TOTAL FACTOR PRODUCTIVITY GROWTH IN THE FOOD CROP SECTOR OF SRI LANKA FROM 1990-2017

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Abstract

The study estimated the Total Factor Productivity (TFP) growth in the Sri Lankan food crop sector from 1990- 2017 using the Tornqvist-Theil index assuming translog production technology and a competitive market. TFP growth of paddy, maize, potato, big onion, chilli and soybean has increased after 2000. The highest TFP growth is recorded for maize from 2011 -2015 that contributed to about 68% of the maize sector growth. The costless advances in applied technology, managerial efficiency, and industrial organization that brought TFP growth in the food crop sector in Sri Lanka are discussed. The diffusion of new technology to the food crop sector has considerably varied by crop. Although the maize sector benefited through technology spillovers, new technology in terms of new varieties with higher yields, adaptability was slow to diffuse to other food crop sectors. Mechanization has largely substituted labour in many crop sectors due to the rising wage rate. The contract grower system is a credible institutional innovation in the food crop sector. Technological capital is a prerequisite for TFP and cost reduction growth. Hence the long-term commitment to agricultural research and development investments from Sri Lankan governments and aid agencies is required.

JEL: *O12, O13, O33, O47*

Keywords: *Total factor productivity growth, Tornqvist-Theil index, Translog production technology food crop sector, Technological and institutional innovation*

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INTRODUCTION

Productivity growth is essential to transform the food crop sector of Sri Lanka from import substitution to an import-competing sector. The Sri Lankan food crop sector has been protected by implementing various import substitution policies even since the food crop sector was opened to foreign trade competition in the early 90s. These include tariffs, quotas, subsidies, administered prices and various other macroeconomic supportive environments. Generally, output growth depends on three factors: the state of technology or the kind of production process utilized, the quantities and types of resources put into the production process, and the efficiency with which those resources are utilized (Capalbo, 1988). Achieving output growth through factor intensification or increasing quantities of resources (factors) put into the production process has two limitations. Generally, factor intensification is subject to the law of diminishing returns and factors are scarce for production in the country. Return to Irrigation investments in Sri Lanka has been declining (Aluwihare and Kikuchi, 1991). Investment in irrigation has been on the rehabilitation and management of the existing irrigation resources, rather than on constructing new systems. Further increasing land for cultivation in the food crop sector is constrained by the demand for land with population pressure. Labour is moving out of agriculture.

The capital is costly. Therefore, productivity growth is a necessary condition for sustainable food crop sector growth that needs to be achieved through technological advancement and improving the efficiency of resource use. On the other hand, productivity growth is a sufficient condition because it increases production at reduced unit cost/prices in real terms to compete with imports. On average, countries that have achieved higher growth in agricultural productivity have also experienced larger reductions in the prevalence of food insecurity (Tandon et al., 2017). Long-run competitiveness and real incomes in the agriculture sector are primarily driven by productivity growth rather than by the growth of production.

In terms of productivity assessment, both partial factor productivity and Total Factor Productivity (TFP) are measured. Partial productivity measures the output in relation to one factor and TFP considers all of the land, labour, capital, and material resources employed in farm production. Total Factor Productivity (TFP) is the portion of output not explained by the number of inputs used in production. Partial productivity measures such as labour productivity and land productivity are commonly estimated measures by state agencies.

Partial factor productivity (e.g. labour productivity) growth may be due to the deepening of other factors (e.g. capital) in the short run. However, the fundamental source of partial factor productivity growth is TFP growth. Therefore, partial factor productivity growth measurements reflect empirically both the productivity growth associated with more use of other inputs and TFP growth. TFP growth captures the technology improvement,

improvement in the efficiency of factor use and growth due to the scale economies. TFP growth is the ultimate source of long-term economic growth. TFP growth comes in many forms—new technology (e.g. new varieties or tools), new processes, new institutions (e.g. new forms of contracts or policy mechanisms), and markets with less transaction cost (Hayami and Ruttan, 1971; Ruttan, 1985; Sadoult and Janvry, 1995; Bernard et al., 1996; Acemoglu, 2008).

Few studies relating to TFP and determinants of TFP growth in the agriculture sector of Sri Lanka are found in the literature. Most studies have dealt with the crop sector including the plantation sector and the livestock sector together using FAO data.

USDA/ERS continuously assesses the TFP growth of the agriculture sector using the growth accounting method implicitly assuming Cobb Douglas production. According to USDA/ERS, the Sri Lankan agriculture TFP growth index increased at an average annual rate of 0.7% during 1961 -2019 taking the 2005 base year. Avila and Evenson (2010) estimated a negative annual TFP growth of the Sri Lankan crop sector of -0.39 during 1961-1980 and -2.19 during 1961-1980 while annual output growth of 2.01 during 1981-2001 and 0.62 during 1961-1980 using growth accounting method. This depicts a situation that Sri Lankan crop sector growth has largely been due to factor intensification.

Coelli and Rao (2003) estimated TFP growth in the crop and livestock sector using Stochastic Frontier Analysis (SFA) and found it to be 0.2 p.a. from 1980- 2000 (Kumara et al, 2008). Following the SFA, Liu et al. (2020) decomposed the agriculture TFP growth of South Asian and South East Asian countries and found that from 2002 to 2016, the change in total factor productivity in Sri Lanka has been negative and -0.0002 p.a. assuming -0.0043 technology efficiency change p.a. Scale change and technological change have been positive and 0.0004 and 0.0038 respectively. Thayaparan (2019) studied the TFP growth in the paddy sector of Sri Lanka over the period 1974-2003 and TFP growth was decomposed into efficiency change, technological efficiency change, pure technical change and scale efficiency change using Malmquist productivity index.

