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Measuring the Sustainability of the UK Food Chain

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Abstract: *Recent policy interest has been directed at the sustainability of food industries, in particular the post-farm gate food chain. This comprises of manufacturing, wholesaling, retailing and catering. In order to measure sustainability Byerlee and Murgai (2001) have argued that productivity measures, alongside key indicators of resource quality trends, should be used to indicate sustainable growth. This paper adopts this approach by presenting Fisher indexes of both Total Factor Productivity (TFP) index and for prominent externalities emerging from the food chain over the period 1998 to 2002.*

TFP shows an average annual growth rate of –0.52% per annum. Input growth, in particular intermediate purchases, has outstripped output growth over the entirety of this period. In addition, major externalities of environmental and social costs have increased over this period. Consequently, both sets of indicators give a somewhat bleak assessment of the sustainability of the UK food chain.

Keywords: Total Factor Productivity; Externalities; Sustainable Growth

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Measuring the Sustainability of the UK Food Chain

1.0 Introduction

The UK food chain has raised a number of concerns from consumers and policy makers. Environmental damage from the production and distribution of food products 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).

Sustainable growth is a key policy concern for this industry. The Sustainable Food and Farming Strategy (SFFS), which was published by Defra in 2002, aimed to bring a 'reconnection' of the food chain with customers, the world economy and the environment. It's central pillars were economic, social and environmental growth. This development would be measured by improvements in indicators of sustainable development. Food chain productivity is one of the 11 headline indicators within the SFFS. In addition, Defra's proposed Food Industry Sustainability Strategy (FISS), which is directed at the four sectors of food manufacturing, wholesaling, retailing and catering, aims to encourage the adoption of best practice to help achieve sustainable development.

Lynam and Herdt (1989) have argued that Total Factor Productivity (TFP), the ratio of most inputs to outputs, is an appropriate means of measuring 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 may be a somewhat charitable view of the ability of a TFP index to pick up the full consequences of sustainable growth within a single 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. Byerlee and Murgai (2001) argue that productivity is a starting point for measuring sustainability, but has to be interpreted in relation to resource quality trends. These trends, identified as changes to the amount of externalities produced by the food industries, could be outlined in Table 1 below.

Table 1: Externalities by Sector: Post farm-gate Food Chain (incl. Sources)

Consequently, this paper focuses on this approach to present both a TFP index for these food industries, alongside indexes of environmental and social impacts, to give a clearer picture of sustainability. The next section presents the methodology adopted for constructing the indexes and data collection issues.

2.0. Methodology

This section outlines the methodology adopted for measuring Total Factor Productivity within the food industries. Ultimately, discussion of TFP construction focuses on a number of important factors which need to be addressed, these are i) choice of indexing procedure, ii) collection of appropriate data, and iii) treatment of capital and labour inputs. These are discussed in detail below.

*Choice of Indexing Procedu*re

As a TFP index is a measure of growth the choice of index is important, as it will affect growth rates if the wrong procedure is chosen. Ultimately, an indexing procedure mimics the underlying production, cost or profit function formed by a firm's behaviour. A number of indexing procedures exist which aim to mimic the function of how inputs are converted to outputs. When the underlying production function is non-linear, more complex indexing techniques can be applied, namely the Fisher index and the Tornqvist-Theil index. The Fisher index is appropriate for a quadratic functional form and is the geometric mean of the Laspeyres and Paasche quantity indexes The Tornqvist-Theil index is appropriate for a translog function and relies on a system of both factor shares and on smoothing a previous year's prices and quantities, rather than relying on a base period. Both have proved the most popular within productivity analysis, 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, primarily for two main reasons. Firstly, 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 (Diewert, 1976). Secondly, whilst the Tornqvist-Theil has been used in several productivity studies the Fisher index is the most popular amongst policy-makers and central statistical agencies and, it could be argued, is broader in scope than solely economic orientations offered by the Tornqvist-Theil. For this study, which constructs indexes of environmental and social indicators, the Fisher index seems to offer a better approach. Formally, the Fisher output index can be stated as:-

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

Essentially, 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 is adopted for inputs. In addition, chaining was adopted to avoid 'substitution bias'. This is because fixing measurements of growth against a particular year will increasingly bias the index away from actual labour and capital substitution as the index moves away from the base year. Chaining obviates this problem by comparing a year's performance against the previous year.

