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Article

Decomposition of Productivity Growth in Sri Lanka's Paddy Sector: Roles of Area Expansion and Chemical Fertilizer Use

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Abstract

Following the policy directive on the ban on imports of chemical fertilizers and pesticides, we decomposed productivity growth in the paddy sector focusing on roles of area expansion and chemical fertilizer use. We examined fertilizer usage in the paddy sector under alternative policy regimes, estimated the elasticities of paddy output with respect to fertilizer application and land under cultivation, and computed total factor productivity of paddy in Sri Lanka creating a basis for evaluating outcomes under non-use of chemical fertilizers. Time series data for the period 1960-2020 extracted from the publications of the Department of Census and Statistics, Central Bank of Sri Lanka and Ministry of Finance of Sri Lanka were used for the analysis. Notwithstanding a secular increase in paddy output and average yield during 1960-2020, the fertilizer usage per unit area started to taper off over the last two decades. The production function estimated using Autoregressive Distributed Lag - Error Correction Model (ARDL-ECM) revealed elasticities of paddy output with respect to harvested area and fertilizer application as 0.41 and 0.23 respectively. The average contributions of area expansion and fertilizer application to output growth were 18% and 35% respectively, suggesting that the contribution of total factor productivity to output growth was 47% during the period 1962-2020. A secular increase in contribution of total factor productivity to output growth has been observed. The contribution of fertilizer to the output has always been positive though it was more pronounced during the early years. The results underline the positive and significant roles played by the chemical fertilizers positing the possible effects under their restrained use.

Keywords:
ARDL-ECM, fertilizer, paddy, production function, total factor productivity growth

1. Introduction

Major macro-nutrients such as Nitrogen, Phosphorous and Potassium (NPK) are vital for agricultural crop production and their application has become an essential component in agricultural production throughout the world. Yet, their improper use causes several adverse environmental effects. For example, when nitrogen and phosphorous reach water bodies, they can cause growth of harmful algal blooms which contaminate surface and drinking water supplies and potentially harm both animal and human health. Environmental costs in the form of soil degradation and water pollution owing to overuse of chemical fertilizer application are well established (Bennett, Carpenter, & Caraco, 2001; Savci, 2012; Sobota, Compton, McCrackin, & Singh, 2015; Yu et al, 2019). Consequently, governments attempt to design and implement fertilizer policies to obtain maximum benefits from balanced use of nutrients while minimizing nutrient pollution problems.

Fertilizer policies in Sri Lanka provide evidence for a good case study. Subsidy to promote chemical fertilizers has been one of the cornerstones of agricultural policy in Sri Lanka. The government of Sri Lanka has provided fertilizers at subsidized rates since 1962. However, during 1990 to 1994 there were no fertilizer subsidies and from 1997 to 2005 subsidies were provided only for urea (Weerahewa, Kodithuwakku, & Ariyawardana, 2010). The country followed a price equalization policy across nutrients for a decade beginning from 2005. As the fertilizer use efficiency depends on the extent to which applications are balanced by the nutrients NPK, ensuring equal price of nutrients followed with the expectation of undoing the excessive use of nitrogen over other nutrients. The series of policies culminated with a complete import ban on chemical fertilizers combined with a subsidy on organic fertilizers and an import licensing scheme. On May 06, 2021, the government suddenly took drastic steps to completely eradicate chemical fertilizers (and chemical pesticides) from the farming systems of the country by imposing a ban on importation of chemical fertilizers[1].Through this policy, the government wished to list Sri Lanka as the first country in the world to make its agriculture toxic free by making the same 100% organic.

Elsewhere, there has been a wide array of policies employed in different countries to address the use of fertilizers. While excessively low use of fertilizers has been a consistent concern in Sub-Saharan Africa, many other countries still rely on subsidy schemes to promote fertilizer use for increased agricultural productivity, and others attempt to promote safe application of fertilizers through establishment of standards and a registration and inspection systems (Weerahewa, Senaratne, & Babu, 2021). As fertilizer usage has been low in Africa (Abate, Abay, & Spielman, 2020), governments have pursued variety of fertilizer policies ranging from state-controlled procurement and distribution systems to wholly private sector–led systems.

Provision of subsidies has been the predominant fertilizer policy instrument of South Asian countries. Even though the fiscal costs of subsidies made by governments in South Asia have been quite large, attempts made to eliminate fertilizer subsidies have not been successful due to economic or political considerations (Kishore, Alvi, & Krupnik, 2021). Global experience, in general, does show a wide range of fertilizer policies aimed at balancing the role of fertilizers in raising productivity and their effects on sustainability and environment. Mahmud, Panday, Mergoum, & Missaoui (2021) further discuss on nitrogen losses and potential mitigation strategies for a sustainable agro-ecosystem. It is interesting to note that eradication of chemical fertilizer has not been the focus of any of these endeavors.

As briefly described earlier, the fertilizer policy of the government of Sri Lanka is characterized by many similarities with those in other countries in terms of subsidization and goals to balance the nutrients and attempts to offset the environmental and health costs. Yet there are several specificities relating to Sri Lanka's fertilizer sector. First, Sri Lanka depends almost wholly on imports for fertilizers where there is almost no domestic production except a small amount of phosphorous production

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[1]On 06 May 2021, Imports and Exports (Control) Regulations No. 07 of 2021 (published in the Gazette Extraordinary No. 2226/48) was issued on mineral or chemical fertilizer banning the importation of some items and imposing import control license for other. On 31 July 2021, Imports and Exports (Control) Regulations No. 11 of 2021 (published in the Gazette Extraordinary No. 2238/45) were issued bringing related mineral or chemical fertilizers under the "import control license" category from the "banned" category (Central Bank of Sri Lanka, 2021).

which is used mainly in plantation crop sector (Weerahewa, Kodithuwakku, & Ariyawardana, 2010). Second, trade policies in terms of tariff and non-tariff barriers play a critical role in Sri Lanka's fertilizer availability and use. Third, the prices at which different fertilizers have been available in Sri Lanka is a direct function of world prices and the size of the subsidy provided by the government. This has been the norm since the introduction of chemical fertilizers way back in the 1960s (Wickramasinghe, Samarasingha, & Epasinghe, 2009; Weerahewa, Kodithuwakku, & Ariyawardana, 2010).

This paper focuses on the paddy sector of Sri Lanka. Of the crop sectors, paddy is likely to be most significantly affected by changes in fertilizer policy environment. Rice, the milled paddy, is the main staple in Sri Lanka. The area sown under paddy in 2019 was 1.117 million hectares (Central Bank of Sri Lanka, 2019) and approximately one million small-scale farmers are engaged in paddy cultivation (Department of Census and Statistics, 2019).

There is undeniably a need in the country to re-design its fertilizer policy framework to restore agriculture productivity in an environmentally sustainable manner. The knowledge on the relationship between fertilizer application and paddy yields is a priority in such investigations. Most previous studies conducted in this regard show a positive and significant relationship between fertilizers and paddy yields. However, direct comparisons of results across different periods are not possible as different econometric techniques and different data sources have been used. The nature of this relationship must have changed over time, owing to changes in technologies, bio-physical environment, awareness of farmers, and policies. Future government incentives should recognize such changes.

This paper fills this void by estimating a production function to determine the fertilizer and area response of paddy production. It then determines the size of productivity growth and decomposes growth in the paddy sector into its components, i.e., area expansion and chemical fertilizer use while attributing the residual to productivity growth. We examine such under alternative policy regimes, creating a basis for evaluating potential outcomes under non-use of chemical fertilizers.

