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RESEARCH ARTICLE

Distributional impacts of irrigation-induced agricultural development in a semi-subsistence economy: new evidence

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Abstract A plethora of literature exists on irrigation-induced agricultural development (IIAD). However, these studies deal only with the theoretical arguments and to date no proper investigation has been conducted to examine the distribution of the long-term benefits of IIAD in a semi-subsistence economy. This study investigates the long-term benefit changes of IIAD using data from the rice farming sector in Sri Lanka. The results show that: (1) IIAD has increased the overall social welfare through consumption of a larger quantity at a lower price, (2) non-farm sector gains are larger than the farm sector gains, (3) the distribution of the benefits among different types of producers depend on the magnitude of the expansion of the irrigated areas as well as the competition faced by traditional farmers and (4) selective technological adoption and subsidies have a detrimental effect on the welfare of other producers who do not enjoy the same benefits.

Keywords Irrigation development · Agriculture · Social welfare · Crowding out

1 Introduction

In many countries, inadequate estimation of total costs and benefits of irrigation development has resulted in irrigated water becoming a subsidised item in some sectors of the economy (see, for example, Gorter and Zilberman 1990; Abu-Zeid 2001).

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Production costs of farmers who receive direct subsidies for irrigation development are relatively lower than those farmers who do not receive direct benefits. However, both these groups pay taxes (at least indirect taxes) to cover the cost of irrigation development, thus increasing inequality in the economy. Conventional agricultural policies are not known to compensate farmers who cannot obtain direct benefits from water projects and face relative cost disadvantages. Moreover, farmers in the newly irrigated regions (referred to as the 'modern' sector in the paper) have other advantages of labour saving technologies, thus increasing efficiency and product quality. As a result, farmers in non-irrigated agricultural regions (referred to as the 'traditional' sector in the paper) faces competition from the sector which receives the direct benefits in the form of irrigation-induced agricultural development, including subsidised water. When analysing the long-term benefits and costs of introducing IIAD, the expansion of irrigated areas as well as the impact of competition on 'traditional' farmers, who face being crowded out, should be taken into account.

Increasing commodity supply due to decreasing costs in the 'modern' agricultural sector can result in shifting the supply schedule in the economy resulting in lowering product prices (Hayami and Herdt 1977; Foster et al. 1986; Ahmed and Sampath 1992). In this context, improved productivity and reduced production costs in the traditional agricultural sector are essential to compete with the modern sector. This issue becomes more severe in the long-term. In a small closed economy a large-scale investment on irrigation development can shift the supply schedule several times in the long-run. This is due to at least three reasons. First, modern sector farmers will adopt new methods of cultivation with newly introduced seeds, chemicals and fertilizers that can increase the productivity in the sector. Second, as this sector is relatively profitable, their reinvestments will be higher and at least at the beginning, it will result in increasing returns to scale. These economies of scale are one of the main reasons why this ongoing development towards larger farms results in lowering costs. Third, most of the large-scale irrigation projects are multi-stage projects. This means that the project is completed over several stages which allow the supply curve to shift several times. For example, most of the irrigation development projects that were implemented in Sri Lanka starting from 1970s were multi-stage projects. Mahaweli development project in Sri Lanka is a good example. When the supply schedules for agricultural commodities of the economy are shifting in this manner, it is expected to decrease the price of commodities produced thus making the market less competitive for traditional farmers.

In the past, the benefits of IIAD have been evaluated assuming that there is no impact of increasing commodity supply on other producers in the economy (Carey and Zilberman 2002). However, this is not a realistic assumption when evaluating the impact of large-scale investment on IIAD in the long-term. If the projects have the ability to shift the supply curve of agricultural commodities, distributional effects should be evaluated by considering its long-term impacts on other farmers. This issue is clearly seen by the changes occurring in paddy production in Sri Lanka. With the introduction of IIAD in selected districts of the dry zone in Sri Lanka, farmers in the wet zone have been unable to compete with them. As a result, farmers have been leaving the farming sector during the last 20 years. Some farmers have abandoned their paddy land, while other farmers have transformed their paddy land into cultivating cash crops which require less water. This situation can be termed as agricultural sector crowding out.