The food supply chain consists of a number of integrated sectors. Thus, most outputs from one sector will become inputs to the next sector downstream. Consequently, some account needs to be made of the contribution of productivity gains in one sector which would also benefit the sectors downstream. Accordingly, not only would total food sector productivity aggregate the four separate indexes produced, but would also 'integrate' the growth in productivity of each sector. Most studies adopt 'Domar' weights which aims to incorporate these integrative effects. Oulton (2004) specified that the aggregate TFP index should be the weighted average in TFP growth rates where the weights are each sector's shares in final output. This is the form of Domar aggregation adopted here.

Data Sources

Table 2 shows the definition of the post-farm gate food chain by UK standard industrial classification.

Table 2. Composition of the Food Chain by Standard Industrial Classification

The main data source for inputs and outputs was the Annual Business Inquiry (*ABI*), which provides data from 1998 onwards of Standard Industrial Classifications[2]. The ABI collects data on 13 variables, including turnover, gross value added, and major inputs such as labour employed and cost, capital expenditure and purchases of materials. Data are collected through the ONS to provide a representative sample of UK businesses and offers a robust data set. Applications of ABI data include production of annual employment estimates, calculation of gross value added for the measurement of GDP, productivity estimates, input-output tables and other national accounts applications. However, given the survey nature of data collection there are both non-response errors and sampling errors. These are discussed in some depth within the quality control section of the ABI website[3].

This was complemented by the ONS Capital Stock Series (*CS*) and the Annual Survey of Hours and Earnings (*ASHE*), also collected by the ONS, to measure total hours worked for full-time and part-time workers for each industry sector. Deflation occurred from specific ONS time series. It therefore provides a data set at sufficient detail to examine the four sectors downstream from farming.

Table 3. Data Sources Used

Treatment of Outputs

An OECD (2001) review of productivity measurement found that, whilst labour productivity is the most frequently calculated index of performance, this is followed by TFP measures using both value-added or total turnover. The advantage of using

[2] http://www.statistics.gov.uk/abi/

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

total turnover is that it includes most factors of production, such as labour, capital, materials and energy, which can be examined as separate factors of production, something the value added approach does not offer. Within the aggregate series total turnover is used as the single output measure. These exist within the Annual Business Inquiry for each sector over the time period of study.

Treatment of Inputs

Three inputs were used for the TFP analysis, specifically capital, labour and intermediate purchases. These are discussed in more detail below.

a) Physical Capital Stock

A firm will have a stock of capital at any one time which will be composed of assets of differing ages. However, this is not a direct input into the production process, it is the 'flow of physical capital services' which should be included into the TFP measure. This is not directly observable but is usually considered as directly proportional to the stock of physical capital. Consequently, to understand how capital affects production, a series for capital stock needs to be constructed which takes into account the loss in relative efficiency from older stock compared to fresher stock. This can be done using the 'perpetual inventory model' (PIM) which allows for this service charge to be computed each year. A PIM can be constructed from:-

$$K_t = \sum_{s=0}^{s} \phi_s I_{t-s} \qquad (2)$$

where K_t is the sum of capital stock for a particular asset in period t, which is composed of a number of assets of s vintages (where s=0,…,S); I is the investment in that particular asset in periods *t-s* and ϕ is the relative efficiency of an s-vintage asset to a new asset. Essentially this model sums an asset's efficiency at a particular point in time, taking into account past investments which will be increasingly less efficient than new investments in that asset and which, at a particular point in time, will be removed from the capital stock series. Consequently, in order to use the PIM several pieces of information need to be obtained, namely:

- an initial estimate of capital stock needs to be made. As the industry has been in existence for a number of years before the series begins, assets have been invested into and exist at the beginning of the study period. This will be added to annually by net capital expenditures (given in the ABI). Fortunately, the ONS have calculated capital stock series for a number of industries from 1948 onwards.

- some assumption needs to be made of the service life of the asset to dictate the depreciation rates used within the capital stock series and, also, to reflect the relative shares of efficiency within the age profile of the stock. Unfortunately, within the ABI series, no split between the type of asset exists. Consequently, this study adopts all assets as one series and takes a rather arbitrary service life for all assets at 20 years.