More specifically, the objectives of this paper are three-fold; firstly, it examines fertilizer usage in the paddy sector under alternative fertilizer reform policies, secondly it estimates the elasticity of paddy output with respect to fertilizer application and thirdly it computes the Total Factor Productivity (TFP) of paddy in Sri Lanka. We estimate the production function of paddy, employing Autoregressive Distributed Lag-Error Correction model (ARDL-ECM) to estimate the elasticities of area and fertilizer use.

The paper is organized as follows. The following section presents an account summarizing the overtime evolution and variation in policies related to the main inputs, i.e. land and fertilizers and a review of previous empirical studies. Next, the model and data used for the estimation is presented. Results and discussion are presented after and the paper ends with conclusions and policy implications.

2. Review of literature

2.1 Landscape of fertilizer in Sri Lanka and fertilizer policies

Table 1, drawn from Atapattu (2021) and Weerahewa, Kodithuwakku, & Ariyawardana (2010), provides the timeline of different fertilizer subsidy schemes in Sri Lanka. There is a rich set of policies that Sri Lanka has possibly uniquely followed over time including canalization, on and off provisions for private imports, price regulations and changes in the rates of subsidies particularly across different nutrients and crops.

As evident from Table 1, the diverse set of policies that includes complete elimination of subsidies (1990-1994), reintroduction of subsidy or restricting to urea (1995 - 2004) and NPK price equalization for a decade from 2005. This was followed by a direct cash transfer system for fertilizers. It is probably safe to say that no other country in the world offers such a rich portfolio of experiments in relation to fertilizer policies. From a research perspective, these experiments offer great opportunities to understand the role of policies in influencing agricultural outcomes. Partly as the COVID response, there has also been a phase in Sri Lankan policies that includes allotment of fertilizers completely free.

Table 1: Elements of different fertilizer subsidy schemes in Sri Lanka

Period	Subsidy regime	Policies
1962-1989	Provision of fertilizer subsidy for all three types of fertilizer (NPK)	• Introduction of fertilizer subsidy at a fixed subsidy rate to accelerate the adoption of new improved rice varieties (1962) • Banning the fertilizer importation by private sector and fertilizer importation becoming a monopoly of the Ceylon Fertilizer Corporation (1971) • Expansion of fertilizer subsidy for crops other than paddy (1975) • Allowing private sector to import fertilizer (1977) which was previously done only by state corporations • Introducing a uniform subsidy rate (50% of the cost, insurance, and freight (CIF) price) (1978) • Revision of the subsidy rates (85% for urea and 75% for other fertilizer) (1979) • Reduction of subsidy rate and elimination of subsidy for sulphate of ammonia and rock phosphate (1988)
1990-1994	Complete removal of the fertilizer subsidy	
1995-2004	Reintroduction of fertilizer subsidy for all three types of fertilizer (NPK) (1995) Limitation of the subsidy to urea (1997)	• Fixed price of LKR 350 for 50kg bag for all 3 fertilizers (1994) • Increment of price of 50kg bag to LKR 600 (1996) • Restriction of subsidy to urea only at LKR 350 per 50kg bag (1997) • Increment of price of 50kg bag to LKR 800 (2003) • Fixing price level of 50kg bag at LKR 600 (2004)
2005-2015	Expansion of subsidy over all three types of fertilizer (NPK)	• One fixed price for N, P and K at LKR 350 per 50kg (2005) • For paddy, restricting fertilizer quantity to amounts recommended by Department of Agriculture up to 5 Ac per farmer • Differentiating subsidy rates for paddy and other crops, extending to vegetables and tea (2008) and coconut (2010) at a difference price

2016-2020	Cash grant (2016 Yala-2018 Yala) Reintroduction of subsidized fertilizer (2018 Maha) Provision of free fertilizer for paddy (2020)	• Cash payment of LKR 25,000/ha/year up to 2 ha for paddy (2016 Yala-2018 Yala) • Ceiling price for NPK at LKR 2,500 per 50kg (2016 Yala-2018 Yala) • Cash payment of LKR 10,000/ha/year up to 1 ha for potatoes, onions, chilli, soya beans and maize (2016 Yala-2018 Yala) • Issuing subsidized fertilizer for LKR 500 per 50kg for paddy and LKR 1500 per 50kg for other crops

Sources: Atapattu (2021); Weerahewa, Kodithuwakku, & Ariyawardana (2010)

Though there have been a variety of land and fertilizer related policies in place, the most recent policy measure discussed above stands out in terms of its radicalness. As indicated, on May 06, 2021, the government of Sri Lanka decided to ban the importation of chemical fertilizers and agrochemicals (including insecticides and herbicides) without paying attention to benefits received from programs that drive rational use of fertilizers. The decision came into effect with the publication of the Sri Lanka Gazette No. 2226/48 of May 06, 2021. The regulation was applicable to the import of items under 9 HS headings, including chemical fertilizers (16 items at HS 8 level) with bills of lading/air waybills issued on or after May 06, 2021. The intention of the government was stated as making a "poison free country" by reducing the use of agrochemicals which causes serious health issues such as Chronic Kidney Disease of unknown etiology (CKDu) and to save the foreign exchange (Ranasinghe, 2021).

Apart from the environmental guardianship guiding the recent move towards completely organic agriculture (subsequently loosened to a licensing system), the economic reason behind banning of chemical fertilizer imports is largely dictated by the implications for foreign exchange requirements since almost whole of fertilizer needs of Sri Lanka are met through imports. The drawdown of foreign exchange reserves is ostensibly the driver of attempts to curtail expenditure on chemical fertilizers indeed under the assumption that organic fertilizers as a substitute would be using comparatively less reserves after accounting for quality differentials[2].

However, the ban was relaxed by Sri Lanka Gazette No. 2238/45 of July 31, 2021 which permitted licensees to import items under 6 HS headings which includes chemical fertilizers (11 items at HS 8 level) such as urea for cultivation in the forthcoming Maha season ("Sri Lanka Relaxes Fertilizer Ban", 2021, August 3). According to this decision the specialized fertilizers can be imported through the Department of Agriculture and other relevant institutions under a special licensing system. The licenses permit packets of compound fertilizers containing the three plant nutrients, namely mineral or chemical NPK, or capsules containing a mixture of two of them, or packets weighing 10kg or less containing such products (Farzan, 2021)[3].

[2] There is moreover a general equilibrium effect of fertilizer trade reducing policies from a foreign exchange reserves perspective. If comparatively low usage of chemical fertilizers were to lead to reduced production and productivity, the import bills could go up on the output side if near self-sufficiency in rice were to recede without or significant reduction in fertilizer use. This could lead to a rebound effect in terms of increased demand for foreign exchange to meet the output import (rice) needs.

The fertilizer imports in Sri Lanka have always been sizable in Sri Lanka. Figure 1 and Figure 2 summarize the profile of rice production and imports along with that of the fertilizers. In 2020, Sri Lankan imports (both state and private sector) of fertilizers reached $259 million, representing 1.6 percent of the country's total imports by value (Central Bank of Sri Lanka, 2020). Fertilizer imports as a fraction of food imports into Sri Lanka was 10% in 2019 whereas it was 28% and 15% in India and Pakistan respectively. The production of organic fertilizer was highly encouraged in Sri Lanka together with the chemical fertilizer ban, and a compensation was guaranteed for any loss of production due to lack of fertilizer ("Chemical Fertilizer Ban Lifted?", 2021). By September 2021, the country opened up its border to import organic fertilizer to meet the deficit requirement.

