of the economy relative to that predicted by the estimated productivity of labour and capital (ibid, pp 95). At the same time, interdependence between variables can be a source of problem due to the simultaneous equation bias (Kores and Drakopoulus, 2009). The technology concept is also present in the I-O models formulated by Leontief (1936) which use inputs required per unit of output to represent the production technology of the given sector. Reazagholi (2006) also opined that the fundamental unit of technology is the technique or the production methods which transform inputs and factors into output. The I-O models emphasise on growth due to structural changes in the economy which are prominent in terms of compositional change in terms of output. In addition, the income shifts influence the demand pattern, reinforcing the Keynesian theory of a demand driven growth, along with factors of production.

These forces interact with the productivity growth, resource availability and policies thus necessitating a multi-sectoral, economy-wide analysis (Syrquin, 1988). Kuznets (1971) also emphasised the importance of structural changes, both economic and social, for realising modern growth which was further underscored by Chenery (1979) through his views supporting a study of interrelated changes in structure of the economy contributing to the area of *development economics*. However, the Leontief framework is criticised for a static representation of the economy which tends to ignore the changes in technology over time. This criticism is circumvented with the help of structural decomposition analysis in the I-O framework which is used for inter-temporal comparisons of different characteristics of the economy. The structural changes, as measured in terms of changing composition of output, technology, among other indicators, are at the centre of modern of economic growth (Syrquin, 1988).

The structure of an economy is described in terms of intersectoral dependencies in the form of economic relations among sectors of the economy and the domestic supply shares (Leontief, 1936). The former reflect the technology of the economic system as presented in the form of a *production recipe*. The interdependence among sectors is emphasised for technological development as Schmookler (1966) argued that the competence of user industry improves with improvements in the inputs purchased from other industries (Drejer, 1999). Technological changes are realised by utilising newer production methods. Posner (1961) acknowledged that newer processes (in absence of newer goods), can lead to comparative advantage in some goods. The shift to an alternate method of production also leads to change in input use and hence in the production recipe thus qualifying substitution as a change in technology arising from a varied input use. Schumpeter also distinguished the 'new way of handling a commodity commercially' as a form of innovation and technical change as the temporal evolution of the productive techniques employed (Archibugi, 1988). Thus, technological change plays important role in expansion or contraction of sector-wise output (Korres and Drakopoulus, 2009).

The effects of technological change are useful to categorise performance of sectors for a comparative analysis. Technological changes may be factor augmenting (saving), using (consuming) or neutral (if they affect all factors equally). Therefore technological changes can have a strong impact on the resource use in a growing economy. Among other factors, energy acquires special significance due to limited reserves and the related GHG emission in a climate change perspective. An energy saving technological change can have a significant moderating effect on the growing energy use of the economy. On the other hand, energy using technological change would accelerate energy demand thus calling for direct policy interventions (Mongia and Sathaye, 1998). This necessitates analysing the energy induced technological changes as attempted in various country specific and multi-country studies. With regards to energy induced technological changes, some SDA studies analysed the contribution of changes in energy intensity to reflect the variations in energy use per unit of output produced, which in turn reflects the technological change in an I-O framework. In a much sited work, Skolka (1989) noted the positive contribution of technology, though not specific to energy, in structural transformation of the Austria economy. Park (1992) illustrated the contribution of energy intensity for Korean manufacturing in reducing energy consumption by 28%. However, the effect was weak to offset the increased energy use due to output and structural effects. Similarly, the analysis by Lin and Polenske (1995) shows the contribution of production technology changes in lowering the energy consumption by 37% in China notwithstanding the stronger counter effect of final demand. In the Indian context, Sathe (2007) emphasised on a significant contribution of technological change in structural transformation of the economy during early periods. Among the studies focused on energy issues specifically, Tiwari (1999) underscored the contribution of energy intensity as the most significant source of changing energy consumption in comparison to the output and structural effects in the economy. Chakraborty (2007) attributed comparably significant contributions of energy intensity and technological changes at 37% each in increasing energy use. Dasgupta and Roy (2002) also note the contribution of energy intensity in lowering the increase in energy demand due to structural changes for later years. The analysis by Mukhopadhyay and Chakraborty (1999, 2000, 2002) show energy savings due to technical change. In a separate analysis Mukhopadhyay (2005) confirmed the reduction in emissions due to technological changes during the later period, as compared to the energy intensity and final demand effects which contributed to increased emissions. On the other hand, decompositions of the compositional shifts in final demand from an energy perspective have been rare. Recently Kahrl and Holst (2014) demonstrated lower energy intensity across all components of final demand. They show that final demand increased faster than energy use leading to improved energy intensity and gains from efficient use.

The recent expansion of the Indian economy is attributed to domestic expansion and exports, with a rather limited contribution of technology at an aggregate level (Tandon and Ahmed, 2013). At a disaggregate level, however, a mixed technology effect is found in specific energy sectors. More recent research highlights the impact of energy efficiency improvement particularly in the non-energy sectors (Tandon and Ahmed, 2016). Improvements in energy intensity of the Indian economy are also noted in other studies (Goldar 2010, Planning Commission 2013). However, decompositions of sources of growth which consider only the supply-side or the demand-side of the economy are partial representations of the growth process (Kubo, Robinson and Syrquin, 1986). The specification used by Lin and Polenske (1995) is appealing with technological change and final demand shifts components, simultaneously. The present study is an attempt in this direction. The present study contributes by analyzing the sector-level changes in India's energy use due to final demand shifts vis-a-vis the technological changes.[2]

3. Methodology and data

The methodological approach of this research is based on the I-O framework of Leontief (1936). Traditional I-O models represent intersectoral flows in monetary values. For a hybrid I-O energy model, the comparable matrices in hybrid units are obtained by substituting the energy rows in physical quantities for the energy rows containing flows in currency values. The resulting hybrid I-O contains rows corresponding to energy commodities in physical quantities while all other commodity rows are maintained with monetary values.