- an age structure of the stock. Sudden death (sometimes know as 'lightbulb efficiency') may be the most realistic schedule to adopt for the food industries as it assumes that both machinery and buildings are maintained to an optimum until they are disposed of. This must be true for a number of sectors within the food chain as plant and machinery, such as refrigeration devices and transportation have to be kept to their optimal efficiency otherwise this would result in food spoilage. The only sector where this may not apply is the food manufacturing sector. However, for the sake of consistency sudden death depreciation has been adopted for all sectors.

b) Labour Inputs

In order to gather data on hours per sector the Annual Survey of Hours and Earnings (ASHE) exists, which charts back to 1998. The advantage of using the ASHE is that it gives median rates for total hours worked by industry (SIC) code and hence obviates the problem of using economy wide rates. Furthermore, it gives an estimate of weekly hours worked both full-time and part-time. A drawback is that median rates are a weekly average and therefore assumptions need to be made on the number of weeks worked per year to provide an annual series. As industry specific estimates could not be gathered, the legal minimal number of weeks allowed for paid leave has been used, which at present is four weeks including public holidays.

c) Purchased Inputs

In the food supply chain purchased inputs compose the bulk of total inputs within the production process. These include purchases of raw materials and, along the supply chain, processed products in addition to energy and packaging requirements. The series directly reflects prices and quantities used as an input and little needs to be done before it is applied to the TFP series. Appropriate sector specific deflators were adopted to provide the quantity series.

d) Externalities to the Food Chain

Undesirable outputs were gathered from several data sources. The Office of National Statistics publishes a range of environmental impacts and resource use data by industry in the Environmental Accounts (ONS, 2004). 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.

In order to produce indexes of growth a constant and current price series needs to be constructed and 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 effect.

3.0 Results

Figure 1 shows the TFP index for the four food industries from 1998 onwards, alongside both output and input series.

Figure 1: TFP, input and output indexes for the food chain, 1998-2002

Figure 1 shows that input growth exceeded growth in output throughout this period. This seems to reflect the depressive effects of retailing and wholesaling, which both experienced strong input growth. Annual average (compound) growth rates of the productivity index over this period were -0.52% for the food chain, which reflects the negative TFP rates recorded in three sectors; wholesale, retail and non-residential catering. Food manufacturing was the only sector to garner positive growth rates.

When examining partial productivity rates it is clear that intermediate productivity is the major cause of downward rates of TFP growth. Figure 2 illustrates them over the period.

Figure 2: Labour, Capital and Intermediate Indexes

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 intermediate productivity series of –0.90%. This has led to higher growth rates in inputs compared to output growth.

Indexes of Externalities

To complement the TFP index presented above a number of fisher indexes are presented to illustrate the changes in externalities over the same period. Essentially five indexes have been constructed, namely i) Energy emissions, ii) Transport Emissions, iii) Transport (social costs), iv) Transport accidents within the Food Chain, and v) Food-borne illness and industrial injuries (Social Costs). These are described in greater detail below.

Figure 3. Fisher Indexes of Externalities within the Food Chain

Energy emissions consist of greenhouse gas emissions, acid rain precursor emissions, PM_{10} and volatile organic compound (VOC) emissions. This index shows a rise over this period, reaching a peak in 2000, which then arcs downward to 1998 levels. The shadow prices for these emissions, and for transport below, are derived from damage estimates reported in AEA Technology (2005).

Transport Emissions show a rise over this same period, the major rise occurs from PM_{10} emissions, of the remainder volatile organic compounds remained relatively stable. (NOx and SOx) CO_2 emissions garner the greatest revenue share of this group with just under 50% of all costs, this is followed by PM_{10}, with a 33% share of costs. The remainder, NOx, SOx and VOC garner the remaining 17%.

Noise congestion and infrastructure constitute the social costs of transport. This index seems to have risen over the period, however impacts due to both LGV and HGV use has declined over the period, which indicates some reduction in the negative effect of the supply chains. This constitutes an average social cost of £2 billion per annum. However, food chain related car usage has substantially increased, predominantly this consists of visits to and from the supermarkets with distances travelled increasing from 12.6 billion to 14.3 billion kilometres over the period. This increase is primarily due to an increase in the average distance of each trip as the number of trips has decreased (AEA Technology, 2005).