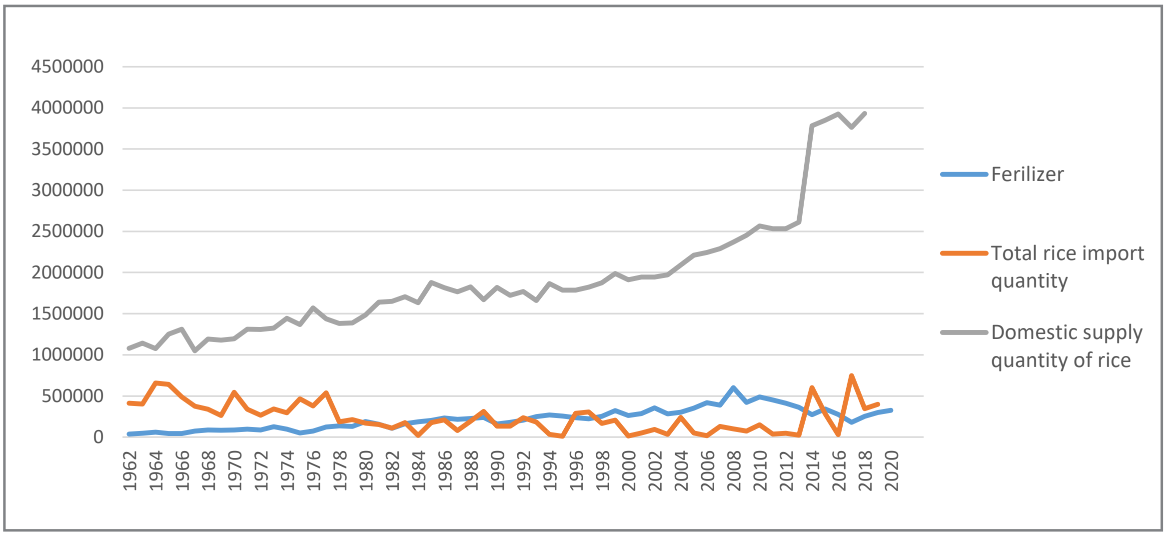

Figure 1: Rice production and imports of rice and fertilizer (in metric tons)

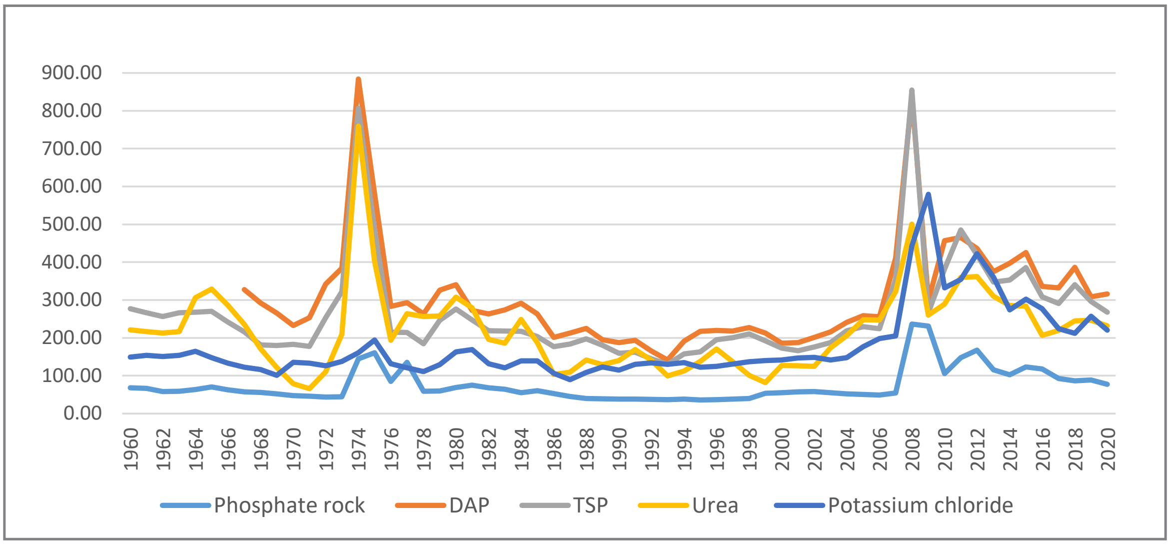

Figure 2: World prices of different fertilizers in real terms (USD/mt) (Base year=2010)

[3] This program is akin to starter program that Malawi and other countries had but the program was a dispensation stage, here it is at import stage.

Over time, due to substantial increases in productivity in paddy, inter alia intensification through the application of fertilizers played a role, it resulted in Sri Lanka becoming nearly self-reliant in rice. This is reflected in nearly zero imports of rice. However, in the counterfactual of no or restricted use of chemical fertilizers, the outcome is not known. The domestic production has exhibited a significantly positive trajectory over time which had a bearing on near zero rice imports of Sri Lanka.

Apart from this, for the import bill of fertilizers, what also matters is the world price. Figure 2 plots the behavior of prices in constant dollars. The world prices in real terms of different fertilizers have been quite variable with two distinct spikes during the oil shock in the 1970s and the food fuel crisis of 2008. During such shocks, adjustments on the extensive margins are comparatively difficult i.e., forming new trading relationships, exploring new suppliers is harder and it involves significant fixed costs. The intensive margins tend to be more resilient during such large shocks.

Tables A.1 and A.2 in the appendix show the fertilizer import policies in Sri Lanka right before the import ban on May 06, 2021, after imposition of the ban and after relaxation of the ban on July 31, 2021. Note that additional to the details mentioned in Table A.1, importation of fertilizer is regulated under the Regulation of Fertilizer Act (No. 68 of 1988) which concerns the importation, manufacture, formulation, and distribution of fertilizers in Sri Lanka. Under this regulation, the importation of fertilizers requires a license issued by the Director of the National Fertilizer Secretariat and there are also provisions relating to packaging and labelling of fertilizers.

2.2 Agriculture land policies of Sri Lanka

Apart from chemical fertilizer use that determines the production and productivity in rice, a principal is land input i.e., area sown. From the colonial times where land was vested in the ruling elite, the first substantive transition came in the form of the land acquisition act of 1950, where land was allocated to peasants. The land ceiling regulations in 1972 and 1976 restricted land ownership and acts in 1979 worked on tenant rights. Though several land policies have tried to make land more widely available, the choice of extent sown has been restricted owing to land scarcity.

Table 2: Summary of land policies in Sri Lanka

Period	Policies
Pre-colonial	• All lands were considered as belonged to the king • Lands were granted to people either for a payment or as a return for services rendered • Some lands were given for religious activities to Buddhist temples (called as "*Viharagam*") and Hindu temples (called as *"Dewalgam"*) • Ownership rights were transferred based on long term use ("*Paraveni* tenure") • A tax on agricultural lands was charged by the kings
Colonial	• Under the Crown Land (encroachment) Ordinance No. 12 of 1840 lands without any documentary evidence for ownership were acquired by the Crown. Almost 90% all the lands were acquired to the British rule and thereby created landless peasant sector in the country • In 1897, the Waste Land Ordinance was enacted to prevent the encroachment of Crown waste lands