Abeysekara and Prasada, (2021) decomposed the TFP change in the coconut sector into two components namely technical change and the returns to scale using stochastic generalized translog cost function and the coconut sector found to have grown at 0.083% per annum during 1961-2016. Technical change and scale of economies contributed to 78% and 22% of the TFP growth in the Sri Lankan coconut sector respectively.

The contribution of total factor productivity to the output growth of paddy was estimated for various fertilizer policy regimes by Weerahewa et al. (2022). In this study, elasticities of paddy output with respect to harvested area and fertilizer application were estimated using Autoregressive Distributed Lag - Error Correction Model (ARDL-ECM) for the period from 1962-2020. Assuming constant elasticities for the entire period, TFP growth was calculated for these policy regime periods by accounting for growth of the harvested area and the fertilizer.

These studies and the TFP literature provide methodological and empirical assessment insights. This study empirically measures the TFP growth of a few selected important crops in the food crop sector over the period 1990-2017 at the national level. In estimating the TFP growth, due consideration is given to choosing a methodology that can capture the Sri Lankan food crop production technology and address the data availability issues. In explaining the TFP growth performances, the factors determining the TFP growth are taken for discussion.

METHODOLOGY

TFP Measurements and Estimation Methods

The earlier literature on the measurement of productivity growth and technical change has been grouped into two broad categories (Capalbo,1988): (a) analyses for which a change in total factor productivity is interpreted as the rate of change of an index of aggregate output divided by an index of aggregate input, a nonparametric index approach or (b) analyses which involve estimating the rate of shift of production relation, a parametric method or econometric approach.

The index approach can estimate technical change spatially and temporally. The econometric studies of productivity change use either a primal approach or a dual approach. The primal approach is based on the direct estimation of a production function whereas the dual approach is based on the estimation of a cost function or profit function.

The econometric approach imposes a functional form and employs econometric techniques in estimating a production function, a cost function or a profit function and takes time in the production (cost or profit) function as a variable assuming extended hicks neutral technical change to estimate TFP change over time. Both index and econometric approaches are mainly applied to time series macro-productivity data sets.

These approaches have been developed to decompose TFP change into technical change and scale change by relaxing the constant-returns-to-scale technology assumption under competitive behaviour and to estimate TFP change under non-competitive behaviour by relaxing the competitive markets behaviour assumption.

The frontier analysis using panel data is the most recent nonparametric/index approach to TFP measurement that estimates the rate of technological change by Data Envelopment Analysis (DEA). DEA is a linear programming methodology, which uses data on the input and output quantities to construct a piecewise linear production frontier for each year over the data points. The estimated Malmquist productivity index through profit–maximization (or cost minimisation) under the Constant Return to Scale (CRS) assumption decomposes the TFP Change as efficiency change and technical change between two periods.

Growth Accounting Approach and Use of Index Numbers for TFP Growth Measurement

The growth accounting or residual method of TFP measurement, parametric estimations of production and cost functions which are based on an estimation of the Cobb-Douglas production functions originates in Solow's 1956 and 1957 articles. Early research by Kuznets and others on national accounts data led to the development of growth accounting as a quantitative tool to decompose the specific factors that contribute to total GDP growth. In the absence of technological advances, the growth in total output can be explained in terms of the growth in total factor input. This view was supported by the neoclassical theory of production and distribution: competitive equilibrium and constant returns to scale imply that payments to factors exhaust the total product. However, if there was a technological advance, payments to factors would not exhaust the total product, and there would remain a residual output not explained by total factor input. This "residual," as Domar termed it, was associated with productivity growth in the early growth accounting literature and remains a fundamental concept in the measurement and explanation of productivity growth (Kendrick, 1961; Jorgenson and Griliches, 1967). In the growth accounting approach, a production function (primal approach) is used to relate measured inputs to measured outputs and it requires the assumption that such a function remains stable over long periods.

The index number method is an extension of and complements, growth accounting. The index number approach does not require an aggregate production function, though an appropriate index can be selected via the economic approach for some specified production function. This method involves compiling detailed accounts of inputs and outputs, aggregating them into input and output indexes assuming perfectly competitive equilibrium, and using these indexes to calculate TFP growth as an Index. The Divisia index of TFP growth measures the residual growth in outputs not accounted for by the growth inputs (Capalbo, 1988). This index is defined in terms of the proportional rate of growth of productivity.

The economic assumptions about the underlying aggregation functions that are implicit in the choice of an indexing procedure have been established (Diewert, 1976, 1981). The theory of index numbers addresses the method by which the raw data is combined to develop aggregate output and aggregate input indexes and the implicit production function. The methodological linkages between index numbers and production technology were delineated in the late 1970s by Diewert and others. The Laspeyres indexing procedure used in much of the early productivity studies has been shown to be exact. or imply, either a linear production function in which all inputs are perfect substitutes or a Leontief production function in which all inputs are used in fixed proportions. Similarly, the geometric index is exact for a Cobb-Douglas production function, and the Tomqvist-Theil index, which is also an approximation to the Divisia index, is exact for a homogeneous translog production function.

The discrete approximations of the Divisia index are given by the Tornqvist-Theil approximations:

$$\Delta\, TFP \;= \sum_i \frac{1}{2}\left(r_{it} + r_{i,t-1}\right)\left(lnq_{it} - ln\, q_{i,t-1}\right) - \sum_j \frac{1}{2}\,(s_{jt} + s_{j,t-1})(\left(lnx_{jt} - lnx_{j,t-1}\right) \quad (1)$$

Where r_{it} is the revenue share of output q_i in period t and s_{jt} is the ratio of the cost of input x_j to total revenue (or total cost) in period t.