We use the SDA to attribute the change in the specified variable i.e change in energy use, to changes in the factors of concern. A detailed description of the model is presented in Tandon and Ahmed (2016).[3] The changes in additional energy use of the economy are expressed as a sum of shifts in – final demand and production technology (Equation 8 in Appendix 1). The changes in final demand are further sub-categorised into three categories namely – i) level effect (Q_t), ii) distribution effect (D_t), and iii) pattern effect (M_t) (Lin and Polenske, 1995) (Equations 12-15 in Appendix 1). The level effect represents the change due to changes in total demand or expenditure which measure the level of spending. The distribution effect captures the changes due to individual consumers or other components of final demand such as capital formation and exports. Changes in sectoral pattern of demand represent the shifts in consumer preference over time. These also include the changes in taste preferences or due to better availability of new products. Also, the impact of policy changes can lead to changes in consumer preferences and hence the commodity-mix. Such changes are integrated in the pattern effect. The change in production technology refers to the net effect of – changes in productivity as consequence of newer technology, lower cost of inputs and trainings; and different input structure encouraged by changes in price and availability. The impact of each of these changes is effective through the changing composition of material and input use, e.g. energy. Thus, technological change essentially refers to the change in material mix. Sector-wise technological change is further separated into changes from energy inputs (such as coal & lignite, etc.) and the non-energy inputs (i.e. other sectors of production) (Equation 19 in Appendix 1). Refer Appendix 1 for details.

3.1 Data

In the present work, inter-temporal changes in additional energy use are analysed using I-O transaction tables: 1993-94, 1998-99, 2003-04 and 2007-08.We base our analysis on the I-O structure in the economy primarily for the two benchmark years: 1993-94 and 2007-08. The effect of specific changes such as those in production technology, through research and development or skill development through trainings etc., may take few years to show up significantly. Therefore, it would be meaningful to study the change after a sufficient time gap in order to assess the impact.

The energy and energy intensive sectors are identified for the present analysis. As emphasised earlier, the present paper fills the gap by bringing in primary electricity sector comprising of hydro and nuclear generation as an explicit sector of analysis (Table 1). This further widens the scope of coverage of energy sector in the present paper.

The present paper defines energy intensity as the quantity of energy required to produce one unit output of a given sector. For the hybrid I-O analysis, energy quantity is measured in million tonne of oil equivalent (mtoe) by using availability of conversions factors from various energy forms. The conversion factors for coal; lignite; natural gas, and electricity are computed separately per unit of output as 0.41, 0.2865, 0.9 and 0.086, respectively.[4] Further, the proportion of non-thermal electricity such as hydro and nuclear electricity is estimated at 21.3 and 16.9% for the years 1993-94 and 2007-08, respectively.[5]

Table 1. Sectors of analysis

S.No	Sector name
1	Coal & lignite
2	Natural gas & crude petroleum
3	Non-thermal electricity[#]
4	Thermal electricity
5	Petroleum products
6	Coal tar products
7	Agriculture & allied
8	Mining
9	Food, beverages & tobacco
10	Paper, paper products & newsprint
11	Chemicals, rubber & plastics & products
12	Non-metallic mineral products
13	Basic metal & metal products
14	Non-ferrous basic metals
15	Machinery & equipment
16	Other manufacturing
17	Construction
18	Transport services
19	Other services

Sources: Based on Central Statistical Organisation (CSO), 2000 and 2012.
Includes hydro and nuclear power.

3.2 Deflation of the Input-Output Transaction Tables

The methodology for deflating the Input-Output Transaction Tables (IOTTs) at 1993-94 base year prices is based on Celasun (1984). This has two advantages. First, it allows for a double deflation through deflating the inputs and outputs using separate deflators. Second, the methodology is useful to convert the nominal technology coefficients directly into real technology coefficients. The conversion process is rather demanding in terms of data requirements as it makes use of separate price indices for gross output, exports and imports which is important to improve the precision of computations. The data are available from Office of the Economic Adviser, Department of Commerce & Industry, Department of Industrial Promotion, Reserve Bank of India (2009, 2013) and the National Account Statistics.

4. Results and discussion

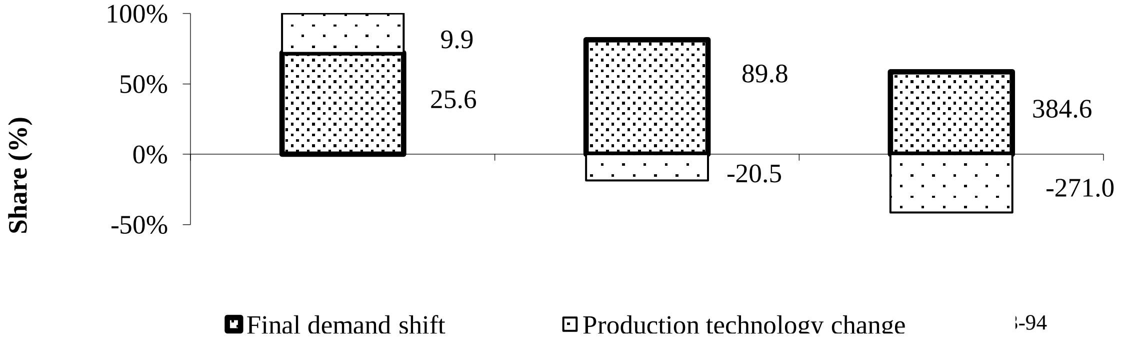
5.

The analysis considers three primary sectors of energy – coal & lignite, natural gas & crude petroleum and non-thermal electricity. The explicit consideration of non-thermal electricity as a primary energy source is a major contribution of the paper. Consequently, the aggregate results of the present analysis differ from the earlier results of Tandon and Ahmed (2016) due to downward revisions in energy use in the non-thermal electricity sector.[6]

Results for the overall economy show that the aggregate energy use increased by 35.5 mtoe during 1998-99 as compared to the value for the base year 1993-94 (Figure 1). More than two-thirds of the increase was on account of final demand shifts while the remaining was due to technological changes. Although final demand continued to drive the energy use during the extended period between 1993-94 and 2003-04, technological changes were helpful in moderating the total additional energy requirements to 69.4 mtoe.[7] The continued growth of energy use in final consumption of goods and services is not surprising in view of the price inelastic energy demand (Phomin and Kimura, 2014). The insensitivity of demand to energy prices is attributed to fuel subsidy and lack of alternate fuels for the transportation sector, particularly during the 90s. During the same period, energy induced technological changes became effective. Moving further in the reference period, between 1993-94 and 2007-08, the contribution of energy induced technological change in lowering the additional energy use is clear. Our results are in sync with findings of Gupta and Sengupta (2012) who observe energy saving technical changes in the overall manufacturing as well as energy intensive industries such as cement; pulp & paper, and aluminum. The adoption of energy saving technological improvements is attributed to the significant and negative effect of energy price on energy intensity in Indian manufacturing as also confirmed by Goldar (2010). Clearly, changes in the final demand are the key drivers of growing use, notwithstanding the contributions of technological improvements.