	• The acquired lands were given to various government departments, projects and alienated for land settlements land grants and leaseholds • In 1927, first Land Commission was established in order to improve welfare of the peasants • The Land Development Ordinance (LDO) was enacted in 1935 • A rapid land settlement began from mid-1930s and continued up to mid-1980s. The holding size of the lands alienated during this period was 8 acres
1948-1977	• The Land Acquisition Act of 1950 acquired lands and alienated among the landless along with free water through a canal system and 2 ac of highland. Low land extent granted was 5 ac in the beginning and reduced to 1.5 ac from 1935 to 1960s • Amendments were made to the Irrigation Ordinance of 1946 in 1951 and 1968 specifying the division of responsibility between the cultivators and the Irrigation Department for maintaining and operating the irrigation system • The Paddy Lands Acts of 1953 and 1958 enacted to secure the rights of tenants • The Land Reform Act No. 1 of 1972 established Land Reform Commission • The Land Reform Acts in 1972 and 1976 imposed a ceiling (50ac highland, 25 ac lowland) on private ownership • Large extents of plantations were nationalized • The Land Reform Commission leases lands and the public could identify land plots under LRC and apply for long term leases with an investment plan • Agriculture Productivity Law No. 22 of 1972 was enacted to ensure that lands acquired, private lands and lands in settlement are properly utilized and developed • Agrarian Services Act of 1979 also aimed at securing tenure rights of tenant cultivators of paddy and improving productivity of paddy lands
1978-2020	• Accelerated Mahaweli Development Program was initiated in 1977. The State Land (Recovery of Possession) Act No. 07 of 1979 and Land Grant (Special Provisions) Act No. 43 of 1979 were enacted to distribute lands under Mahaweli Development Program • Land Development (amendment) Act No. 27 of 1981 provided legal provisions to mortgage the lands only to prescribed banks and institutions • Registration of Title Act No. 21 (1998) was enacted to provide clear titles to lands • The Agrarian Development Act No. 46 of 2000 and the Amendment Act No. 46 of 2011 constituted legal environment on matters relating to landlords and tenant cultivators of paddy lands and restricts cultivation of paddy lands (lowland) only to paddy • Land Title Registration Program (*Bim Saviya*) in 2007 was launched to strengthen ownership of land

Source: Weerahewa, Hemachandra & Pushpakumara, 2021

2.3 Pattern of fertilizer use and paddy yields of Sri Lanka

Figure 3 presents the paddy yields and fertilizer use across the three-time period 1961-1980, 1981-2000 and 2001-2020. Strikingly, in the last two decades the fertilizer application of Sri Lanka has witnessed a significant decline in terms of kg/ hectare. This decline can be attributed to three aspects. The first is the reductions in distribution of fertilizers associated with revision of fertilizer recommendations (Sirisena & Suriyagoda, 2018), the second is the voluntary reductions associated with the switch to cash grant scheme (Atapattu, 2021), and the third is the productivity gains associated with good agricultural practices.

2.4 Estimation of paddy output elasticities

Several studies have estimated the production function of paddy using micro level farm data and calculated input elasticities including fertilizer elasticity (Hafi, 1985; Karunaratne & Herath, 1989; Gunaratne and Thiruchelvam, 2002; Illukpitiya & Yanagida, 2004; Udayanganie, Prasada, Kodithuwakku, Weerahewa, & Little, 2006; Gedara, Wilson, Pascoe, & Robinson, 2012; Shantha, Ali, & Bandara, 2013; Warnakulasooriya and Athukorala, 2016).

Only few studies have estimated the relationship between paddy production and fertilizer using aggregate time-series and/or panel data (Weerasooriya & Gunaratne, 2010; Kanthilake & Weerahewa, 2016). Rajapaksha & Karunagoda (2009) analyzed the impact of fertilizer subsidy on paddy supply and fertilizer demand using biannual data from 1990 to 2006. The authors derived the factor demand for paddy cultivation using translog profit function and estimated input demand and supply response elasticities for four different districts representing various agro climatic regions. Hasanthika, Edirisinghe, & Rajapakshe (2014) estimated the paddy production function with related risk properties to see how variation in climatic variables and production factors affect the probability distribution of paddy yields. The study has used data which consisted of a panel of six major paddy growing districts for the period, 1980 to 2010 for the two major paddy growing seasons, *Yala* and *Maha.*

Table 3 presents a summary of estimated elasticities with respect to different inputs comprising fertilizer, labor, and land. These have been commonly used as variable inputs in the derivation of production function whereas, land, machinery, capital have been used as fixed factors. However, fertilizer elasticities found from these studies show a wide range of heterogeneity. This may have been attributed to the study location, time period, unit of analysis, type of data (cross sectional, panel or time series), or econometric techniques used. For a complete review paddy production function in Sri Lanka, see Weerasooriya & Hemachandra (2020).

Distinct from previous studies, current study examines the long-run and short-run effect of fertilizer on paddy production in Sri Lanka over the period 1962–2020 by using the ARDL-ECM approach proposed by Pesaran, Shin & Smith (2001).

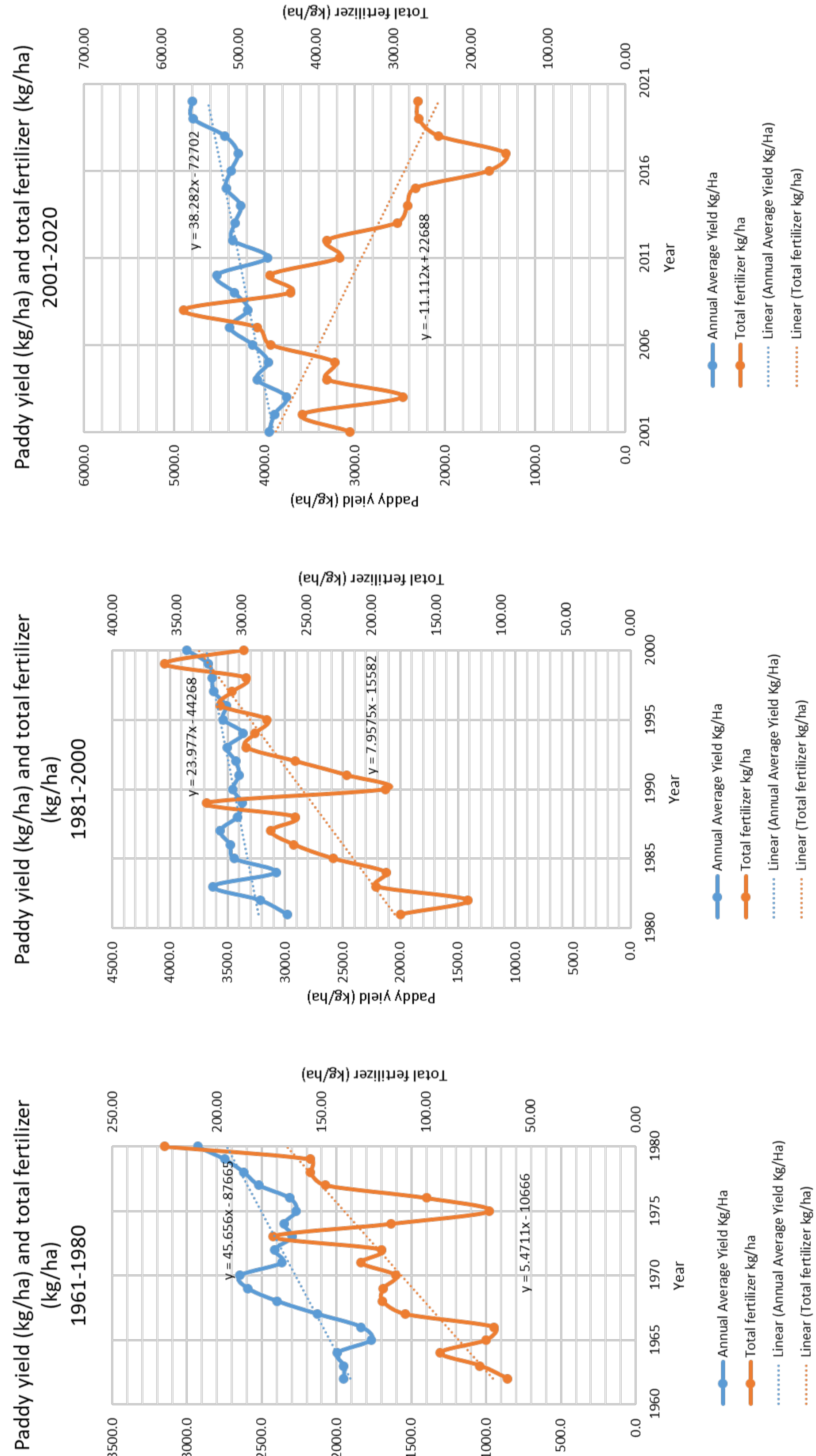

Figure 3: Trends in fertilizer use and paddy yields by period

Table 3: Summary of estimates of elasticity of paddy production with respect to input use

