A Total Social Factor Productivity Index for the UK Food Chain Post-Farm Gate

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Abstract: *The UK post-farm gate food chain comprises manufacturing, wholesaling, retailing and catering. Current turnover is around £250 billion per annum. Total factor productivity measures the ratio of inputs to outputs. However, most studies have only included the marketable inputs and outputs within the system.*

Following criticisms of the negative effects of the food chain this paper adopts an index based approach to measuring Total Social Factor Productivity, which includes the major externalities within the food chain. Generally, whilst TFP growth rates low over the period 1998-2002, these have reduced even further when negative externalities are included.

Introduction

Total Factor Productivity (TFP) is the ratio of all factor inputs to outputs. Lynman and Herdt (1995) have argued that Total Factor Productivity (TFP) is an appropriate measure of sustainable development, because a non-negative trend in TFP growth implies that outputs are growing at least as fast as inputs. Within the whole schema of sustainability it could be argued that positive TFP growth allows economic and social benefits as well as an indication of greater efficiency of resource use, which ultimately improves environmental quality. However, this is a somewhat charitable view of the ability of a TFP index to pick up the full consequences of sustainable growth within a relatively simple measure. Sustainable growth comprises a set of complex interactions typified through the physical, natural and social sciences. As a result the relationships between these aspects of sustainability cannot be adequately modelled through a solely market-based measurement instrument.

From the late 1980's onwards a change in policy making and a general awareness of the external effects of production have led to a strand of productivity analysis concerned with adjusting Total Factor Productivity (TFP) for externalities. This concept, usually referred to as Total Social Factor Productivity (TSFP), has proved popular when examining agriculture, but no studies exist which apply these techniques to the industries up and downstream from agricultural production.

From a policy making point of view, the environmental and social costs of growth have only become a concern relatively recently. Environmental damage has led to a very real degradation in the quality of life in both rural and urban areas. In essence, awareness has been growing regarding the levels of nitrate within water supplies, the effects of ammonia on the quality of air and the overall effects on human health of chemical application to food products. For the consumer generally, the issue of food miles and congestion seems to be of major importance (AEA technology, 2005). There is, therefore, a growing concern that the full costs have not been accounted for by traditional approaches to measuring growth. Accordingly, this paper presents both a TFP and a TSFP index for the food chain, post farm gate. This consists of four major sectors, namely food manufacturing and processing, wholesaling, retailing and catering. This paper is structured as follows, namely i) outlining the conceptual background to TSFP measurement, ii) methodological approach and data collection, iii) results, and iv) conclusions.

Conceptual Background

A number of studies exist which are concerned with the development of a performance measure which accounts for the creation of undesirables within a production economics framework. The majority seem to have focused on agricultural production (Ball *et. al*., 1994; Oskam, 1991; Barnes, 2002) as both a growing policy need for multi-functionality within farming has been coupled with a belief that primary food production has strong environmental and social impacts.

Essentially, adjusting productivity measures relies on the concept of joint outputs. Production of desirables is usually coupled with production of undesirables. Externalities such as air pollution, waste and noise are a consequence of production within the food chain. The implication is that it is impossible to reduce undesirables to zero and still produce desirables, i.e. some cost will always be incurred when producing marketable goods. A way to overcome this problem is to reduce desirable output, hence undesirables would also decrease. However, from a producer point of view this is not an acceptable condition. Hence economists have sought formulations in which producers seek a minimal decrease in desirable outputs at the cost of a minimal increase in undesirable outputs.

Two main approaches have been developed for adjusting productivity measures. The first is based on estimating the technical efficiencies of individual firms. This requires extensive firm level data both on desirable and undesirable output and input quantities. These are not usually available in the UK due to the prohibitive cost of data gathering. However, some work has been conducted in Canada (Hailu and Veeman, 2000) and the US (Ball *et. al.* 1994) using these techniques.

The second approach is to use index numbers. Essentially, aggregate productivity indexes can be adjusted for the non-market costs of production. This approach has advantages as most data are available at an aggregate level. The major disadvantage is that it requires both quantity and price data over time. However, if collected, the index number approach can provide macro-level indications of resource use, consistent with other national or industry level indicators. For this reason, this paper adopts the index number approach.