Tornqvist-Theil quantity index is a superlative index number which has been used by Christensen and Jorgenson (1970), Star (1974), Jorgenson and Griliches (1972) and Star and Hall (1973) as a discrete approximation to the Divisia index. An aggregator functional form is said to be 'flexible' if it can provide a second-order approximation to an arbitrary twice differentiable linearly homogeneous function. An index number functional form is said to be 'superlative' if it is exact (i.e., consistent with) for a 'flexible' aggregator functional form. In view of the second-order approximation property of the homogeneous translog function, the Tornqvist-Theil quantity index is exact for a homogeneous translog aggregator function and is a superlative quantity index. The Tornqvist-Theil index provides consistent aggregation of inputs and outputs under the assumptions of competitive behaviour, constant returns to scale, Hicks-neutral technical change, and input-output separability. However, Caves et al. (1982) have shown that Tornqvist-Theil indices are also superlative under very general production structures, i.e., nonhomogeneous, and non-constant returns to scale, so they should provide consistent aggregation across a range of production structures (Antle and Capalbo, 1988).

The translog function (Christensen et al., 1973) is an integral tool for analysing the production structure of many firms and industries. The translog function is conceptually simple and imposes no a priori restrictions on elasticities of substitution and allows scale economies to vary with the level of output. Marginal rates of substitution are identified with the corresponding price ratios. The translog production function has been used to examine input substitution (Berndt and Christensen, 1973), separability and aggregation (Denny and Fuss, 1977), technical change and productivity growth (May and Denny, 1979, Myyrä et al., 2009) and productive efficiency (Martin and Page, 1983).

An alternative approach to measuring changes in total factor productivity is based on a direct application of the Torqvist-Theil index number theory, rather than indirectly as an approximation to continuous-time derivatives. This alternative approach leads to an exact formula for TFP that is suitable for discrete data, but the formula is contingent on the cost function being of the translog form. As a result, the exact index number approach to TFP measurement also involves an approximation, since it is unlikely that the technology can be precisely represented by a translog cost function over the entire range of prices and quantities. Furthermore, since the Tornqvist-Theil indexes are based on cost and revenue shares and utilize Shephard's lemma in their derivation, the exact index number approach implicitly assumes competitive behaviour (Capalbo, 1988).

TFP Growth and Explanation of TFP Growth

Changes in TFP are empirically measured as the changes in the difference between increases in aggregate measured outputs and increases in aggregate measured inputs. Changes in TFP measure the changes caused by changes in technology or changes in efficiency and/or in the scale of operations of firms. The definition of change in TFP is approximated to the effect of ' costless ' advances in applied technology, managerial efficiency, and industrial organization if measurement errors are duly accounted (Jorgenson and Griliches, 1967; Lipsey and Carlaw, 2004). TFP change measures only the costless components of technological change, which are mainly associated with externalities and scale effects (Jorgenson and Griliches, 1967; Hulten, 2001). V

irtually all technological changes are embodied in one form or another: new or improved products, capital goods, or other forms of production technologies; and new forms of organization and are assumed to be accounted for in aggregating measured inputs. The error of measurement is primarily caused by not accounting for unmeasured/unconventional inputs and unmeasured/not assessed qualities of inputs. For the fact that errors of measurement are not accounted for in aggregating inputs, change in TFP captures it and is misinterpreted as advances in the technology. Tornqvist index measures the cumulative of technological change, technical efficiency change and, scale effect and in estimation, it assumes competitive markets and hicks-neutral technological change.

New technology will usually cause output to increase over time by increasing the marginal product of one or more inputs and increasing the elasticity of production. New technology makes one input more productive relative to the other input. New technology could cause the per unit cost of the input to decrease which may or may not affect the use of the other inputs. New technology could increase the elasticity of substitution and allow for significant changes in the mix of inputs and lowers the cost.

Changes in total factor productivity or shifts in a given production function may be accompanied by movements along a production function or factor deepening. For example, changes in applied technology may be associated with the construction of new types of capital equipment. The alteration in patterns of productive activity due to this new technology must be separated into the part which is "costless", representing a shift in the production function, and the part which represents the employment of scarce resources with alternative uses, representing movements along the production function.

Factor deepening takes place in response to price incentives, to non-price factors such as public investment which affect the profitability of private investment, and to the relaxation of constraints on, for instance, access to credit (Sadoult and De Janvry, 1995) are accounted in the aggregate input index in addition to the resultant movement along the production function due to new technology.

Practically, technical change arises from three sources: innovation within firms; changes in the relative size of firms with different technologies; and the entry and exit of firms, which again carry different technologies. Technological change (TC) or technological development is an overall process of invention, innovation and diffusion of technology or processes. Technical efficiency gives a measure of the total factor productivity gap for an individual firm relative to the production frontier which describes the best available technology.

The traditional neo-classical growth models assume that technological progress is disembodied or independent of capital accumulation (Solow, 1957). Disembodied technical progress delineates improvements in technical knowledge that allow more output to be obtained from given inputs without the need to invest in new equipment. With embodied technical progress, the improved technique is built into the new equipment and therefore most important technological advances are embodied in the new capital. Alternatively, disembodied technological change does not necessarily raise TFP and the presumption that all disembodied changes are costless is not true. It entails some heavy development and learning costs.

Barro (1999) uses production functions that allow R&D to generate expanding product variety or quality with increasing returns to the intermediate R&D inputs. In Barro’s case, because of the increasing returns to the intermediate R&D input, there is a Hicks-neutral, ‘manna from heaven’ component of technological change that is measured by changes in TFP and a component of the endogenous technological change generated from costly R&D that is not measured by changes in TFP. Hicks-neutral technological change leads to an increase in the efficiency of all factors in the same proportion and the marginal rate of substitution remains the same.