Study	Types of data	Data period	Functional specification	Estimation method	Elasticities		
					Fertilizer	Labor	Land
Abeysekera (1980)	Cross-sectional	1972/73 Maha	Cobb-Douglas	OLS	0.598	0.203	0.257
Hafi (1985)	Cross-sectional	1983/84	Cobb-Douglas Stochastic Frontier	OLS MLE	0.003 0.003	0.098 0.116	0.329 0.333
Kotagama (1986)	Cross-sectional	1981 Yala & 181/82 Maha	Cobb-Douglas	OLS	0.174	0.42	0.463
Ekanayake (1987)	Cross-sectional	1984/85 Maha	Cobb-Douglas Stochastic Frontier	MLE	0.262	0.145	0.76
Karunatane & Herath (1989)	Cross-sectional	1986 Yala & 1986/87 Maha	Cobb-Douglas Stochastic Frontier	OLS	0.028 -0.065	0.018 0.652	0.874 0.512
Gunaratne & Thiruchelvam (2002)	Cross-sectional	2000/01 Maha	Cobb-Douglas Stochastic Frontier	MLE	0.198	-0.119	0.265
Illukpitiya & Yanagida (2004)	Cross-sectional	1989/99 Maha	Cobb-Douglas	OLS MLE	0.347 0.32	0.062 -0.024	0.471 0.522
Tiruchelvam (2005)	Cross-sectional	2000/01 Maha	Cobb-Douglas Stochastic Frontier	MLE	-0.191	0.099	0.418

Udayanganie et al (2006)	Cross-sectional	2003/04 Maha	Cobb-Douglas Stochastic Frontier	MLE	0.01	-0.001	0.68
Gedara et al (2012)	Cross-sectional	2009/10 Maha	Translog	MLE		0.16	
Shantha, Ali, & Bandara (2012).	Cross-sectional	2009/10	Cobb-Douglas Stochastic Frontier Translog	MLE MLE	0.396 0.282	0.463 0.35	0.403 0.347
Kanthilaka & Weerahewa (2016)	Panel	2005-2016 Aggregate Data	Cobb-Douglas	OLS	urea 0.229 MOP 0.030 TSP -0.075	-0.006	
Waranakulasooriya & Athukorala (2016)	Cross-sectional	2009 Yala & 2009/10 Maha	Cobb-Douglas Stochastic Frontier	MLE	Yala 0.145 Maha 0.219	0.122 0.089	0.681 0.441
Weerasekara, Wilson, Lee, & Hoang (2021)	Panel	2000-2017 22 Districts	Cobb-Douglas Translog	MLE MLE	0.297 1.342	-0.123 0.648	0.748 -0.541
Mean Standard Deviation					0.217 0.318	0.169 0.226	0.442 0.304

Source: Extended version of Weerasooriya and Hemachandra, 2020

2.5 Computation of productivity growth

No attempt has been made so far to compute growth of (TFP) of paddy in Sri Lanka. However, a few estimates for TFP of the agriculture sector are available. According to Avila and Evenson (2004) as cited in Kumar, Mittal, & Hossain (2008), the average growth in TFP of crop agriculture during 1961-1980 period and 1981–2001 period were -0.39 and -1.21 respectively. Despite high irrigation infrastructure, the agricultural growth in Sri Lanka was the lowest among the South Asian countries as per the comparative study done by Kumar et al (2008).

Fuglie (2017) provides internationally consistent and comparable agricultural TFP growth rates for agriculture. Most data on production and input quantities used in his analysis came from Food and Agriculture Organization (FAO). TFP growth of agriculture has been calculated by subtracting input growth from smoothed output growth which was calculated by smoothing the gross agricultural output for annual fluctuations by using the Hodrick-Prescott filter at Lambda equal to 6.25. Input growth is calculated by aggregating the growth rates of land, labor, livestock (for draught), machinery and fertilizer. TFP growth in agriculture sector of Sri Lanka computed by Fuglie (2017) demonstrates that it has been erratic. The estimates of growth rate was estimated to be 1.20 percent during 2001-2014 period and it explained approximately half of the output growth. However, the estimates by Fuglie (2017) does not provide TFP by different sub-sectors of agriculture.

A decomposition of annual average percentage changes in total agriculture output growth into irrigated lands, new land expansion, yield growth, material input usage and TFP in Sri Lanka 1961-2014 using the estimates of Fugile (2017) provides some interesting findings. They show the decade prior to 1970 and the period after the ending of civil strife, i.e., from 2009, the output growth was largely due to bringing back the areas abandoned into cultivation. The contribution of TFP to output growth has been the highest during 1971-1980 and the contribution of TFP was negative during the period 1981-1990 as per the estimates. Despite the steady increase in fertilizer application over the period 1961-2014, its contribution to output growth was found to be moderate.

Bandara & Karunaratne (2013) found a growth in TFP in food manufacturing and industrial sectors in Sri Lanka during 1978-1998. Swarnathilake, Weerahewa, & Bandara, (2019) found that the average TFP growth in Sri Lanka's food manufacturing industries was negative (−0.61%) for the 1978–2014. The average TFP growth had improved over time from −2 percent during the 1978–1994 sub-period to 0.7 percent over the 1994–2014 sub-period. Furthermore, large-scale food manufacturing industries achieved higher TFP growth compared to that of their small-scale counterparts. Distilling, rectifying spirits, manufacture of grain mill products and prepared animal feeds industries showed a positive and higher TFP growth while cocoa, chocolate and confectionery industries demonstrated a lower TFP growth.

3. Methodology

3.1 Empirical model

A Cobb-Douglas production function was specified in the log form to estimate the fertilizer response of paddy in Sri Lanka for the period 1962-2020.

$$\ln Y_t = \propto + \beta_1 \ln F_t + \beta_2 \ln A_t + u_t \qquad (1)$$

Where, Y is paddy production which is a function of fertilizer (F) and area under paddy production (A) and u_t is the stochastic error. Since all variables are in natural logarithm form their coefficient can be represented in the form of elasticities.