The inclusion of the external impacts of car use may be questioned in an exercise aimed at determining the sustainability of the food chain industries as these relate to externalities generated by the household sector. However, the increased use of cars in distance terms does represent a transfer of externality generation from the food industry to households. The shadow prices for the social external costs are derived from estimates provided in AEA Technology (2005).

Transport accidents show the trend in accident rates for vehicles operating within the food chain. Accident rates for lorries LGV and HGV have reduced over the period where accidents from car usage saw a slight increase over 2000 to 2001 and then returned to 1998 levels. However, around 60% of the cost share of this index come from car accidents. The externality costs of road transport accidents comprise casualty related costs (lost output, medical and ambulance, and human costs) and accident related costs (police costs, insurance and administration, and damage to property) and are derived from Department for Transport estimates based on vehicle type and accident severity (DfT, 2003).

Food-borne illness and industrial injuries constitute the social costs of the food chain. Generally, the number of injuries related to the food chain have declined over the period as have the cases of food poisoning. Both series have reduced by around 20 points. However, injuries are minimal making up only 16% of the external costs of the food chain of this group. The remaining 84%, around £350 million, emerges from cases of food poisoning. Estimates of the external costs for incidences of food-borne illness include the costs of lost production, health service costs, and pain and suffering, and were derived from FSA (2004). The external costs of industrial injuries include health service costs and pain and suffering. Health service costs estimates were not available, so only pain and suffering costs were included, these being estimated from willingness to pay to avoid death and varying severities of injury as published in FSA (2004).

The final figure shows both the TFP index and an index for all externalities, determined using the Fisher indexing methodology outlined above.

Figure 4. Fisher Indexes of Externalities and Total Factor Productivity Index, 1998 = 100

Essentially, the TFP index is downward, which reflects the higher growth in inputs compared to outputs which indicates a negative trend sustainable growth for the food chain over this period. In addition, the high growth in externalities throughout most of this period, also shows a reduction in resource quality trends and thus negative impacts on sustainable growth. Consequently, we can conclude that on both fronts that the food chain post-farmgate is not producing a sustainable level of growth.

Conclusions

UK policy making aims to promote sustainable growth within its industries. Productivity, which relates trends in input usage to output growth, is often used by Government as it offers a particular perspective on an industry's development. Nevertheless, with an increased policy focus on measuring sustainable growth, TFP seems inadequate when aiming to fully reflect quality changes in resource use due to the complexity of relationships between economic, social and environmental development. Accordingly, when coupled with indicators of resource related externalities, a more detailed picture of sustainable growth emerges.

This study has found that TFP indexes are decreasing over the period of study, in conjunction with a general increase in the index for externalities produced by the food chain. Accordingly, for the bulk of this period, both indexes seem to have trended away from sustainable growth. There are consequences for the long term sustainability of the food chain. Firstly, a long term trend in TFP gives an indication of an economy's underlying productive capacity. It can therefore be used as a measure of potential growth and possible inflationary pressure. Furthermore, the differential between rates of input and output growth is composed of a number of phenomena, such as economies of scale and cost efficiencies, important for business. Consequently, Harberger (1998) identified that growing productivity is an indicator of the potential real cost savings that can be achieved over time. These benefits are consequently being lost to the food chain if TFP continues this trend.

The rise in externalities provide further evidence of movement away from sustainable growth. The major cost to the food chain in terms of externalities are the social costs of transport, i.e. the congestion, noise and infrastructure related to food transportation. However, HGV and LGV use has declined over this period. The main negative impact is with the use of cars, which has increased substantially from 1998 onward. Predominantly, this is due to increased distances travelled to supermarkets for food shopping (the number of shopping trips has decreased). However, moves have been made by retailers to improve convenience in terms of internet shopping and smaller city centre based retail units. In time these might have the effect of reducing externalities by altering shopping patterns and thus reversing the trends observed here.