In view of the predominance of final demand shifts in increasing the energy use, a detailed scrutiny becomes necessary. The aggregate changes in final demand of energy goods are further decomposed into the changes due to – level of energy requirements for production activity (level); restructuring of the demand sources (distribution), and the consumption mix of goods and services (pattern). During the period from 1993-94 to 2007-08, primarily the level and distribution effects pushed the additional energy requirements for final demand upwards by 277.4 and 768.9 mtoe, respectively (Table 2).[8] Ceterus paribus, the joint effect resulted in additional energy requirement of 1046.3 mtoe.

Figure 1. Sources of change in energy use in India - relative significance of factors



Source: Author's computations based on CSO, 2000, 2005, 2008 and 2012.

Notes: 1. Values represent the change in energy use measured in million tonne of oil equivalent (mtoe).
2. The change in energy use is the additional energy required in comparison to the base year 1993-94.
3. Additional energy use is determined as the sum of final demand shift and production technology change (Equation 8 in Appendix 1).

4.1 Level effect of final demand

The level effect refers to the expansionary transition of the economy. The level effect contributed to increase energy use by 176.5% of the aggregate base year value (Table 2). Increase in the (level of) final demand (of a particular product) stimulated the producers to expand the output. However, in case of supply shortages within the domestic economy, imports were required to plug in the demand-supply gap. During the period, real demand increased by 175.1%. Increasing population created further demand in the economy through requirements for food; health & sanitation; education; housing; transportation, and services.[9] In addition, higher incomes from economic growth spurred commodity demand. For instance, India's per capita income increased from $309 during 1991 to $1582 during 2014 which facilitated diversification of the food basket. The per capita consumption of food items such as pulses; edible oils, and sugarcane increased between 1993-94 and 1999-00 while the consumption of rice; wheat, and other cereals increased between 1993-94 and 2004-05 (Mittal, 2012). The per capita public spending on health services also increased invariably across states (Hooda, 2013). Demand for houses increased due to a composite of reasons including rising population; fragmented families/ smaller household size which drives ownership of major appliances such as TV, refrigerator (Can et al., 2009); urbanisation (Dun & Bradstreet; Can et al. 2009); rising incomes and low interest rates.[10] Greater use of transport services resulted from urban movement, increased travel for trade and tourism, and employment.[11] Rising demand for consumer goods, particularly durables resulted in improved financial and banking services in the economy. In addition, output expansion also increased in response to increase outward orientation of the economy which encouraged exports.

4.2 Distribution effects of final demand

The distributional changes within final demand contributed to increase energy use by 768.9 mtoe. This means that in absence of technological improvements, the restructuring of final demand components required an additional energy use of 489.1%. The changes in energy use (or the additional energy use) are observed due to increasing private consumption; capital formation; exports and government consumption in that order.[12] It is important to acknowledge that the increase in final use for consumption and capital formation may also be sourced through imports in addition to supply from domestic production. The effect is known as output leakage and indicates that the expansion in domestic output is smaller when imports substitute for domestic shortages. Therefore, it becomes necessary to subtract the additional use of energy due to imports, which is already accounted within each of the final demand components viz. private and government consumption; capital formation, and exports. This is required to avoid any double counting of energy use.

The distribution of final demand into constituent categories highlights the continued importance of private consumption, albeit with a falling share which is jointly captured by capital formation and exports (Figure 2). The absolute increase in private expenditure, despite a relatively low share in total demand, required an additional energy of 262.6 mtoe (Table 2). Growth in private demand is attributed to rising incomes and young working population (Dun & Bradstreet). A greater proportion of the working population also reduced the dependency ratio which in turn reflected as higher purchasing power, stimulating further demand in the economy. Although investment accounted for more than a quarter of the final demand, its contribution in increasing energy demand has been dis-proportionately high. In fact, additional energy use of 241.6 mtoe due to greater investment activities is comparable to the contribution of private consumption which has a much high share of 45% in final demand. The improvement in business confidence and market oriented economy led to increasing private investments which were funded by households and foreign investment (Bisht and Singhal, 2011). The role of public investments declined over time, partly due to poor expenditure management. In fact, declining public share led to infrastructural deficits which have been major roadblocks for realizing faster growth. With regards to exports, an additional 182.6 mtoe were required. Much of the credit for increasing the share of exports in overall demand is attributed to service exports. Although India has maintained a comparative advantage in the traditional labour intensive exports, the segment is rather constrained with slow growth in international demand and protectionism (Chauvin and Lemonie, 2003). Government demand, which includes government expenditure of goods and services along with compensation to employees, maintained a stable share over time with an additional energy requirement of 38.4 mtoe. The growing imports of direct energy (e.g. crude petroleum) as well as energy intensive products (such as capital goods) contributed to increased use of energy in the economy. Imports of capital goods such as textile machinery and machine tools are attributed to India’s comparative disadvantage as a result of failure to provide increasingly sophisticated requirement of the domestic industry (Malik, 2012).