Pittman (1983) was the first to adjust indexing techniques on Wisconsin paper mills. He collected quantities of pollutants directly attributable to paper mill outputs and then estimated shadow prices of specific elements of water and air pollution. Several indexes were then

constructed to compare solely desirable outputs with components of undesirable outputs to test the differences in growth rates. Other authors have followed this lead with the bulk focusing solely on agricultural productivity adjustment (Archibald, 1988; Oskam, 1991; Repetto *et al.,* 1996; Shaik and Perrin, 2001). Only Barnes (2002) has applied these techniques to UK agriculture. Using quantities of N and P recorded by the ONS and prices for organic aid schemes, deflated over the period of study, a Total Social Factor Productivity Index was constructed.

The main issue for these authors was not the collection of quantities, which in some countries are considerably detailed, but in the collection of appropriate price estimates to reflect damage. Pittman (1983) was the first to propose replacing the output revenue shares of an index to non-positive shadow prices. These shadow prices were estimated using optimisation techniques after data were gathered from several surveys. Oskam (1991) estimated prices for a number of agro-chemicals which were either based on unit costs of measures taken in the future, or, the marginal costs of environmental measures taken in other parts of the economy. Barnes (2002) uses prices directly from agricultural pollution abatement schemes, specifically payments made to farmers to reduce applications of either fertilisers or pesticides under the nitrate sensitive area and organic aid scheme. These prices, he argued, reflect the value present society places on past damages. Hence these prices could be used to directly weight the undesirable outputs within an index. However, the ideal prices could be derived from willingness to pay studies on environmental valuation to fully reflect the marginal effect of these environmental costs to the public. Some of these are available for the food chain. Consequently, the remainder of this section focuses on the methodology adopted for constructing a TSFP measure and the results of this procedure.

Methodology

An index is a form of aggregation of series that reflects the underlying production technology inherent within the observed industry. A number of indexing procedures are available, the

most prominent in the literature of productivity measurement are the Tornqvist-Theil and the Fisher Index. These two have proved the most popular, principally because they are flexible functional forms and make no prior assumptions over the relationship between inputs and outputs. For this research the Fisher index was chosen as, from an axiomatic point of view, the Fisher index passes a number of statistical tests and therefore offers something that is more robust statistically than the Tornqvist-Theil index (Diewart, 1976). In addition, chain weighting was adopted to obviate the substitution bias that emerges when fixing indexes to any one year.

Formally the Fisher index for desirable outputs (y_g) can be stated as:-

$$y_g = \sqrt{\left(\sum_{i=1}^{M} W_0 \frac{y_{it}}{y_0}\right) \times \left(\sum_{i=1}^{M} W_t \frac{y_{it}}{y_0}\right)}$$

This is simply an index which concentrates on wholly marketable outputs. Essentially, the Laspeyres and Paasche indexes are constructed as the sum of weights, i = 1…M, multiplied by each '*i*-ith' output quantity change in period t compared to the base period. A similar formulation exists for undesirable outputs (y_b):-

$$y_b = \sqrt{\left(\sum_{i=M+1}^{Q} W_0 \frac{b_{it}}{b_{i0}}\right) \times \left(\sum_{i=M+1}^{Q} W_t \frac{b_{it}}{b_{i0}}\right)}$$

The indexes are constructed as the sum of the weights i = M+1,…,Q which are the negative revenue shares from the undesirable externality. These are multiplied by the changes in quantities of each externality over a base time period.

The Fisher input index remains the same for the desirable and undesirable TFP indexes, as externalities here are considered as outputs. Accordingly, this can be restated as:-

$$x = \sqrt{\left(\sum_{k=1}^{P} Z_0 \frac{x_{kt}}{x_0}\right) \times \left(\sum_{k=1}^{P} Z_t \frac{x_{kt}}{x_0}\right)}$$

where the weights (Z) are the *k-ith* cost share of each input multiplied by the quantity change of that input relative to the base period.