TFP change measures only the costless components of technological change, which are mainly associated with scale effects and the externalities caused by technology spillovers. Technological or R&D spillovers are most often defined as externalities (Jorgenson and Griliches 1967; Hulten, 2001; Lipsey and Carlaw, 2004) Accordingly, TFP change or TFP growth measures the Hicks-neutral technical change that includes the costless component of technological change and the costless component of the technical efficiency change and the error of measurement.

Chan and Mountain (1983) showed how the Divisia or Tornqvist-Theil index of total factor productivity can be modified to account for non-constant returns to scale. Berndt and Khaled (1979) estimated aggregate cost function models for the U.S. manufacturing sector that simultaneously identified substitution elasticities, scale economies, and the rate and bias of technical change. Denny et al. (1981) have relaxed the competitive equilibrium assumptions for the output market and decomposed the rate of productivity growth for a regulated sector into scale effects, non-marginal cost pricing effects, and technological change.

Empirical Estimation

Following the Exact index method, the Tornqvist-Theil index is used in this study to empirically estimate the TFP growth in the food crop sector at the national level. Theoretical presentation of the production technology, rationality of assumptions on which the estimations are made, and the data availability are the factors for the choice of this methodology. TFP growth is estimated on a crop basis and the underlying technology of the production function in this estimation is assumed to be exact for a homogeneous translog production function. One Output and aggregated inputs are taken for the calculation.

Expressed in logarithmic form, the Törnqvist-Theil TFP index for crop *i* is defined as:

$$\ln\left(\frac{TFP_{it}}{TFP_{it-1}}\right) = \ln\left(\frac{Q_{it}}{Q_{it-1}}\right) - \frac{1}{2}\sum_j (S_{ijt} + S_{ijt-1}) \text{ x } \ln\left(\frac{X_{ijt}}{X_{ijt-1}}\right) \quad (2)$$

Where Q_{it} is crop production (output) for *crop i,* S_{ijt} is the share of input *j* in total cost for crop *i,* X_{ijt} is input *j* used in the production of crop *i,* and *t* indexes time (year).

Considering the scope of the food crop sector emphasis has been given to import-substituting crops that can be transformed into import-competing crops. Törnqvist-Theil TFP index is calculated for rice/paddy, maize, potato, chilli, onion, and soya bean for the period spanning from 1990 to 2017. The output index is just a single crop output index. Data on crop-specific inputs are used in the computation for each crop’s TFP and include series for the sown area, labour, seed, fertilizer, pesticide and weedicides, machinery and equipment, and other material inputs. Irrigation is considered a factor that determines the quality of cultivated land and land quality was adjusted by taking the productive capacity of rainfed land as equivalent to 75 % of irrigated land. Labour man days is adjusted to the quality of labour by activity.

Setting TFP in the base year to 100 and accumulating the changes over time based on the equation above provides a time series of TFP chained index for each crop. Cost share weights used in calculating the aggregate input index vary over time (Paasche and Laspeyres indexes use fixed weights whereas the Tornqvist-Thiel and other chained indexes use variable weights). Allowing the cost share weights to vary reduces potential "index number bias" (USDA, ERS). Index number bias arises when producers substitute among inputs depending on their relative cost. In other words, the growth rates in X_j are not independent of changes. It allows the factor substitutability in the production function. The Tornqvist-Theil index also accounts for changes in the quality of inputs. Because current factor prices are used in constructing the weights, quality improvements in inputs are incorporated, to the extent that these are reflected in higher wage and rental rates (Rosegrant and Evenson, 1995).

Nevertheless, in constructing the input aggregate, certain unmeasured inputs and unmeasured quality of inputs are missed out from the calculation. Any change in output growth due to those factors will lead to the error of measurement of TFP change. Input such as water by precipitation (rainfall), new infrastructure and processes like soil degradation have not been accounted for in the calculation. However, those factors together with other public expenditures and institutional innovations are considered in the descriptive TFP analysis. Data on input and output levels and the prices of inputs are taken from the cost of cultivation data of the Department of Agriculture (DOA) from 1990 to 2017. These data provide the average cost of production per ha calculated from sample surveys covering various locations. These average values are approximated to regions identified in the study as representative values for the region.

The extent and production data collected by the Department of Census and Statistics from crop-cutting surveys are taken to estimate weights and to calculate the total use of different inputs considered in the study. Then factor shares (cost shares) are also calculated at the aggregated level. Land rental price (paddy land rent) is implicitly calculated based on tenant agreements and some market values. Instead of stock of capital, capital services are taken as an input and the prevailing market prices (e.g. tractor hire, machinery rental) are taken from the cost of cultivation data. Price is assumed to capture the quality of input and the embodied technology. Activity-specific working man-hour requirements per day are accounted for in calculating labour man-days. Machinery and tractors use is accounted for by taking the land area that is machine ploughed and harvested. The rupee value of weedicides and pesticides cost is converted to US dollars by the official exchange rate to account for the foreign exchange expenses on agrochemicals and is approximated to weedicides and pesticide use due to data limitation. These data were verified through triangulation.

Output growth, total input growth and TFP growth are estimated in this study for main import substituting crops: paddy, maize, potato, big onion, soya bean and chilli. When TFP growth estimates are presented for the sub-period, Cobb- Douglas production technology was assumed, and average factor shares for the sub-period were taken for the calculation.

RESULTS AND DISCUSSION

The estimates of productivity growth for the food crop sector using the Tomqvist-Theil chained index of TFP are presented on a crop basis in Table 1. The average annual rates of growth of output, inputs, aggregate input, and TFP of paddy, maize, potato, big onion, chilli and soya bean crops by sub-periods are given in Table 2. Chained TFP index by crops grew at an average annual rate of 1.14% – 3.94% over the period 1990-2017 and the highest TFP growth rate is observed for maize over this period, the crop that gained economic importance in the food crop sector after the ’90s.