Table 2. Structural Decomposition Analysis, 2007-08 over 1993-94

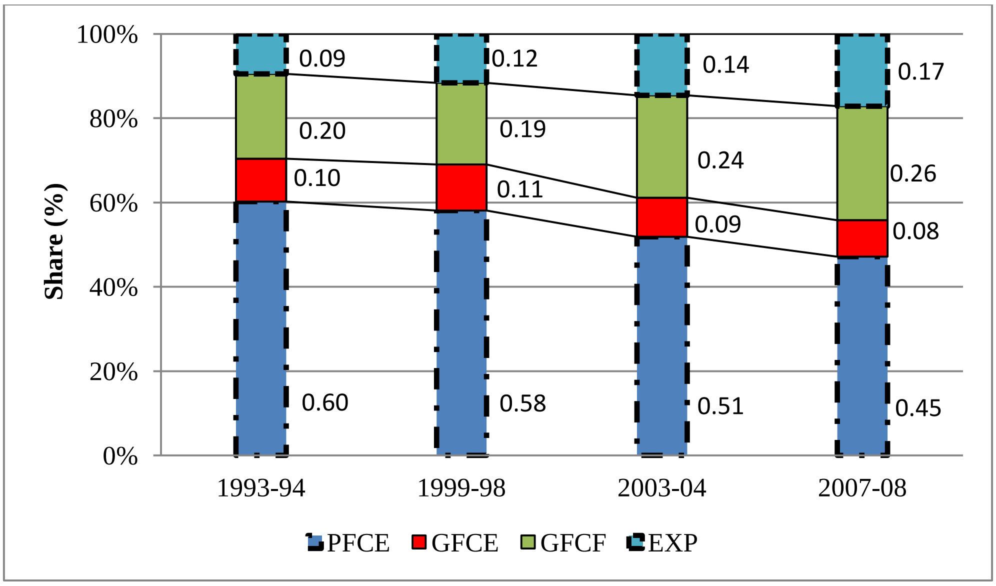
Decomposition factor	Energy use change (mtoe)				Energy use change (%)			
	Coal & lignite (1)	Natural gas & crude petroleum (2)	Non-thermal electricity (3)	Total primary energy (1)+(2)+(3)	Coal & lignite	Natural gas & crude petroleum	Non-thermal electricity	Total primary energy
Actual change (a+b)	89.3	19.0	5.3	113.6	83.4	43.7	80.7	72.3
Final demand shift (a)	189.4	182.2	13.0	384.6	176.8	418.7	199.2	244.7
1. Level effect	189.0	77.0	11.5	277.4	176.4	176.8	176.3	176.5
2. Distribution effect	144.7	620.8	3.4	768.9	135.1	1426.1	52.3	489.1
3. Pattern effect	-144.3	-515.5	-1.9	-661.7	-134.7	-1184.3	-29.5	-421.0
Final demand shift for demand source, h								
1. PFCE	93.6	162.6	6.4	262.6	87.4	373.5	98.8	167.1
2. GFCE	19.2	17.7	1.5	38.4	18.0	40.6	22.3	24.4
3. GFCF	142.8	92.2	6.6	241.6	133.3	211.9	101.7	153.7
4. CIS	35.1	51.6	1.4	88.1	32.7	118.6	21.4	56.0
5. EXP	58.3	120.9	3.4	182.6	54.4	277.8	52.8	116.2
6. IMP	159.6	262.8	6.4	428.8	148.9	603.8	97.8	272.8
Final demand shift for product group, k								
1. Coal & lignite	-40.4	-0.8	-0.1	-41.2	-37.7	-1.8	-1.1	-26.2
2. Natural gas & crude petroleum	-1.3	-162.1	-0.1	-163.5	-1.2	-372.4	-1.2	-104.0
3. Non-thermal electricity	1.2	0.4	1.2	2.8	1.1	1.0	18.5	1.8
4. Thermal electricity	14.4	6.2	0.4	21.0	13.5	14.1	5.9	13.3
5. Petroleum products	2.3	151.6	0.2	154.1	2.2	348.2	2.4	98.0
6. Coal tar products	1.7	0.9	0.0	2.6	1.6	2.1	0.1	1.7
7. Agriculture & allied	3.9	5.5	0.4	9.8	3.6	12.7	5.4	6.2
8. Mining	0.9	1.6	0.1	2.6	0.9	3.7	1.4	1.7
9. Food, beverages & tobacco	7.9	7.9	0.4	16.3	7.4	18.2	6.8	10.3
10. Paper, paper products & newsprint	2.9	0.9	0.1	4.0	2.7	2.1	1.4	2.5
11. Chemicals, rubber & plastics & products	11.2	13.0	0.6	24.8	10.4	29.8	9.3	15.8
12. Non-metallic mineral products	-0.8	-0.3	0.0	-1.1	-0.8	-0.6	-0.3	-0.7
13. Basic metal & metal products	23.0	7.3	0.5	30.8	21.5	16.7	8.3	19.6
14. Non-ferrous basic metals	-7.6	-3.6	-0.4	-11.5	-7.1	-8.2	-5.9	-7.3
15. Machinery & equipment	25.3	16.9	1.3	43.6	23.7	38.9	20.0	27.7
16. Other manufacturing	41.1	32.6	2.7	76.5	38.4	75.0	42.0	48.6
17. Construction	50.5	28.3	1.8	80.7	47.2	65.1	28.1	51.3
18. Transport services	20.4	48.4	1.6	70.4	19.0	111.1	24.5	44.8
19. Other services	32.6	27.3	2.2	62.2	30.5	62.8	33.5	39.5
20. Total (1-19)	189.4	182.2	13.0	384.6	176.8	418.7	199.2	244.7
Production technology change (b)	-100.1	-163.2	-7.7	-271.0	-93.4	-375.0	-118.5	-172.4
1. Energy inputs	-76.5	-186.7	-8.0	-271.2	-71.4	-428.8	-122.8	-172.5
2. Non-energy inputs	-23.6	23.4	0.3	0.1	-22.0	53.8	4.3	0.1

Notes: 1. Figures represent the additional energy in 2007-08 as compared with the energy use in the base year, 1993-94.

2. The aggregate change in energy use is the sum of changes due to final demand shifts (a) and change in production technology (b) (Equation 8 in Appendix 1).
3. The changes in final demand (a) are the sum of changes due the level, distribution and composition effect (Equation 12 in Appendix 1).
4. At the same time, the aggregate final demand shift (a) is also the sum of all components of final demand (Equation 13 in Appendix 1). However, it must be noted that requirements for final use are inclusive of the imports which are required to meet domestic shortages. Therefore, it becomes necessary to explicitly subtract (the effect due to) imports so as to rule out any double counting of energy use. Thus, total Final demand shift (a) = PFCE+ GFCE+ GFCF+ Exports- Imports. It may be clarified here that the structure of final demand is as provided in the CSO Input-Output data.
5. Also, change in aggregate final demand is expressed as the sum of change in final demand for each of the 19 sectors (Equation 15 in Appendix 1).
6. The decomposition formulation helps to cut-across final demand shift in three alternate ways, which separately add up to the same aggregate effect (a) without any overlap.

Source: Computations based on CSO (2000 and 2012).

Figure 2. Composition of final demand (normalised at 1993-94 prices)



Source: Same as Figure 1.

4.3 Pattern effect of final demand

The sector-wise final demand changes of embodied energy use highlight the compositional shifts among different sectors of the economy. The net change in commodity mix of final demand effectively saved (-)661.7 mtoe of primary energy use; highlighting the energy saving potential of consumer choice.