Accordingly, two TFP indexes can be constructed by dividing each output index by the same input index. A desirable index (TFPg) and an undesirable index (TFPb) which can be stated formally as:-

$$TFP^g = y_g / x$$

$$TFP^b = y_b / x$$

Finally, these two TFP indexes need to be aggregated to create a TSFP index. Following Carlson *et al*. (1993) generalised revenue shares can be expressed as :-

$$\text{Revenue Shares} = \frac{P_i Y_i}{\sum_{i=1}^{Q} P_i Y_i}$$

Where desirable outputs, i= 1..M, can be expressed as:-

$$W^g = \sum_{i=1}^{M} W_g$$

Undesirable outputs, i = M+1…Q can be expressed as:-

$$W^b = \sum_{i=M+1}^{Q} W_b$$

Where $W^g > 0$, as it is a desirable output and adds to the growth of the industry, and $W^b < 0$, if it is an undesirable output. This directional measure aims to capture the problem of joint output. These weights ($W^g + W^b$) sum to 1, therefore the adjusted measure (TSFP) can be expressed as:-

$$\text{Total Social Factor Productivity} = W^g (TFP^g) + W^b(TFP^b)$$

Data Sources

Table 1 shows the details and sources of the data used. The main data source for market inputs and outputs was the Annual Business Inquiry (ABI), which provides data from 1998 of Standard Industrial Classification[1]. This was complemented by the ONS Capital Stock Series and the Annual Survey of Hours Worked, also collected by the ONS, to measure to total hours worked for full-time and part-time workers for each industry sector. It therefore provides a data set at sufficient detail to examine the four sectors downstream from farming.

Table 1. Data Sources Used within Analysis

	Price Series	Quantity Series	Source
Desirable Outputs			
Turnover	£	£(2000)	ABI
Undesirable Outputs			
Energy Emissions	£	'000 tonnes	ONS
Transport Emissions	£	'000 tonnes	AEA Technology
Social costs of transport (noise, congestion, accidents, infrastructure)	£	Per kilometre	AEA Technology
Food borne illness	£	Person	Public Health agencies
Accidents and mortality	£	Person	Health and Safety Executive
Inputs			
Labour	£	Annual Hours Worked	ABI
Capital	£	Perpetual Inventory Method*	ABI
Intermediate Purchases	£	£/£ (2000)	ABI

See OECD (2001) for further details.

Undesirable outputs were gathered from several data sources. The Office of National Statistics publishes a range of on environmental impacts and resource use by industry. A number of other data sources have also been used specifically for transport externalities (AEA Technology, 2005); food borne illnesses (UK public health agencies) and accidents and mortality (Health and Safety Executive). However, caveats and omissions should be noted. Much of the data on energy use and emissions is collected at a lower resolution than the food chain. Whilst data for food and drink manufacturing is sector specific, data for wholesaling, retail and catering does not distinguish between food and non-food chain businesses. Furthermore, there are important gaps in the data, specifically on waste generation and water consumption.

[1] http://www.statistics.gov.uk/abi/quality_measures.asp

In order to produce a constant price series some deflation needs to occur, appropriate price deflators were adopted for the four sectors from the ONS and then aggregated. For externalities, deflation is not required as quantities exist for each external effects.

TFP Index

The ratio of desirable outputs to inputs gives the total factor productivity series for the food chain downstream from farming. Figure 1 shows this as an index of growth from 1998 onwards. High input growth throughout the series has forced the TFP rate downwards. However, these fluctuations only vary by around 2 points below the baseline.

Figure 1. UK Food Chain TFP Index, weighted by turnover (1998=100)

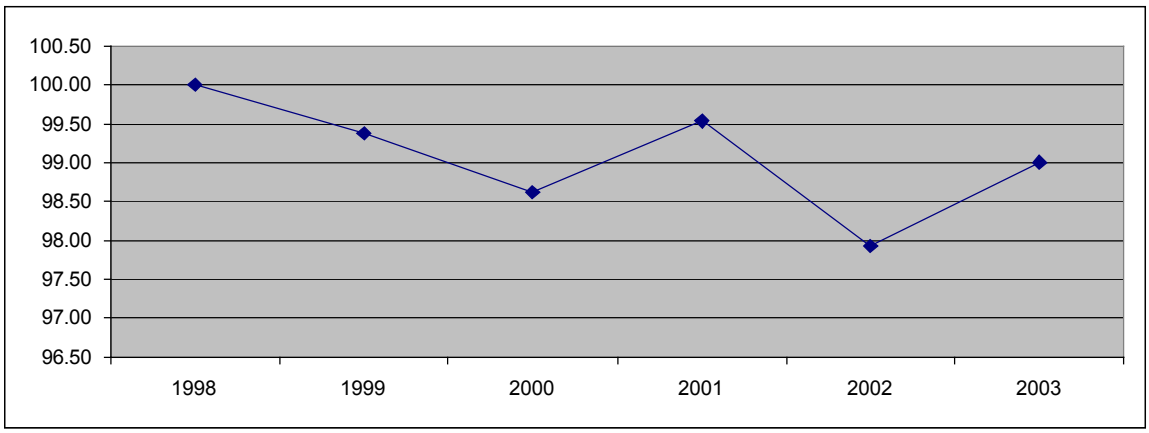


Table 2 shows the annual average growth rates of the productivity indexes presented above. It shows an average rate of growth of -0.52% which reflects the negative rates embodied in the three sectors; wholesale, retail and non-residential catering.