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Table 1: Externalities by Sector: Post farm-gate Food Chain (incl. Sources)

	Air	Water	Land	Social
Manufacturing *(production, packing, storage, water use)*	Energy Use (resource, CO_2, NO_2, SO_2) -	Abstraction and discharge (resource use, biodiversity, contamination, transformation) -	Waste -	Odour (operation) -
	Process emissions (GHG, Heavy metals, Particulates) -	Run-off (contamination, flooding) -	Land take (soil, biodiversity) -	Noise (operation) -
			Landscape Effects -	Landscape Effects - Mortality and accidents - Food-borne illness - Landscape Effects - Nutritional Standards ±
Wholesaling (*transportation storage)*	Energy Use (resource, CO_2, NO_2, SO_2) -	Mains abstraction and discharge (resource use) -	Waste -	Congestion and infrastructure -
	Transport (GHG, heavy metals, particulates) -	Run-off (contamination, flooding) -	Land take (soil, biodiversity) -	Odour (operation and transport) -
			Landscape Effects -	Landscape Effects - Noise (operation and transport) - Mortality and accidents -
Retailing *(transportation storage packaging)*	Energy Use (resource, CO_2, NO_2, SO_2) -	Mains abstraction and discharge (resource use) -	Waste -	Macroeconomic (trading position) ±
	Transport (GHG, heavy metals, particulates) -	Run-off (contamination, flooding) -	Land take (soil, biodiversity) -	Food Miles -
			Landscape Effects -	Congestion and infrastructure - Landscape Effects - Consumer Choice (increased choice, food deserts) ± Nutritional Standards ± Mortality and accidents - Food-borne illness -
Catering *(storage preparation)*	Energy Use (resource, CO_2, NO_2, SO_2) -	Mains abstraction and discharge (resource use) -	Waste -	Mortality and accidents -
	Transport (GHG, heavy metals, particulates) -			Food-borne illness -

- negative externality; + positive externality

Table 2. Composition of the Food Chain by Standard Industrial Classification

Sector	I-O INDUSTRY GROUP	STANDARD INDUSTRIAL CLASSIFICATION
Manufacturing	Manufacture of Food Products and beverages	15
Wholesaling	Wholesale of food, beverages and tobacco	51.3
Retailing	Retail sale of food, beverages and tobacco in specialised stores	52.2
	MINUS Retail Sale of tobacco products	52.26
	PLUS Retail sale in non-specialised stores with food, beverages or tobacco predominating	52.11
	MINUS Other retail sale in non-specialised stores	52.12
NRC	Restaurants	55.3
	Bars	55.4
	Canteens and catering	55.5

Table 3. Data Sources Used

	Price / Quantity	Description	Source
Output			
Turnover	£ / £ (2000)	Sales of Products Deflated to 2000 prices	ABI ONS
Inputs			
Labour	£ / Annual Hours Worked	Labour Costs Annual Hours Worked adjusted by industry estimates for fulltime and part-time hours	ABI/ ASHE
Capital	£ / Perpetual Inventory Method	Capital Expenditure A 20 year 'sudden death' depreciation rate begun in 1995 and continued from an estimate of capital stock from the ONS 1994	ABI/ ONS CS
Intermediate Purchases	£ / £(2000)	Intermediate Purchases Deflated to 2000 prices	ABI ONS