The two sectors namely, natural gas & crude petroleum and petroleum products have an outstanding contribution in defining the pattern of energy use. The negative sign for the natural gas & crude petroleum sector is due to the huge imports which are required to meet domestic shortages (Table 2). The petroleum product sector, as a main downstream user of crude petroleum, registered an increased energy use of 154.1 mtoe, almost equally distributed between domestic private consumption and exports. Although primary energy used in the form of fuel in transport sector is a relatively small proportion in comparison to residential energy and even smaller in total energy consumption, the ownership of motorized vehicles has increased rapidly (Can et al., 2009).[13] With regard to exports, India has become a leading producer and exporter of petroleum products. This is attributed to improvements in refining capacity and efficiency with private sector participation from private sector players such as Reliance, and also due to suitable geographical location in the Asian region as a supplier to neighboring countries. Other major contributors to increasing energy use include construction; other manufacturing; transport services, and other services with additional requirements of 80.7, 76.5, 70.4 and 62.2 mtoe, respectively. Energy changes in the construction sector have been due to heavy investment (capital formation) to improve infrastructural deficiencies in the country. For instance, Golden Quadrilateral was among the large-scale infrastructural projects undertaken by the government in 2002 (Bag and Gupta, 2010). At the same time investment, both private and foreign, in Indian manufacturing also encouraged new constructions. The increasing energy use in other manufacturing sector is a net effect of many counter-active forces. Energy use increased on account of private consumption and capital formation. Increased exports from the sector represent a stable comparative advantage in traditional exports of labour intensive textiles; leather, and gems & jwellery. Simultaneously, energy embodied in imports of other manufacturing is due to imports of transport equipment such as railway wagons; ships, and aircrafts. Increasing energy use due to transport services is rather intuitive form the rise in private spending due to increasing urbanisation and travel for jobs; government expenditure, and growing trade orientedness of the economy. The growth in energy use embodied in other services is due to increased consumption from changes in relative price and high income elasticity of demand (Guha, 2007). At the same time, exports play a key role due to the incremental demand from external sources in addition to greater use as intermediate input (Guha 2007; Gordon and Gupta 2003*)*.

Among the remaining sectors, machinery & equipment contributed to increased energy use from greater investment in industrial machinery which is often imported. Increasing use of coal & lignite was also sourced through imports. The increased energy use in the ferrous metal and products sector, a low-skill, technology, capital and scale intensive manufacturing, was due to increasing use in the new construction process while energy was also embodied in exports. The chemical, rubber & plastic sector is interesting due to high amounts of energy embodied in both exports and imports. This includes high-skill, technology, capital and scale intensive manufactures like organic and inorganic chemicals, pharmaceuticals and fertilisers (Chauvin and Lemonie, 2003). Greater consumption of processed food articles explains the increased in embodied energy of 16.3 mtoe in mechanisation of the food processing sector. Increasing energy use embodied in thermal electricity consumption is obvious due to increased appliance diffusion into private households as well as for lighting both in rural and urban households.[14] The non-ferrous metal sector has been dependent on imports. The changes in the remaining four sectors have been small in magnitude.

4.4 Changes in production technology

In the present context, innovation manifested in through a technological change is realised if the same amount of output is produced with a distinguished composition or level of energy inputs. The energy induced technological change can be effective through methods which directly employ energy or through the use of non-energy inputs which embody energy in their own production. The former is referred as the technological changes in direct energy inputs while the latter represents energy changes from indirect or embodied energy use in non-energy inputs. During the initial period from 1993-94 to 1998-99, the technological changes contributed to increase the additional energy use in the economy (Figure 1 and Table 3). Although with a relatively small magnitude, technological changes amounted to one-third of the increase from final demand. The increase was on account of indirect energy use as the technological changes with regard to direct energy use were energy augmenting (Table 3). During the period 1993-94 to 2003-04, technological change with regard to non-energy inputs continued to use more energy. However, technology for direct energy inputs improved significantly to offset the additional demand from indirect inputs of energy. Interestingly, the energy use embodied in non-energy inputs also improved during the longer period between 1993-94 to 2007-08 as observed from the nearly neutral effect of technological changes in non-energy inputs which embody energy use. This confirms the relatively slow and gradual response of non-energy inputs, as compared with the direct energy inputs, in the process of technological change.

The changes in production technology contributed to saving primary energy requirements between the period 1993-94 and 2007-08. Improvements in production technology helped in saving more than two-third (70.5%) of the additional requirements to meet growing final demand (Table 2). In other words, energy requirements for meeting the final demand requirements in 2007-08 have been 172.4% lower than if the 1993-94 technologies were used (Table 2). This in turn indicates overall energy savings from improvements in production technology. Improvements in production technology of the primary energy sectors helped in reducing primary energy requirements by (-)172.5% equivalent to 271.2 mtoe. This primarily refers to reduced use of primary energy inputs as the direct users of energy. At the same time, production technology in non-energy sectors helped to contain the energy use in embodied form without any significant increase.

Table 3. Changes in energy use due to production technology change (mtoe)

Period	Energy use due to technological change		
	Energy inputs (a)	Non-energy inputs (b)	Total (a+b)
1998-99 over 1993-94	-39.3	49.3	9.9
2003-04 over 1993-94	-94.9	74.4	-20.5
2007-08 over 1993-94	-271.2	0.1	-271.0

Source: Computations based on CSO (2000, 2005, 2008 and 2012).

The sector-wise technological changes show a mixed response of sectors in total, energy and non-energy changes (Table 4). These include technological changes related to direct energy use within the specific sectors, and also technological changes in the associated input providing and output consuming industries. Energy saving technological changes were noted for the following sectors: non-thermal; thermal electricity; mining; food, beverages & tobacco; paper, paper products & newsprint; chemicals, rubber & plastics & products; non-metallic mineral products; machinery & equipment; other manufacturing; transport services; other services, and petroleum products.[15] Among these, technological changes in thermal electricity and petroleum products contributed significantly to lower the additional energy demand. Invariably, direct energy issue was lower in each of the sectors.[16] The energy savings in thermal electricity have been the result of technological changes arising from use of different/newer input materials as result of the policy mandate to use washed coal which has low ash content. The use of low ash coal improved operational efficiency of the generation plant which required comparatively less energy to produce one unit of electricity. Energy savings in the petroleum product sector have been primarily on account of lower inputs of direct energy which essentially refers to crude petroleum as a major input due to the set up of private refineries with superior technology with some plants operating above 100% capacity. The reduced energy use in chemical industry has been essentially on account of savings from direct energy use due to shifts in feedstock from coal to natural gas in the production of ammonia and methanol. The lower energy use in both transport and non-transport services has been mainly from the savings in direct energy use, though indirect energy use also improved over time.[17] The direct energy savings are the result of efforts to reduce operational business costs from increasing energy costs. The transport sector diversified its fuel base to natural gas in an attempt to insulate form the fluctuating price of crude oil, and also towards the cleaner forms such as the CNG. Also, the Indian railways became less dependent on direct coal use due to increasing electrification. Within the non-transport services, electricity costs for lighting, ventilation and cooling have been lower due to use of energy efficient gadgets.