Following Nwani & Bassey (2016); Nwani, Iheanacho, & Okogbue (2016); Chandio, Jiang, Joyo, & Pickson (2018), the present paper uses the ARDL bound testing approach proposed by Pesaran et al (2001). The ARDL approach provides some desirable advantages over the other traditional cointegration approaches such as Engle Granger (EG) and Johansen-Julius Cointegration Approach (JJCA). On the other hand, these cointegration approaches require that all variables be integrated into the same order. The ARDL test process provides effective results, whether the variables are integrated at I(0) or integrated at I(1) or mutually cointegrated (Pesaran et al, 2001). A small size of observations and several orders of integration of the study variables make ARDL the preferred method of this study. The equation of an ARDL model is specified as:

$$\Delta \ln Y_t = \propto_0 + \sum\nolimits^{p}_{i=1} \propto_{1i} \Delta \ln Y_{t-i} + \sum\nolimits^{q}_{i=1} \propto_{2i} \Delta \ln F_{t-i} + \sum\nolimits^{q}_{i=1} \propto_{3i} \Delta \ln A_{t-i} + \beta_1 Y_{t-1} + \beta_2 F_{t-1} + \beta_3 A_{t-1} + e_t \qquad (2)$$

where, ΔlnY, ΔlnF, ΔlnA are the first differences of the logarithms of total paddy production (ln Y), total fertilizer issued (ln F), and extent of paddy sown (ln A), respectively. e_t is a disturbance term assuming white noise and normal distribution. p and q are the lags used for the dependent and independent variables respectively.

The first step in the ARDL bound testing approach is to estimate Equation (2) by ordinary least squares in order to test for existence of a long-run relationship among the variables. Conducting an F-test for the joint significance of the coefficients of the lagged level variables is required using critical value bounds for the F-statistic (Pesaran et al, 2001). If the computed F-statistic falls below the lower bound critical value, the null hypothesis of no-cointegration cannot be rejected. Contrary, if the computed F-statistic lies above the upper bound critical value; the null hypothesis is rejected, implying that there is a long-run cointegration relationship amongst the variables in the model. Nevertheless, if the calculated value falls within the bounds, inference is inconclusive. In the second step, once cointegration is established, the conditional ARDL long-run model for Y_t can be estimated as:

$$\ln Y_t = a_0 + \sum\nolimits^{p}_{i=1} b_{1i} \ln Y_{t-i} + \sum\nolimits^{q}_{i=1} b_{2i} \ln F_{t-i} + \sum\nolimits^{q}_{i=1} b_{3i} \ln A_{t-i} + u_t \qquad (3)$$

where, all variables are previously defined. This involves selecting the orders of the ARDL (p, q) model using Schwarz Bayesian Criterion (SBC). In the third and final step, we obtain the short-run dynamic parameters by estimating an error correction model associated with the long-run estimates. This is specified as follows:

$$\Delta \ln Y_t = a_0 + \sum\nolimits^{p}_{i=1} a_{1i} \Delta \ln Y_{t-i} + \sum\nolimits^{q}_{i=1} a_{2i} \Delta \ln F_{t-i} + \sum\nolimits^{q}_{i=1} a_{3i} \Delta \ln A_{t-i} + \lambda ECT_{t-1} + v_t \qquad (4)$$

where, a_1, a_2, and a_3 are the short-run dynamic coefficients of the model's convergence to equilibrium and λ is the speed of adjustment parameter and ECM is the error correction term that is derived from the estimated long-run equilibrium relationship.

3.2 Computation of TFP growth

In measuring productivity of an operation, two measures namely partial productivity and TFP have been used. Partial productivity measures treat one factor at a time and illustrate output per unit of factor under consideration. Land productivity that measures output per unit area and fertilizer productivity that measures output per unit of fertilizer are two examples of partial productivity measures. They are the average products. One of the limitations of partial productivity measures is their inability to accommodate changes in other inputs. For example, an increase in land productivity could be due to usage of more of other inputs such as fertilizers, pesticides, machinery etc. TFP accommodates changes in all inputs and measures productivity of the entire operation. TFP compares the rates of increase in all inputs and those with the total amount of output. If total output is growing faster than the rate of growth in total inputs, there exists a growth in productivity in all inputs, i.e., TFP growth.

Consider the Cobb-Douglas production function specified in equation (1). The β_1 and β_2 correspond to the shares of area and fertilizer in output, given the factors of production are paid their marginal product under the perfectly competitive market environment. They are the input elasticities and they capture marginal productivity as opposed to average productivity. According to the residual approach, the TFP growth is the residual of output growth once the growth of inputs has been accounted for. Thus, TFP growth can be obtained as follows:

Growth in TFP_t = Growth in Y_t - β_1* Growth in A_t + β_2* Growth in F_t

Note that β_1 and β_2 which represent the intensities of input use are used in the computation of growth of TFP. The contributions of TFP, extent and fertilizer to the growth in total output can be computed for each period as follows.

Contribution of TFP = (Average growth in TFP/Average growth in Y)*100

Contribution of Extent = (Average growth in A/Average growth in Y)*100

Contribution of Fertilizer = (Average growth in F/Average growth in Y)*100

3.3 Data sources

Annual data for the period 1961-2020 were used in the study. The data for annual paddy production and the total extent of paddy sown were obtained from the Paddy Statistics of Department of Census and Statistics and Central Bank of Sri Lanka (CBSL).

Data on fertilizer usage were obtained from National Fertilizer Secretariat for the period of 1962-2007 and from CBSL for the period of 2008-2015. As the cash grant for fertilizer was introduced in the 2016 Yala season, the fertilizer usage data were not available for the same season. Therefore, an approximation for annual fertilizer use was done for the year 2016 by adding the fertilizer usage of 2015/2016 Maha season obtained from Annual Report Ministry of Finance 2016, and a half of the usage of the 2015/2016 Maha season as the usage of Yala season (as the extent sown in the Yala season is approximately half of that of Maha season). For 2017-2018 period fertilizer usage data were obtained from the AgStat publication of the Department of Agriculture. For the year 2019 and 2020, inconsistencies were observed in the different sources namely CBSL, Annual Report Ministry of Finance, and AgStat. CBSL data were used in this analysis.

Table 4 presents descriptive statistics for the entire period of the dataset. Few facts stand out in the data. There is comparatively a low variation in paddy sown area with a relatively larger variation in production indicating role of productivity. There has been a large variation in total fertilizer use which could be a function of the policies as well as international prices of fertilizers.

Table 4: Descriptive statistics for the period 1960-2020

Measure	Paddy production ('000 mt)	Extent of paddy sown (ha)	Total fertilizer use (mt)
Mean	2,525.51	862,964	221,767
Median	2,477	844,000	224,500
Standard Deviation	1,083.35	159,231	127,080
Coefficient of Variation (%)	42.90	18.45	57.30
Kurtosis	-0.34668	0.14207	0.1215
Skewness	0.501341	0.71994	0.59597
Minimum	758	590,000	38,100
Maximum	5,120.92	1,254,000	602,000
Count	59	59	59

Source: Authors' calculations

4. Results and discussion

4.1 Partial productivity measures

Table 5 presents the partial productivity of land and fertilizer across different fertilizer policy regimes. The highest fertilizer productivity and land productivity was observed during the nutrient price equalization i.e., 2005-2015. Results on partial productivity show highest returns when NPK are handled as a combination in terms of subsidization where relative price distortions are minimized. Yet, nutrient price equalization might not be the cause as relative price ratio of 1:1:1 is not likely to translate into optimal NPK ratios.