TFP growth of paddy during 1990-2000 is negative and that 1% p.a. growth of output was achieved through factor intensification. The aggregate input index grew at 1.74% p.a.

over this period and fertiliser use increased by 7.35% p. a. (Table 2). When the sub-periods after 2000 are considered, the highest TFP growth for paddy is observed during 2005-2015 and it contributed to about 44% of the output growth (Table 3). Of the main inputs, fertiliser use dropped after 2000 and labour has continuously decreased from 1990 onwards in paddy farming.

Table 1: Chained TFP Index and its Annual Average Growth, 1990- 2017

Year	Paddy	Maize	Potato	Big Onion
1990	100	100	100	100
1991	109.5	112.3	100	100
1992	104.7	92.6	114.1	110.2
1993	102	98.6	99.4	102.3
1994	95	70.3	93.5	112.9
1995	98.4	70.3	123.6	87.7
1996	85.4	102.4	118.8	65.2
1997	96.5	111	82.5	96.3
1998	99.7	112.2	64.3	124.6
1999	102.4	102.2	100.3	112.2
2000	98.8	108.5	114.9	116.2
2001	106	117.8	119	105.8
2002	103.9	108.5	115.9	102.7
2003	101.1	151.7	104	114
2004	106.6	156.5	125.5	116.4
2005	106.2	99	120.8	114.2
2006	116.2	139.8	130.5	116.2
2007	125.7	162	133.5	132.8
2008	117.3	175.6	137.2	140.9
2009	119.1	176.8	132.3	155.5
2010	124.7	176.8	120.4	147.7
2011	101.7	196.1	119.6	168.2
2012	128.6	198	135.1	154.1
2013	126.7	214.8	134.7	161.9
2014	120.5	223.7	132.4	148.1
2015	131.2	215.8	146	157.7
2016	132.7	220.5	145.2	163.8
2017	108.8	233	138.5	172.8
Annual Average	**1.14%**	**3.94%**	**1.58%**	**2.44%**

Source: author's calculations

Maize records an output growth of 9.15% p.a. after 2000. This increasing maize output growth is predominantly contributing to meeting the derived demand in the processed food and feed industry in Sri Lanka. Maize output growth achieved during the 2000-2010 period which was 17.1% p.a. was mainly achieved through factor intensification. Moreover, the share of TFP growth contributed 77% to the output growth of maize during 2010-2017 which grew at 3.05% p.a. Significant TFP growths are observed for soybean, potato, and chilli after 2010. Chilli output growth of 1.38% p.a. has been achieved after 2010 due to TFP growth when the area under chilli has come down by 2.24% p.a.

As the definition of change in TFP above, the costless advances in applied technology, managerial efficiency, and industrial organization that brought TFP growth in the food crop sector in Sri Lanka are discussed here. The Tornqivst-Theil index captures the cumulative Hicks neutral effect of technological progress, changes in technical efficiency and scale changes. Although there are methodological advances to distinctly measure the main determinants of TFP growth and its components separately and on specific variables which affect productivity, this study estimates the TFP growth as the cumulative effect of all determinants. Nevertheless, this study follows a method to explain the TFP growth in terms of new technology and organizational innovations introduced in the food crop sector and its adoption into the discussion. Also, the possible measurement errors are taken into consideration when the growth of TFP is explained with the above factors.

Table 2: Factor and Productivity Growth by Crop and by Period

Paddy	**1990-2000**	**2000-2005**	**2005-2015**	**Maize**	**1990-2000**	**2000-2010**	**2010-2017**
Land	1.62	0.25	0.64	Land	-1.28	7.7	1.74
Labour	-2.38	-0.45	-1.4	Labour	-1.17	5.2	-4.28
Machinery power	6.05	0.69	1.66	Machinery power		23.1	4.08
Fertiliser	7.35	-0.14	-0.1	Fertiliser		16.8	7.48
Agro chemicals	0.9	**0.17**	**0.71**	Agro Chemicals		38.3	2.25
Seed	1.2	0.05	0.14	Seed	-1.81	5.2	3.09
Output growth	1	1.79	2.94	Output growth	-0.84	17.1	7.55
Total Input growth	1.74	0.57	1.66	Total Input growth	-1.6	11.7	0.44
TFP growth	-0.73	**1.22**	**1.28**	TFP growth	0.76	**5.4**	**7.11**
Big Onion	**1990-2000**	**2000-2010**	**2010-2015**	**Potato**	**1990-2000**	**2001-2010**	**2010-2017**
Land	4.12	7.25	9.31	Land	-11.6	-3.4	3.1
Labour	4.83	3.43	9.31	Labour	-14.2	-5.31	2.15
Machinery power	6.16	8.12	9.31	Machinery power			10.61
Fertiliser	16.48	1.3	7.04	Fertiliser	-5.74	-10.82	0.66
Agro Chemicals	11.59	8.77	16.15	Agro Chemicals	-1.53	**3.47**	**8.36**
Seed	4	6.38	6.16	Seed	-11.6	-3.84	2.73
Output growth	7.6	10.72	9.36	Output growth	-10.4	2.16	8.52
Total Input growth	6.31	5.28	9.44	Input growth	-9.56	-2.97	3.23
TFP growth	1.3	**5.44**	-0.09	TFP growth	-0.84	**5.13**	**5.29**
Chilli	**1990-2000**	**2001-2010**	**2010-2017**	**Soybean**		**2004-2010**	**2010-2016**
Land	-4.46	-2.97	-2.24	Land		7.21	19.3
Labour	-7.43	-3.08	-9	Labour		5.84	16.6
Machinery power				Machinery power		8.33	24.1
Fertiliser	3.1	-4.33	1.02	Fertiliser		4.91	17
Agro Chemicals	-9.94	6.39	6.15	Agro Chemicals		29.12	12
Seed	-1.16	-10.5	-7.97	Seed		6.97	20.5
Output growth	-2.88	-1.23	1.38	Output growth		-1.16	23.2
Total Input growth	-5.79	-2.83	-4.74	Total Input growth		7.66	17.8
TFP Growth	2.91	1.6	**6.12**	TFP Growth		-8.82	**5.3**