Table 2 . TFP Growth Rates for the Food Chain, percent

	Tov/Lab	Tov/Cap	Tov/Purch	Inputs	Output	TFP
1998	100.00	100.00	100.00	100.00	100.00	100.00
1999	101.74	102.96	98.74	102.63	101.98	99.38
2000	101.29	105.28	97.65	106.25	104.73	98.62
2001	100.78	103.20	98.80	104.01	103.43	99.54
2002	101.70	104.66	96.34	109.02	106.56	97.93
Average	0.43%	1.16%	-0.92%	2.22%	1.62%	-0.52%

Labour productivity shows strong growth over the period of 0.4% per annum. The highest growth rate has been in capital stock which shows an average increase of 1.16% per annum. However, this is negated by strong falls in the purchases productivity series of –0.9%. This has led to higher growth rates in inputs compared to output growth. Thus TFP has fallen by 0.52% per annum on average over this period.

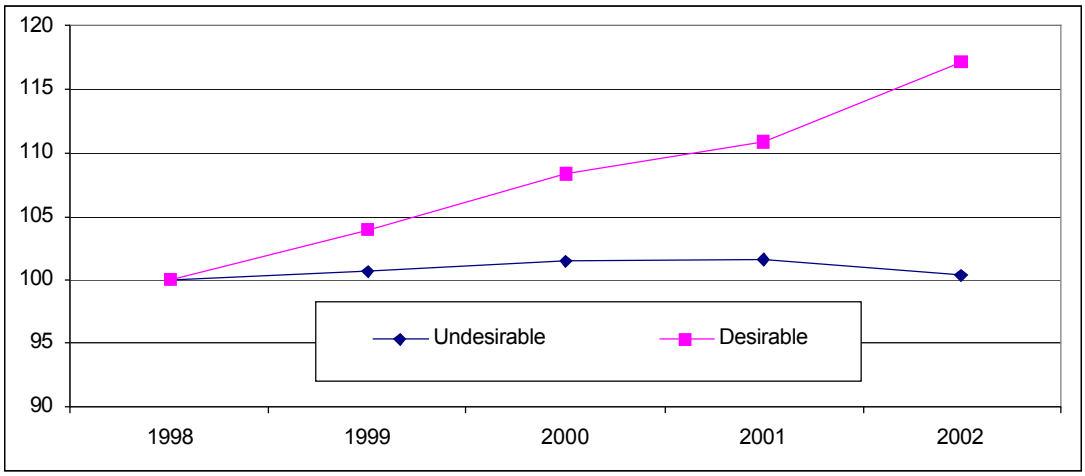
A small number of studies have sought to measure productivity within specific sectors of the food chain away from agriculture, however these are of minimal use to this study as they relate to previous periods and economic climates and also only focus on specific sectors within different countries. In fact the only UK study previous to this is by Macdonald, Rayner and Bates (MRB) (1992) who used input-output analysis to asses the productivity of agriculture and food manufacturing. Whilst vague on specific rates of growth it did find that food manufacturing was lower than other UK manufacturing.

The bulk of research work seems to have occurred in the US and focuses on the food manufacturing or processing industry. Jorgenson and Stiroh (2000) found that food processing grew by 0.6% between 1958 and 1991. Gopinath, Roe and Shane (1996) calculated this sector had a growth rate of 0.41% over the period 1959 to 1991. Huang (2002) reported that food manufacturing grew by 0.32% between 1975 to 1997, but a number of sub-periods showed negative growth. Finally, Hazeldine (1991) examined food processing in Canada and found that, dependant on assumptions, growth rates varied from 0% to 0.5%.

Total Social Factor Productivity

The undesirable and the desirable outputs are presented as chained Fisher indexes below.