In addition, technological improvements related to non-energy inputs have also been observed for coal & lignite; non-thermal electricity; mining; machinery & equipment; other manufacturing; transport services, and other services. Among these, strongest effects have also been observed for basic metal & metal products; machinery & equipment, and other manufacturing sector.

The changes in production technology of sectors such as construction; basic metal & metal products, and non-ferrous basic metals necessitate a separate discussion due to the importance of these sectors in the economy and the nature of results. The technological changes are often used as proxy for efficiency improvements. For instance, lower energy use from technological changes can be inferred as improvement in energy efficiency.[18] However, this may not be appropriate in specific situations. For instance, SDA results show an increasing energy use in the construction sector, almost entirely on account of increasing energy use in embodied form. This does not necessarily point to the worsening energy efficiency of the sector. Instead, the Indian construction sector has followed a continuous path of development through technology upgradation by employing newer equipment and machinery. The construction technology has irreversibly mechanised with increasing use of backhoe loaders, excavators, soil compactors, pneumatic drilling machines (Built Constructions, 2016). Also, mechanical arms and cranes have been widely used. The use of *in-situ* (pre-cast) construction as an attempt to replace labour and expedite the construction duration has lead to increased use of heavy machinery, all of which embody energy use. Thus, increasing energy requirements of the construction sector are indicators of technology upgradation which replaced labour with capital machinery & equipment leading to higher energy requirement in their own production process. The other two sectors, namely, basic metal & metal products and non-ferrous basic metals primarily represent the iron & steel and aluminum industry. A higher energy use in direct form indicates the continued energy intensive commodity mix in the production process.

The technological changes essentially indicate the change in energy use per unit of output produced which further interacts with the final demand shifts to give the net change in energy use. The relative effectiveness of final demand and technology changes at sector level is shown in Figure 3. It is important to note that the negative contribution of final demand in changing the total energy use of the coal & lignite and natural gas & crude petroleum sectors is due to increased import dependency to plug in domestic supply shortages. In fact, final demand of both sectors expanded notably compared to technological changes. Electricity generation, both non-thermal and thermal, witnessed notable savings from technological changes to offset the increase from additional demand. The net change in energy use increased despite technological improvements in the following sectors: transport services; other services; petroleum products; other manufacturing; machinery & equipment; processed food, and mining sectors. The chemical sector is uniquely placed with savings from improved technology exceeding the additional use from demand expansion.[19] The three sectors namely, ferrous metal; non-ferrous metals, and construction are critically placed due to energy using technological changes alongside an increasing final demand shift and therefore need special policy attention. The former two sectors performed badly in terms of direct energy inputs, while the latter sector requires improvement in indirect energy inputs.

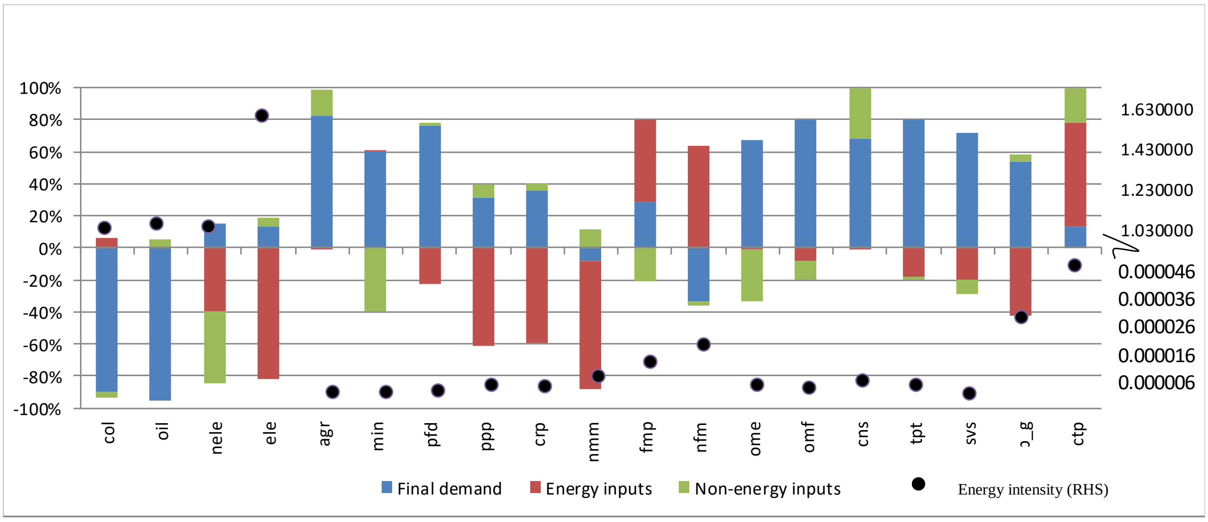
Table 4. Sector-wise technological changes, 2007-08 over 1993-04 (mtoe)

S.No.	Sector	Technological change		
		Energy inputs (a)	Non-energy inputs (b)	Total (a+b)
	Total	-271.2	0.1	-271
1	Coal & lignite	3	-1.8	1.2
2	Natural gas & crude petroleum	0	8.6	8.6
3	Non-thermal electricity	-7.3	-8.5	-15.8
4	Thermal electricity	-129.8	8.4	-121.4
5	Petroleum products	-119.1	10.6	-108.5
6	Coal tar products	12.4	4.2	16.6
7	Agriculture & allied	-0.1	1.9	1.8
8	Mining	0	-1.8	-1.8
9	Food, beverages & tobacco	-4.7	0.4	-4.4
10	Paper, paper products & newsprint	-7.6	1	-6.6
11	Chemicals, rubber & plastics & products	-40.8	2.7	-38.2
12	Non-metallic mineral products	-10.6	1.6	-9
13	Basic metal & metal products	53.8	-21.7	32.1
14	Non-ferrous basic metals	22.4	-1.1	21.3
15	Machinery & equipment	-0.8	-20.6	-21.4
16	Other manufacturing	-8	-11	-18.9
17	Construction	-0.6	36.6	36
18	Transport services	-15.9	-1.8	-17.8
19	Other services	-17.4	-7.4	-24.7

Source: Same as Table 2.