Source: author’s calculations

Varietal technology is assumed to be Hicks-neutral technology that increases the efficiency of all inputs. Public research and development have been largely responsible for varietal technology development in Sri Lanka that brought large yield frontier shifts since the green revolution. Rice varietal development in the 1990s in Sri Lanka and later couldn't push the yield potential that was acquired by outstanding varieties such as BG 94-1 developed in the 1970s. The country experienced yield stagnations in paddy in the 80s and also the ’90s with the complete adoption of this technology mostly developed in the ’70s. Not only the national rice grain yield was stagnating, but also grain yields in research fields were gradually declining in the 90s (Dhanapala, 2000). Towards the late 1990s high yielding varieties such as BG 94-1, BG 300, and BG 350 had been almost adopted by the paddy farmers. Rice varietal development in the 1990s and later mainly focussed on breeding varieties against pests and abiotic stresses.

In 1998 onwards DOA implemented the Rice Yaya (tract) Program, a ‘technology package’ consisting of eight mandatory practices that were introduced to all the farmers of an entire Yaya (tract). The adoption of BG 352 and BG 358 also happened during this period. TFP growth during the period from 2000-2005 was 1.2% p.a. which contributed 68% of the growth of output. In the period after 2010, the main varieties that had been in cultivation for more than 30 years have been replaced with two new varieties, At 362 and Bw 367 particularly in major dry zone paddy-producing areas. These varieties are very high-yielding varieties with more adaptive characters. Continuous TFP growth after 2000 can be attributed to these new varieties amidst the continuous decline of fertilizer use. Return to Investment by different breeding methods shows that return to RGA conventional and hybrid technologies are higher although Sri Lanka has not been able to commercialize any hybrid rice variety until today. At the beginning of the '90s, Vietnam's rice yield exceeded the Sri Lankan rice yield due to their hybrid rice research program.

Table 3: Share of TFP Growth in Output Growth by Crop by Sub-period Recorded

Crop	Period	Output growth	Total Input growth	TFP growth	Share of TFP in output growth
Paddy	2005-2015	2.94	1.66	1.28	44%
Maize	2010-2017	7.55	0.44	7.11	94%
Big Onion	2000-2010	10.72	5.28	5.44	51%
Potato	2010-2017	8.52	2.32	5.29	62%
Soybean	2010-2016	23.2	17.8	5.3	23%
Chili	2010-2017	1.38	-4.74	6.12	444%

Source: author’s calculations

After the mid-90s, open economic policies continued in Sri Lanka with further liberalization and with increased private-sector participation. This paved way to factor embodied technology transfer from overseas by way of exotic hybrid seeds, tractor imports and other agrochemicals and equipment imports. Imports of all seeds and planting materials became duty-free in 1995. The first hybrid maize variety was introduced by Ceylon Agro Industries in 1998 (Wickramasinghe, 2020). The highest TFP growth was observed in maize with the adoption of hybrid varieties, particularly after mid-2000 and the TFP growth has been becoming more significant that its share in output growth increased to 94 % during the period after 2010. Sri Lanka cultivates varieties developed by multinational companies to the brand name Pacific which are also cultivated by Bangladesh, the country in South Asia that has the highest yield. Bangladesh also has several locally developed hybrid varieties for commercial cultivation.

The highest TFP growth of chilli is observed during the period from 2010 to 2015 when new improved high-yielding chilli varieties released from the FCRDI of Department of Agriculture (DOA) started their adoption. The introduction of *MICH HY 1* is a breakthrough in technology generation by public research organizations in the last few decades. A late but promising chilli hybrid developed in 2015 is superior to imported hybrids. However, bad weather prevailed during 2016 and 2017 delaying its adoption.

No or little advances in the varietal technology development of soybean, big onion and potato are evidenced since its commercial cultivation began. *PB 1* is the most grown soybean variety as a promising variety which is the first exotic variety introduced to the country in the 1970s. *PB 1* is cultivated now for more than 40 years. Although the TFP gap among farmers or the technical inefficiency has been narrowed by bringing the farmer yields to the potential best farmer yields with a contract grower system, the research gap and science gap are needed to be filled. *Dambulu Red* selection, a local selection of *Pusa red* emerged as a promising cultivar of big onion after 30 years of its cultivation. Considerable progress in true seed production *Dambulu Red* selection has made a TFP growth after 2005.

Granola is the only promising variety cultivated in potato farming in Sri Lanka. Using breeding methods of heterosis and biotechnology India and Bangladesh have produced several improved varieties with very high yields. Sri Lanka has only been able to introduce tissue-cultured mini tubers as yield enhancing strategy in potato farming.

Propagation of early-generation mini tuber seeds through tissue culture technology is widely adopted in potato farming for higher yields and disease-free plants. Several tissue culture techniques are adopted in India, Bangladesh and other countries. In 1997, the Seetha-eliya agriculture research station of DOA started the government rapid multiplication program using tissue culture technology and it started to make an impact on the seed potato supply and the potato output growth. More than 5 % TFP growth per annum is observed after 2000 in potato farming.