Table 5: Partial productivity of fertilizer and land and fertilizer use by subsidy regime

Period	Subsidy regime	Partial productivity		Fertilizer use (metric tons of fertilizer/ha)
		Fertilizer (metric tons of paddy/metric ton of fertilizer)	Land (metric tons/ha)	
1962-1989	All NPK	15.31	2.17	0.16
1990-1994	No subsidy	12.13	2.96	0.25
1995-2004	All NPK/ only for urea	9.67	3.20	0.34
2005-2015	All NPK for 350	9.71	3.69	0.40
2015-2020	Mixed policies	15.21	3.80	0.25
1962-2020	**Pooled**	**12.99**	**2.83**	**0.25**

Source: Authors' calculations

4.2 Unit root analysis and econometric estimation

First, the stationary properties of the variables in the production function were tested using the Augmented Dickey Fuller (ADF) unit root test to avoid spurious results. According to the results (see Tables A.3 and A.4 in the appendix) the explanatory variables are a mixture of both I(0) and I(1). Therefore, the bound testing procedure was employed (Pesaran & Pesaran, 1997; Pesaran & Shin, 1999; Pesaran et al, 2001) within an ARDL to test for cointegration relationships. The bound testing approach for cointegration is applicable irrespective of the order, I(0) or I(1), in which the regressors are integrated (Pesaran & Pesaran, 1997). As per the bound testing results (see Tables A.3 and A.4 in the Appendix), the existence of the cointegration relationships was confirmed. These results imply that the stable long-run relationships can be observed between the paddy production and its determinants for the period 1962-2020.

Once the existence of cointegration relationship among the variables was confirmed, equation (3) was estimated for the long-run coefficients of the selected ARDL (1, 1) model based on the SBC and its results are presented in Table 6. The results reveal that the estimated coefficients of extent sown and fertilizer are positive and significant at one percent level. It shows that in the long run, one percent increase in the fertilizer use leads to 0.23 percent increase in the paddy production all things being equal. Further, one percent increase in the extent sown leads to 0.41 percent increase in paddy production. The production function exhibits diminishing returns and the optimal input usage depends on the relative prices of inputs. Table 3 presented a comparison of elasticities with respect to fertilizer, labour and land use in paddy farming in Sri Lanka, as reported in previous studies. Most of these studies in the past have used cross-sectional data. Current study used annual time series data over the period 1962–2020 and followed ARDL approach to cointegration in order to examine the short-and long-run association in the model with desired variables. However, our elasticities are broadly similar to the mean values of elasticities reported in other studies. This lends confidence to our estimates, the selection of the functional forms and the econometric approach.

Table 6: Estimated long-run coefficients using the ARDL (1, 1) approach

Variable	Coefficient	Standard error
Extent sown	0.409*	0.214
Fertilizer	0.233**	0.090

***, * Significant at 5%, 10% level, respectively*
Source: Authors' calculations

The results of short-run dynamic coefficients associated with the long run relationships obtained from the ARDL-ECM equation (4) are presented in Table 7. The optimal lag length for the selected error correction representation of the ARDL (1, 1) model is determined by the SBC.

Table 7: Error correction representation for the selected ARDL (1, 1) model

Variable	Coefficient	Standard error
Extent sown	1.046***	0.108
Fertilizer	0.152***	0.054
ECT	-0.134*	0.060

****,* Significant at 1% and 10% level, respectively*
Source: Authors' calculations

Table 7 shows that the estimated error correction coefficient is negative and significant at one percent level ensuring that the adjustment process from the short-run deviation is quite slow. More precisely, it indicates that only 13 percent of the disequilibrium in paddy production from the previous period's shock will be converged back to the long-run equilibrium in the current period. The estimated coefficient of fertilizer and extent sown are positive and significant at one percent level. Further, this implies that in the short run, one percent increase in the fertilizer use leads to 0.15 percent increase in the paddy production all things being equal.

4.3 Decomposition of output growth and computation of TFP

The estimation results above show how paddy output changed when area under paddy cultivation and fertilizer application to paddy lands, when all the other inputs contributing to paddy output are held at constant levels. Such inputs include irrigation, research, extension, weather, credit and insurance. The following section presents the contributions of fertilizer, area expansion and combined effect of all other factors to paddy output growth.

The detailed results of the computation of TFP are shown in Table 8 and Figure 4. Detailed data illustrate that during 1962-2020, paddy output grew at a rate of 0.045 and fertilizer use and extent grew at rates of 0.0686 and 0.0196 respectively. Table 8 shows the weighted growth rates, which were computed by multiplying growth rates of fertilizer and extent by their elasticity values. They were 0.016 and 0.008 for fertilizer and extent respectively suggesting that the composite growth rate of the two inputs was 0.024. These values indicate that contribution of all other factors to output growth, which was the TFP, was 0.021. The percentage contribution of TFP, fertilizer and extent were 47%, 35% and 18% respectively for the period 1962-2020 as shown in the last row of Table 8.

Computation of similar indices for different subsidy regimes reveal how fertilizer policy influenced fertilizer use and its contribution to output growth. The period 1962-1989 is characterized by a heavy subsidy on all three nutrients, NPK, and a marginal expansion of area under consideration. Fertilizer use during this period increased at a faster rate due to the subsidy and 66% of output growth was owing to fertilizer use. The extent grew at a slower rate and the contribution of extent to output growth was 10%. During 1990-1994, fertilizer was not subsidized and its contribution to output growth was only 18%. During this period, land expansion for paddy cultivation has been significant.

Output as well as input growth was relatively slower during 1995-2004 though fertilizer subsidy was reinstated. The highest contribution to output growth was TFP during this period. When '*Kethata Aruna*' was introduced in 2005, it was tagged to a quota (only a limited quantity approved by the Department of Agriculture was given) hence a slower rate of growth of fertilizer was recorded even though this period shows the highest usage of fertilizer as shown in Table 8. During this period too, the highest contribution to paddy output growth was by TFP which was 59%. Since 2015, fertilizer policy has been ad-hoc (including a cash grant program in place of a price subsidy) and the rate of growth of fertilizer use was very slow. The largest contribution to output growth was from the TFP.

5. Conclusions and implications for policy

This study examined the long-run and short-run effect of fertilizer on paddy production in Sri Lanka over the period 1962–2020 by using the ARDL-ECM approach proposed by Pesaran et al (2001). It was found that the elasticities of paddy production with respect to fertilizer use, as well as that of extent under cultivation, were positive and statistically significant in both the short-run and long-run.

Table 8: Results of the TFP calculation by subsidy regime

Period	Subsidy regime	Average growth				Contributions to growth (%)		
		Output	TFP	Fertilizer*	Extent*	TFP	Fertilizer	Extent
1962-1989	All NPK	0.039	0.009	0.026	0.004	24.26	65.51	10.23
1990-1994	No subsidy	0.059	0.026	0.011	0.022	44.48	18.21	37.32
1995-2004	All NPK/only urea	0.027	0.015	0.009	0.004	54.79	31.32	13.89
2005-2015	All NPK for 350	0.058	0.034	0.006	0.018	59.48	9.77	30.75
2015-2020	Mixed policies	0.078	0.065	0.006	0.006	84.17	8.14	7.69
1962-2020	**Pooled**	**0.045**	**0.021**	**0.016**	**0.008**	**46.71**	**35.46**	**17.83**