Figure 1: TFP, input and output indexes for the food chain, 1998-2002

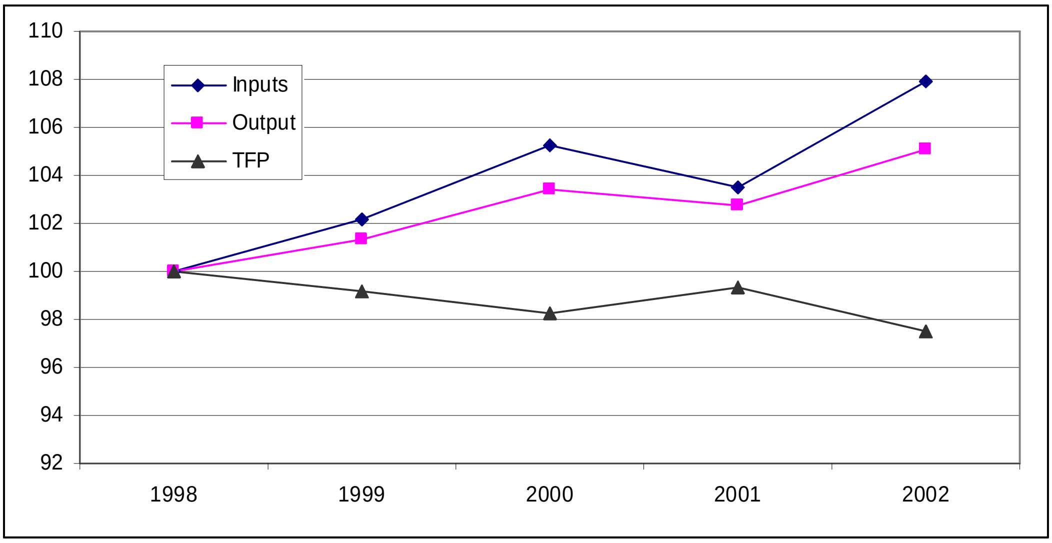

Figure 2: Labour, Capital and Intermediate Indexes

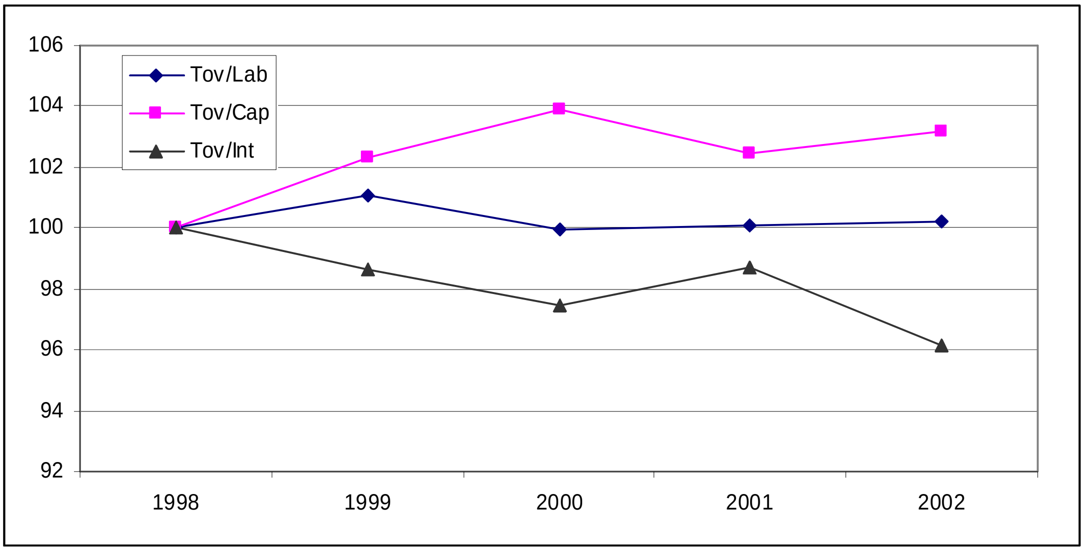

Figure 3. Fisher Indexes of Externalities within the Food Chain

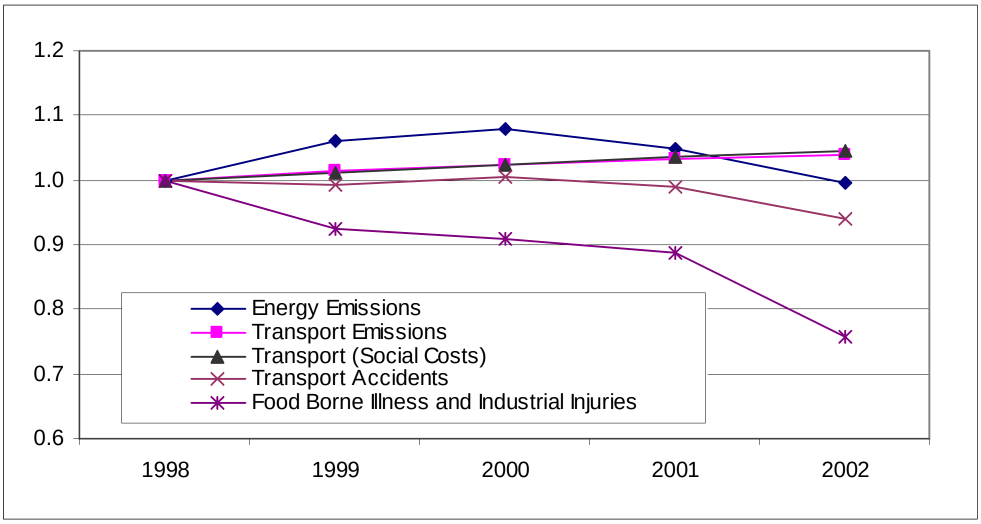

Figure 4. Fisher Indexes of Externalities and Total Factor Productivity Index, 1998 = 100