In 1994, the government waived duty on machinery and equipment imported for use in the application of new and innovative technologies in agriculture after the second wave of liberalization in the mid-90s. New technology such as new machinery could increase the elasticity of substitution and allow for significant changes in the mix of inputs and lowers the cost. Due to the high wage rate of farm labour which is principally determined by the non-agriculture operating surplus (Karunagoda, 2004), machinery power use and application of weedicides became common practices among farmers. The use of machinery and weedicides has contributed to the TFP growth by lowering the cost through substitution.

Therefore, these two inputs have been widely adopted by farmers. The value of tractor imports increased from USD 20 million in 2000 to USD 80 million in 2017 and the pedestrian controlled 2-wheel tractors were replaced with new technology 4-wheel medium-sized tractors. Harvesting and threshing machinery imports increased from USD 0.63 million in 2001 to USD 34 million in 2016. Herbicide formulations imported to Sri Lanka increased from 2 million kg in 2001 to 6 million kg in 2014 until the implementation of the complete ban of paraquat and regional restriction of sale on propanil and glyphosate. About 80% of Sri Lankan farmers reported weeds as the main constraint in rice production which drop 40% to 50% of crop yields (Marambe & Herath, 2019).

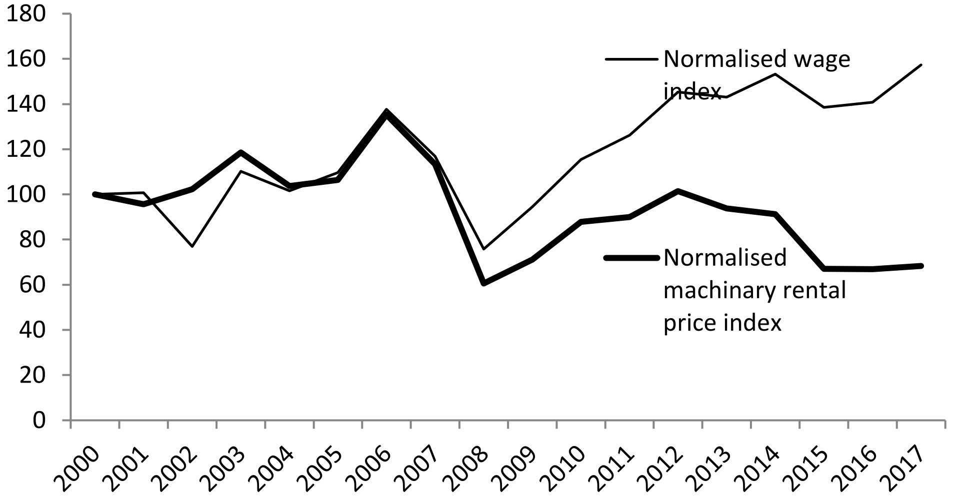
The highest TFP growth experienced in paddy farming in 2005-2015 coincides with higher growth in agrochemical use, particularly weedicides. TFP change caused by costless components of these technological changes is mainly associated with externalities and scale effects. However, the social cost associated with environmental damages has not been accounted for weedicide application and TFP growth is in financial terms positive.

New technology-embodied capital inputs particularly tractors and weedicides have increased the marginal product of labour that caused to increase in labour productivity in all crops over time. Also, new technology has caused to decrease in the relative per-unit cost of the machinery input compared to the wage rate (Figure 1). This led to labour input use in the food crop sector drastically coming down, particularly in the paddy sector (Figure 2). Accordingly cumulative costless component of new technology of these inputs has attributed to increases in the TFP through factor substitution in the food crop sector in general i.e., net cost reduction in draft power and harvesting power.

Input intensification to increase yield/ land productivity as the strategy to increase food production has been the widely adopted policy of the government (Wickramasinghe & Samaratunga, 2021). Increased input availability such as fertiliser and agrochemicals through liberalising the trade, increased participation of the private sector, providing subsidies and promotion of its use diverted a significant amount of public and private investment and transfers into factor intensification in the food crop sector. However, this policy was challenged for its unsustainability and policies towards fertiliser use efficiency, and new varieties to withstand biotic and abiotic stress to maintain the potential yield of those varieties became the important policy of the government.

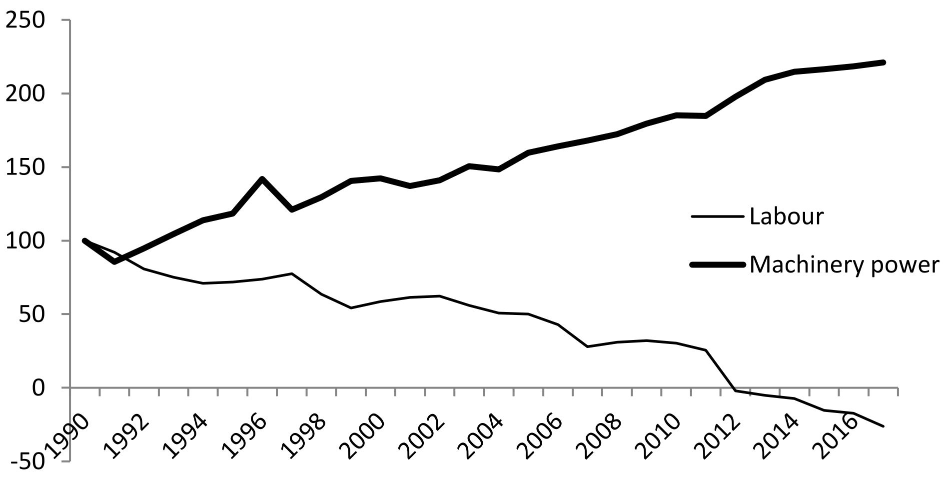
Increasing fertiliser use efficiency became an important policy agenda of the DOA in the mid-2000 against the urea-biased policy which was implemented during the ’90s.