**Average growth rates were discounted by the intensities of the inputs*
Source: Authors' calculations

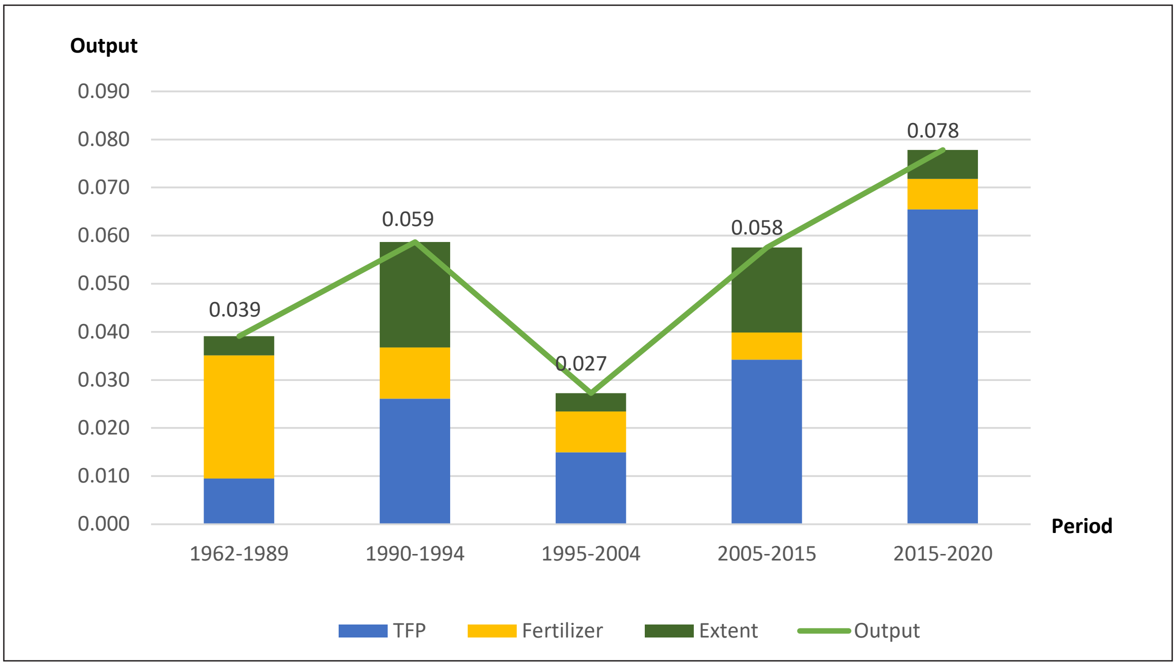

Figure 4: Contributions to output growth of paaddy in Sri Lanka, 1962-2020

When the paddy output growth was decomposed for contributions of fertilizer and area expansion, results show that the former contributes 35% and the latter contributes 18% to output growth. On average, productivity growth was 47% during 1962-2020. The contribution of fertilizer to output growth during 1962-1989 was 66% that declined over time but remained positive at 8% during 2015-2020. The positive contribution of fertilizer underlines its important role in Sri Lankan agriculture and that recent policies (first ban and subsequent licensing) restricting fertilizer availability can have output effects for the main staple i.e., rice. Notwithstanding the expected decline in fertilizer productivity over time, restricting fertilizer supply can have first-order production and productivity effects.

Sri Lanka has followed a rich set of fertilizer policies that can help understand the effectiveness of different interventions. Though subsidy has been commonly used in most developing countries, the objective of maximizing productivity requires approaches that depend on several factors including crop choices and balanced use of different nutrients. In addition, greater use of fertilizers has to be weighed against environmental costs. Our productivity estimates and elasticities of output with respect to different inputs show that these costs need to be compared with the yield discounts that would follow from cessation or restraints on some inputs. The policies that aspire for economic gains from reduced import bills and economizing on foreign exchange must internalize the spillovers and general equilibrium effects of the policies.

Moving towards complete organic cultivation might be desirable or sustainable only under conditions where there is a significant market premium for such production. With yield discounts and unmatched price premium the farm returns can fall and there can be multiple threats to food security. There is indeed a need for more environmentally and economically sustainable fertilizer policies but extreme solutions such as a complete ban or restrictive licensing might not be optimal in the short run. Attempts should be made for a comprehensive approach that looks at multiple inputs together and also takes into account the market implications domestically and internationally. Policies related to land, fertilizer or other fundamental inputs require experimentation for understanding and should be accorded time for the effects to be realized. Sudden policies might end up having high costs.

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Appendix

Table A.1: Import policies of Sri Lanka 2021

HS category at level 4	Relevant HS categories at level 8	Prior to May 06, 2021[1]															On and after May 06, 2021[2]	On and after July 31, 2021[3]
		ICL/ SLSI	Preferential Duty										General Duty	VAT	PAL			
			AP	AD	BN	GT	IN	PK	SA	SF	SD	SG						
3101	3101.00.00	ICL					Free	Free		Free	Free	Free	Free	Ex	10%		ICL	ICL
3102																		
	3102.40.00						Free	Free		Free	Free	Free	Free	Ex	7.5%		Banned	ICL
	3102.60.00						Free	Free		Free	Free	Free	Free	Ex	7.5%		Banned	Banned
	3102.80.00						Free	Free		Free	Free	Free	Free	Ex	Ex		Banned	Banned
	3102.90.00						Free	Free		Free	Free	Free	Free	Ex	7.5%		Banned	ICL
3103																		
	3103.11.00						Free	Free		Free	Free	Free	Free	Ex	7.5%		Banned	Banned
	3103.19.00						Free	Free		Free	Free	Free	Free	Ex	7.5%		Banned	ICL
	3103.90.00						Free	Free		Free	Free	Free	Free	Ex	Ex		Banned	ICL
3104																		
	3104.90.00						Free	Free		Free	Free	Free	Free	Ex	7.5%		Banned	ICL
3105																		
	3105.10.00						Free	Free		Free	Free	Free	Free	Ex	7.5%		Banned	ICL
	3105.20.00						Free	Free		Free	Free	Free	Free	Ex	7.5%		Banned	ICL
	3105.30.00						Free	Free		Free	Free	Free	Free	Ex	7.5%		Banned	Banned
	3105.40.00						Free	Free		Free	Free	Free	Free	Ex	7.5%		Banned	Banned
	3105.51.00						Free	Free		Free	Free	Free	Free	Ex	7.5%		Banned	ICL
	3105.59.00						Free	Free		Free	Free	Free	Free	Ex	7.5%		Banned	ICL
	3105.60.00						Free	Free		Free	Free	Free	Free	Ex	7.5%		Banned	ICL
	3105.90.00						Free	Free		Free	Free	Free	Free	Ex	7.5%		Banned	ICL

Note: ICL: Import Control License

Sources: [1]Custom Tariff Guide of Sri Lanka 2020, [2]Extraordinary Gazette of Sri Lanka No. 2226/48 of 6th May 2021 and [3] Extraordinary Gazette of Sri Lanka No. 2238/45 of 31st July 2021

Table A.2: Non-tariff measures imposed on fertilizer on any import source by Sri Lanka

Non-tariff measures imposed on any import source	HS 3102	HS 3103	HS 3104	HS 3105
Sanitary and phytosanitary	-	-	-	-
Technical barriers to trade	2	2	2	2
Pre-shipment inspection	-	-	-	-
Contingent trade protective measures	-	-	-	-
Quantity control measures	1	1	3	1
Price control measures	1	1	1	1
Other measures	-	-	-	-
Export-related measures	-	-	-	-

Source: https://trains.unctad.org/Forms/TableView.aspx Accessed on 8/8/2021

Table A.3: Results of unit root test (ADF test)

Variable	1962-2020	
	ADF test (at level)	ADF test (at first difference)
lnY	-1.58	-10.64***
lnA	-2.87**	-12.34***
lnF	-2.26	-8.45***

****, **, Significant at 1% and 5% level, respectively*

Table A.4: Bound test results for the existence of cointegration

k_2	1962-2020
Confidence interval	99%
I(0)	3.41
I(1)	4.68
Calculated F	40.291