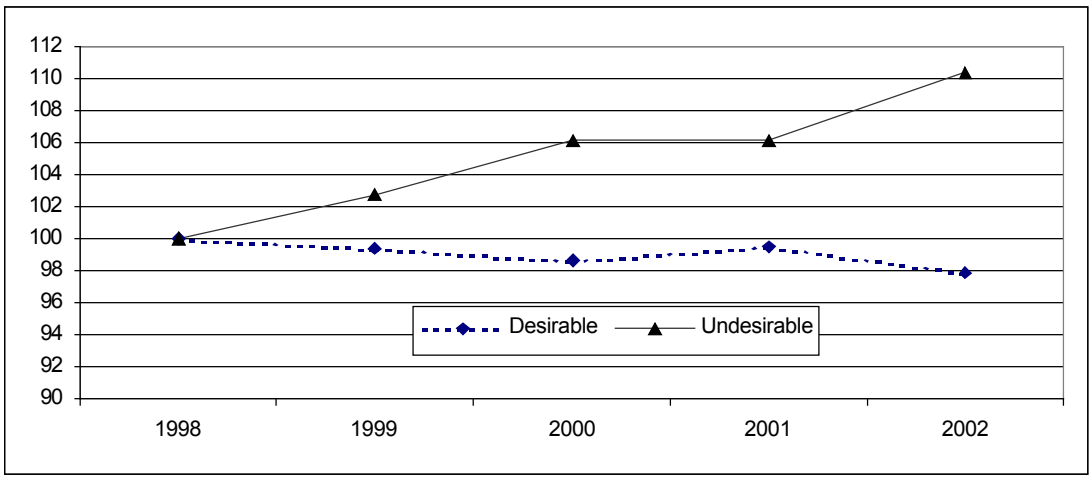
Figure 2 . Undesirable and Desirable Output Indexes (1998=100)



Considerable growth can be seen in desirable outputs, in this case turnover, which grew rapidly for the food chain over this period. Undesirable outputs tended to rise also, but then fell to 1998 levels at the end of the period.

However, this does not give an indication of resource usage, as inputs need to be equated into these trends. The two Fisher indexes of desirable and undesirable TFP are shown in Figure 3 below.

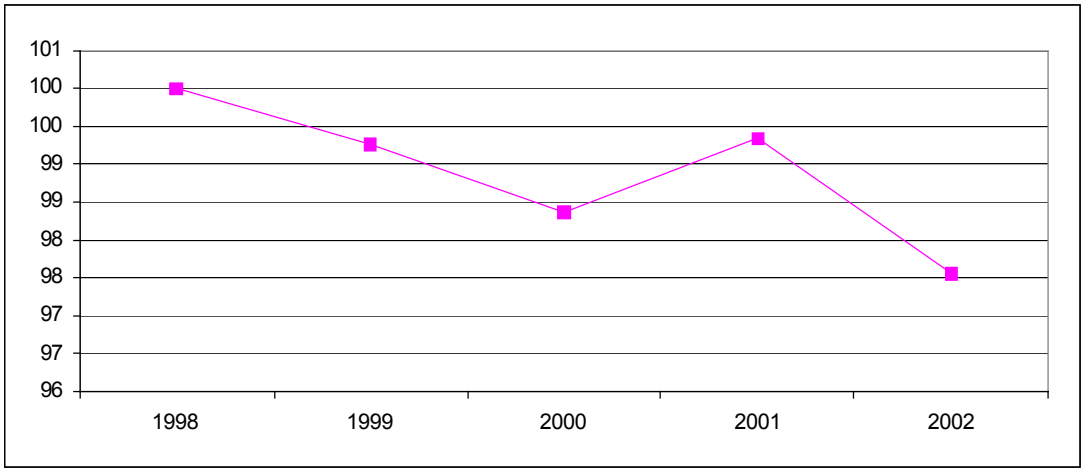
Figure 3. TFP Indexes for Desirable and Undesirables (1998=100)



Whereas the growth rate of the desirable productivity is -0.52% per annum, undesirable productivity grew by 2.5% per annum. Both results prove problematic for the food chain. Firstly, growing inefficiency is occurring when converting inputs into desirable outputs. However, the food chain is becoming more 'efficient' at producing undesirables. Consequently, whenever there is a growth in bad output, this is exacerbated by the increased efficiency of conversion.