Figure 1: Wage and Machinery Rental Price Normalised by Paddy Price, 2000=100



Source: Author’s calculations

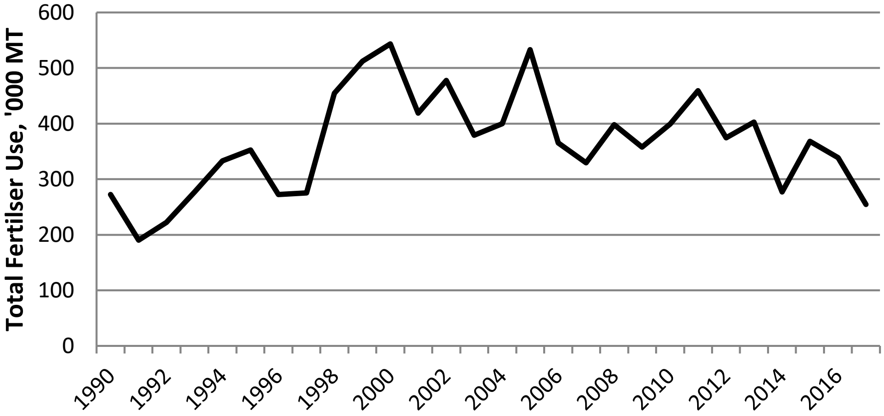
Figure 2: Per Ha Labour and Machinery Use in Paddy Farming, 1990 = 100



Source: Author’s calculations

Promotion of the use of organic matter and micro-nutrients, reduced recommended basal nitrogen application, and introduction of soil testing methods and soil treatment methods received important attention from DOA. Taking fertiliser use to its optimum improves the allocative efficiency of fertiliser and subsequent TFP growth. The Paddy sector reports an 8.5 % annual growth rate of fertiliser use over the period 1990-2000 and the use dropped to the level of the beginning of the 90s (Figure 3). Extension and regulatory elements embodied in the fertiliser policy after 2005 largely accounted for the drop in fertiliser use in addition to the 2013 recommendation revision. Fertiliser use in the paddy sector dropped by 2.82 % p.a. during 2001-2010 and 5.29% p.a. during 2011-2015, while TFP grew by 2.62% and 2.42% p.a. respectively. Nevertheless, fertiliser and irrigation are essential inputs for the realization of advances in varietal technology. The land area under irrigation continued with large budgetary expenditures to increase the cropping intensity and the cultivated extent. Extension of irrigation increases the effective land input.

Figure 3: Fertilizer Use in Paddy Sector, 1990 -2016 Estimated from Cost of Cultivation Data of DOA



Source: Author's calculations

The contract grower system emerged as an institutional innovation for new technology adoption in the late 90s. The contract grower system which was introduced by the central bank in 1999 through its Forward Sale Contract (FSC) program ensured greater participation of farmers in commercializing maize to become the second-largest field crop in the country. This innovation has given solutions to extension systems that had been dilapidated after the devolution of agriculture extension service in the mid-80s by converging farmers to the best performing farmer's level.

Through contract agreements, producers may learn more skills and knowledge relating to the efficient use of resources, methods of input use, record keeping, the significance of product quality and characteristics of different markets. These contribute to improving the productivity of agricultural production (Eaton and Shepherd, 2001). In addition, transaction costs that are clearly in imperfect markets such as agricultural markets in developing countries can be reduced by increasing technical efficiency and allocative efficiency. Theoretically, contract farming is expected to improve the income and productivity of farmers because of risk minimization, access to the market and economies of scale (Simmons, 2002).

Contract farming brought new technology to maize farming and increases the technical efficiency and allocative efficiency by assuring market and input and credit facilities that caused significant TFP growth in the maize sector. With the private sector investments in soybean farming through contract grower systems, the application of agrochemical use has increased. Pre-weedicide application, plant protection chemicals application and nitrogen-fixing bacteria inoculation are some of the management practices encouraged by the private sector. These inputs have components of capital-embodied technology and disembodied technology that increase the TFP. The use of good quality seeds for planting is also a contributory factor for increased TFP with the private sector coming into venturing into soybean production. Soybean experienced a 5.32 p.a. TFP growth during 2010-2016 and output growth of 23 p.a. during the same period due to area expansion under soybeans.

Weather is a very important factor determining TFP in the food crop sector. The years 2016 & 2017 badly affected by drought were excluded from the sub-period analysis of long-term growth. Since the weather has not been explicitly considered in the estimation of TFP growth, in addition to technological and institutional innovations, the effect of weather is also encompassed in the TFP growth measurements.

CONCLUSIONS

A growth accounting method was applied to estimate TFP growth in the Sri Lankan food crop sector for the period from 1990- 2017. The rate of TFP growth by crop was measured using the Tornqvist-Theil index that represents the translog production technology in a competitive market model. The TFP growth performances of all food crops have been relatively improved during the period from 2000-2015 than the period from 1990-2000.

The TFP growth achieved from 2000 can be attributed to technological innovations such as hybrid maize imports, varietal release in the paddy sector, rapid mechanization, quality seed production and institutional innovations. The highest TFP growth of 9.96 p.m. was observed for maize during the period from 2011 -2015 which contributed to about 68% of the maize sector growth. This sector largely benefited through technology spillovers and institutional innovations. New technology in terms of new varieties with higher yields and adaptability was slow to diffuse to other food crop sectors. Paddy sectors showed 2.4-2.6 TFP growth per annum after 2000.

TFP growth estimates in the Sri Lankan food crop sector are lower compared to the trading partners in the region (USDA, ERS; Avila and Evenson, 2004). Technological capital is required for TFP and cost reduction growth by means of investment in agricultural research systems. Investments in technological capital require long-term commitments to investments by Sri Lankan governments and by aid agencies.

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