It is also important to view the changes against sector-wise energy intensity.[20] The net energy savings as a joint effect of final demand shifts and technological changes are noted in only four sectors namely thermal electricity; paper, paper products & newsprint; chemicals, rubber & plastics & products, and non-metallic mineral products. The savings from technological improvements are heartening particularly for non-metallic minerals, although with a much smaller magnitude, but appreciable given the high energy intensity of the sector. The remaining two sectors – paper, paper products & newsprint and chemicals, rubber & plastics & products also exhibit technological improvements. Technological improvements in thermal electricity are notable. The net energy use has increased in all remaining sectors of the economy. Particularly, the energy intensive non-energy sectors such as basic metal & metal products; other manufacturing; construction, and transport services have not performed up to the mark. The basic metal and transport services occupy a key position in the economy due to above average linkages with the supplying and using sectors (Ahmed and Tandon, 2014). The changes in energy use of the non-energy sectors have profound implications on energy requirement of the economy. Therefore, these sectors are sensitive to overall growth, implying greater energy use during their expansion to meet growing needs of the economy. Hence, it becomes necessary to target energy reduction in these sectors.

Figure 3. Sector-wise decomposition of energy use, 2007-08 over 1993-94 (% change)



Note: Energy intensity of the primary energy sectors is measured in mtoe per mtoe; for remaining sectors in mtoe per mr (million rupee).

Source: Same as Table 2.

5. Conclusions

The paper attempts to analyse the changes in energy use in the Indian economy between 1993-94 and 2007-08. Using hybrid I-O model for structural decomposition analysis to study the relative contributions of sector-wise technological change and final demand shifts, the paper shows the contribution of technological improvements in moderating growing energy use. To put in perspective, the key finding is encouraging specifically in view of the 12th SDG which emphasises to ensure sustainable production patterns (UN, 2015).

Results for the overall economy show that changes in the production technology have been energy saving while final demand shifts as a source of energy demand contributed to increasing energy use. Further decomposition of technological change highlights significant contributions from direct energy savings. Technological changes from indirect energy use, embodied in non-energy products used as inputs, show a rather neutral effect on additional energy use in the economy. A slow, gradual and rather insignificant response of non-energy inputs, as compared with energy inputs, in the process of technological change is also confirmed.

Comparison of the changes in energy use from final demand shifts and technological changes highlights the need to drive conservation attempts to lower energy demand. The saving potential of consumption patterns indicates that consumer preferences based on price and availability may be exploited to achieve energy conservation. Therefore, a market based price policy, taking into account the resource scarcity and environmental impacts, can be instrumental in changing the energy use through fuel shift or adoption of conservation measures which would be reflected in consumer preferences. While market corrections may hurt the poor in short run, the revenue savings can be used to finance compensatory cash transfers in a more targeted manner to the most affected poor. Alternately, carbon tax can be useful to influence consumption patterns. Given the relatively lower energy intensity of the basic requirement such as food and services, as compared with core manufacturing sectors which are relatively intense users of energy, the impact of cardon tax on overall consumption basket of the poor may be less intense. Or, at the least increasing energy use from final demand should be compensated with a corresponding technological improvement. Such sectors are clearly distinguished from the sector-level analysis in the paper.

In terms of relative contribution from technological change, specific sectors under the manufacturing category along with the construction sector are identified with relatively slow and gradual performance from the energy perspective. The results show that the construction and basic metal product sectors have the highest contribution to increasing additional energy use of the economy. Moreover, changes in technological progress and demand shifts, in these two sectors have been disheartening in comparison to other sectors. On the other hand, technological improvements in thermal electricity and petroleum product sectors are notable.

To sum up, two broad conclusions follow. First, technological changes in energy intensive sectors need to be accelerated. Second, the final demand shifts can be made effective either by price corrections or along with a parallel improvement in technological performance.

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Disclosure statement
The authors declare that there is no potential conflict of interest.

Notes

1. The terms sector;, commodity; process; industry, and production activity are used interchangeably.
2. Other contributions of the paper in terms of sectors of analysis and the use of price indices are highlighted in the Section 3 on Methodology and Data.
3. Refer Equations (1) to (4) in Appendix 1 of Ahmed and Tandon (2016) for the traditional I-O model.
4. Output of coal and lignite is measured in thousand tonne, natural gas is measured in million cu mtr and electricity is measured in billion kwh. Source: Energy Statistics (2011).
5. Ministry of Petroleum and Natural Gas (1993-94 and 2010-11).
6. The earlier analysis of Tandon and Ahmed (2016) is based on three energy forms – coal & lignite, natural gas & crude petroleum, and electricity. The electricity sector is the composite of primary and secondary electricity (essentially thermal) and the changes attributed to electricity have been proportionally attributed to different sources. In the present paper, separation of non-thermal electricity (from thermal electricity) as a primary energy source has resulted in the downward revision of the estimates.
7. Technological changes are fast in only some industries. Since technological change has a relatively gradual behavior, in comparison to consumer preference, we prefer to use an extended timeframe while keeping the reference year fixed at 1993-94. Also, the I-O analysis is useful for a long term analysis and therefore consecutive IOTTs are not necessarily helpful to study the impact of reforms. However, a long time horizon e.g 1993-94 to 2007-08 is helpful to study the cumulative effect of reforms.
8. For brevity, the discussion henceforth maintains a focus on the longer reference period in order to assess the cumulative effect over the longer term.
9. India's population increased at an average rate of 1.7% during 1991 to 2014 (World Bank).
10. The average household size decreased from 5.8 in 1990 to 5.3 in 2005 (Beekman and Kapas, 2006).
11. The share of urban population increased from 26% to 29% (Can et al., 2009).
12. There is an additional demand source in the form of changes in inventory and stocks. This is mostly used as a balancing entry in the IOTT but its effect in terms of energy use is insignificant. Therefore, it is omitted in further discussions.
13. The demand for fuel is equally distributed between passenger movement and freight transport.
14. For instance, TV ownership doubled from 13% of the rural households in 1993 to 26% in 2002, while the comparable numbers for urban households are 49 and 66%. The change is even more striking for refrigerators which recorded an increase in ownership from 12% to 28% in urban areas and 1% to 4% in rural areas (Can et al., 2009).
15. These results are aligned with the findings of Gupta and Sengupta (2012) for paper & pulp, cement (included in non-ferrous metal sector); iron & steel, and textiles sectors. Technological improvements

in the chemical industry are also noted by Ray and Reddy (2007) in the form of declining energy intensity. Similarly, technological improvements are manifested in the form of lower energy intensity of components of the aluminum industry such as aluminum extrusion and aluminum foil (Ray and Reddy, 2008).