The desirable index can now be adjusted to include the undesirables, adopting the methodology outlined above. However, imposing the adjusted TFP shows the reliance on share weights within the food sector. In total £247 billion is produced in desirable benefit, i.e. turnover, whereas only around £8 billion is incurred as a negative revenue share. Consequently, its influence on food chain TFP as a whole is minimal. The adjusted series, whilst slightly downward, strongly mimics the desirable TFP index.

Figure 4. TSFP Index for the Food Chain (1998=100)



Nevertheless growth rates are reduced from –0.52% per annum to –0.62% per annum when including undesirables. This is predominately due to the rises in the social costs of car usage, which has the largest negative revenue share of all externalities.

Conclusions

A number of policy-makers and researchers have criticised the conventional TFP index's ability to capture the full effects of sustainability. Total Social Factor Productivity (TSFP) can be adopted as an alternative which expands a single measure to capture non-market effects of production. From the mid-1980s onwards academics have concentrated on developing approaches to include undesirable outputs within the measurement of productivity. Two issues need to be addressed when constructing a TSFP index. Firstly, there are methodological issues with modelling joint outputs. Ideally a producer would aim to maximise good output and minimise bad outputs. A second problem relates to the availability of data for measurement. Quantity and price data have to be available for inclusion into the series. Since the late 1990s there has been an increase in the collection of quantity data on major externalities. A number of studies have also attempted to estimate prices on these quantity data.

Nevertheless, for both indexes the growth rates are negative. There may be a number of reasons for this, namely:-

Measurement Errors, most data sets contain errors, through measurement and response bias. As these data sets are collected for a wide range of analysis, production economists have to admit that some of this 'residual effect' which is interpreted as TFP growth may be due to this error. *Intermediate Purchases*, the major cause of downward growth rates is lack of efficiency in purchasing intermediates. These intermediates are outwith the control of the firm hence some volatility may occur in the production process. Some of these inefficiencies are caused by purchasing perishable products, which could also be affected by blockages in the supply chain for raw materials.

*Low Agricultural TFP Growth, c*ompared to agricultural productivity growth rates, the food chain estimates of TFP are disappointing. Improving efficiencies in the agricultural production sector will have positive effects on the remaining food sectors downstream from farming. Thirtle *et al.* (2004) report a decline in agricultural TFP during the 1990s. Their series ends as our begins so it is difficult to fully compare growth rates. Nevertheless, it would seem from their evidence that the trend in agricultural TFP is downward. This trend has been further evidenced with this research where rates reach negative levels. Accordingly, low agricultural growth may have had knock-on effects on downstream food-chain productivity.

Low R&D Investment

An argument proposed by Thirtle *et al*. (2004) is that low agricultural TFP is a result of reductions in R&D spending during the late 1980s and 1990s. Similarly an emphasis on near-market (applied) research at the expense of more fundamental long-term basic research funding may have pushed this TFP rate downward. Compared to agriculture, few analyses of food sector R&D have been made. However, the DTI (2005) present a scoreboard of R&D

intensities, measured in terms of R&D expenditure as a percentage of sales. The only sector which appears in the top 700 companies are food producers and processors as the 11th most intensive sector. Other sectors within the food chain do not appear. Consequently, this may be some indication towards the cause of TFP decline within the remaining sectors.

Non-Tangible Benefits

Whereas the marketable outputs of the food chain have been measured within TFP a number of non-tangible effects occur, which may impinge on TFP performance but have not been quantitatively measured. These benefits may include longer opening hours for retailers or increased diversification of activities. Whilst this may dampen productivity growth it does improve the quality of life of consumers. Similarly, reductions in working hours or deliveries of materials at specific times of the day may also improve quality of life but also reduce TFP growth rates. Thus, whilst data for a number of externalities can be collected, it is problematic that no data for positive externalities can be used. If it were possible to value and quantify these effects then the regressive effects on TSFP growth may be dampened.

Whilst available statistics have been consulted there are gaps in the data sources. Most prevalently in terms of finding an effective time series for waste and water usage. Similarly, the lack of any positive externality data has also proved a hindrance in compiling a full Total Social Factor Productivity index. The exclusion of positive externalities may lead to criticism of a downward trend. However, the non-inclusion of waste and water usage which, according to AEA technology (2005), may be substantial, would also have significant depressive effects on TFP growth.

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