16. Mining is the only exception with a rather neutral change in direct energy use.
17. Improvement in energy use refers to lower energy use as compared with the base year.
18. Improvement (worsening) in energy efficiency implies that the lesser (more) amount of energy is required to produce the same amount of output.
19. Although the case of non-thermal electricity is similar, the magnitude is insignificant in comparison to the chemical sector.
20. Energy intensity is measured as the amount of energy required for unit of output.
21. The Goal 12 is stated as follows: Ensure sustainable consumption and production patterns.

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Appendix 1. Input-Output model

The matrix notation of I-O model is as:

$$A * X + Y = X \quad \text{Eq (1)}$$

where **A** is the technical coefficient matrix, **X** is the column vector of sector-wise outputs and **Y** is the column vector of sector-wise final demand. The Leontief inverse (total requirement matrix), **L**, is defined as

$$L = (I - A)^{-1} \quad \text{Eq (2)}$$

For an *n* sector economy with *m (m<n)* energy sectors, we introduce a diagonal matrix, e (*m* X *n*) with binary values as 1 at column locations corresponding to energy sectors and 0 elsewhere (Lin and Polenske, 1995). The matrix e, is useful to extract *m* energy sector rows from the hybrid I-O. Multiplying both sides of the Equation (1) with the energy selective matrix (e), we get:

$$\underbrace{eAX}_{\text{intermediate energy use}} + \underbrace{eY}_{\text{final energy use}} = \underbrace{eX}_{\text{total energy output}} \quad \text{Eq (3)}$$

Thus we write the following:

$$\underbrace{E_g}_{\text{intermediate energy use}} + \underbrace{E_d}_{\text{final energy use}} = E \quad \text{Eq (4)}$$

Substituting Equation (3) and using Equations (1) and (2) in Equation (4), we get:

$$E_g = E - E_d = e\,(X - Y) = e[(I - A)^{-1} - I]Y = FY \quad \text{Eq (5)}$$

where $F = e[(I - A)^{-1} - I]$ is a function of the production technology of all inputs.

Substituting Equations (5) and (3) in Equation (4), we get:

$$E = FY + eY \quad \text{Eq (6)}$$

The Equation (6) expresses energy use at the time *t* as a function of production technology and final demand. Substituting and rearranging we can write changes in energy use between the time *t* and the base period (referred as 0) as follows:

$$\Delta E = \underbrace{(F_tY_t - F_0Y_0)}_{\text{changes in intermediate consumption}} + \underbrace{e(Y_t - Y_0)}_{\text{changes in final demand}} \quad \text{Eq (7)}$$

$$= \underbrace{F_0(Y_t - Y_0) + e(Y_t - Y_0)}_{\text{final demand shifts}} + \underbrace{(F_t - F_0)\,Y_t}_{\text{production technology change}} \quad \text{Eq (8)}$$

$$= \Delta E_Y + \Delta E_T. \quad \text{Eq (9)}$$

The final demand, Y_t is represented as product of the three components viz. i) level effect ($\mathbf{Q_t}$); ii) distribution effect ($\mathbf{D_t}$), and iii) pattern effect ($\mathbf{M_t}$), so that we have:

$$Y_t = M_tD_tQ_t \quad \text{Eq (10)}$$

Using this representation of $\mathbf{Y_t}$ in the first componenet on the RHS of Equation (8), we have

$$\Delta E_Y = F_0(M_tD_tQ_t - M_0D_0Q_0) + e(M_tD_tQ_t - M_0D_0Q_0) \quad \text{Eq (11)}$$

Upon transformations, Equation (11) is finally written as

$$\Delta E_Y = \underbrace{[F_0M_0D_0(Q_t - Q_0) + eM_0D_0(Q_t - Q_0)]}_{\text{level effect}} + \underbrace{[F_0M_0(D_t - D_0)Q_t + eM_0(D_t - D_0)Q_t]}_{\text{distribution effect}} + \underbrace{F_0(M_t - M_0)D_tQ_t + e(M_t - M_0)D_tQ_t}_{\text{pattern effect}} \quad \text{Eq (12)}$$

The additivity of final demand into its components in Equation (11) allows to express final demand shifts as sum of changes due to each of the components, *h* as follows

$$\Delta E_Y = \sum_h \Delta E_Y^h = \sum_h [F_0(Y_t^h - Y_0^h) + e(Y_t^h - Y_0^h)]. \quad \text{Eq (13)}$$

Thus, final demand shifts due to specific component *h*, can be written as

$$\Delta E_Y^h = F_0(Y_t^h - Y_0^h) + e(Y_t^h - Y_0^h). \ldots \ldots \text{Eq (14)}$$

Further, the final demand shifts due to a specific sector or product group, P can be expressed as

$$\Delta E_{Y,P} = F_0 P(\widehat{Y}_t - \widehat{Y}_0) + eP(\widehat{Y}_t - \widehat{Y}_0). \ldots \ldots \text{Eq (15)}$$

where P (*n* X *n*) is a matrix with values as 1 at the row locations corresponding to specific sector or product and 0 elsewhere, $\mathbf{\widehat{Y}_t}$ is the diagonal matrix of final demand at time *t*.

For the production technology changes as given in Equation (8) we have

$$\Delta E_T = (F_t - F_0)\, Y_t. \ldots \ldots \text{Eq (17)}$$

Upon transormation and simplification we have

$$\Delta E_T = eL_t(A_t - A_0)L_0Y_t. \ldots \ldots \text{Eq (18)}$$

$$\Delta E_T = \sum_{j=1}^{n} E_T^j = \sum_{k=1}^{m} eL_t(A_{t,E}^k - A_{0,E}^k)L_0Y_t + \sum_{j=m+1}^{n} eL_t(A_{t,NE}^j - A_{0,NE}^j)L_0Y_t \ldots \ldots \text{Eq (19)}$$

where the hypothetical matrices $\mathbf{A_{t,E}}$ and $\mathbf{A_{t,NE}}$ facilitate the separation of the flow matrix into two exclusive and complementary technology coefficients of energy and non-energy sectors, respectively.

Technology changes for a given sector j are given as:

$$\Delta E_T^j = \underbrace{eL_t(A_{t,E}^j - A_{0,E}^j)L_0Y_t}_{\text{changes in production technology of energy inputs}} + \underbrace{eL_t(A_{t,NE}^j - A_{0,NE}^j)L_0Y_t}_{\text{changes in production technology of non-energy inputs}} \ldots \ldots \text{Eq (20)}$$