In this context, this study analyses the distributional effects of IIAD using data from Sri Lanka. The research questions that will be addressed are: (1) What is the overall welfare change of the society due to IIAD? (2) How are the changes in benefits of IIAD distributed between consumers and producers as well as among producers? (3) What are the determinants of the distribution of the benefits estimated above? A model based on previous work conducted by Ahmed and Sampath (1992) is used to analyse the possible benefits of IIAD under a semi-subsistence economy with possible population and income dynamics. The study focuses attention on the cultivation of rice in Sri Lanka. At least three factors influenced the selection of rice as a representative commodity. First, becoming self-sufficient in terms of rice is one of the main objectives of government investment in IIAD in the Sri Lanka. Second, rice cultivation is highly dependent upon irrigation water in Sri Lanka. Third, while rice is the staple food for many Asians, it is cultivated not only in Asia, but also in most other countries where large-scale irrigation projects have been implemented.

The paper is organized as follows. In Sect. 2 previous studies on IIAD are reviewed. Section 3 presents the theoretical model that is used to address the distributional issues of IIAD. The data sources are also discussed. While Sect. 4 defines the important variables and the estimation procedure, Sect. 5 presents the results of the analysis and the discussion surrounding the results. The last section summarizes the key findings of the study and discusses the policy implications.

2 Literature review

Theoretically, the choice and implementation of appropriate policies should play a central role in achieving basic objectives of IIAD (Samad et al. 1992; Dinar and Keck 1997; Molden 2007). In this context, Sampath (1983) investigated the returns from development of irrigation water projects analysing the welfare effects on society. This study derived analytical expressions for measuring consumer and producer surpluses when public irrigation investment shifts the supply function for agricultural commodities. Foster et al. (1986) analysed the distributional welfare implications of subsidising irrigation water in California. They concluded that unsubsidized producers bear part of the cost of a subsidy through lower commodity prices, while consumers may gain by the resulting increased production due to subsidies. Jensen et al. (1990) analysed the benefits of physical and institutional improvements of irrigation systems rather than investing in large irrigation projects.

Rahman (1999) analysed the distributional impact of technological change in agriculture. This study concluded that while modern agricultural technology significantly increases income, it also contributes substantially to existing inequality depending on the level of adoption of new technology. Fan et al. (2002) developed a simultaneous equations model to estimate the effects of irrigation development. The results showed that government investments on irrigation contributed not only to agricultural production growth, but also reduced rural poverty and regional inequality. Dridi and Khanna (2005) investigated irrigation technological adoption, farmers' welfare and the political economy of water pricing. This study revealed that adverse selection reduces the adoption of modern irrigation technology.

Bhattarai et al. (2007) presented results of a study on the direct and indirect economic impacts of the Bhakra multipurpose dam system in northern India. The results relating to income distribution show that the gains to agricultural labour households from the dam have been higher than the gains to other rural and urban households. Hussain (2007) explored the links between irrigation development and poverty alleviation in six Asian countries (India, Pakistan, Bangladesh, China, Vietnam and Indonesia) with the aim of improving the overall performance of the existing irrigation systems. According to this study indirect benefits of irrigation at the local and broader economy level could be much larger than the direct crop productivity benefits of irrigation.

The review of the above-mentioned studies revealed that there are at least three shortcomings of the relevant literature. First, these studies fail to empirically investigate the distributional issues of the benefits of IIAD between consumers and producers as well as among the different producers (some of whom gain direct benefits from the irrigation project and those who do not benefit from it).[1] Second, most of the reviewed studies do not attempt to take into account semi-subsistence nature of the economy and the resulting benefit changes in the long-run. Third, although there are a few studies which attempt to estimate the benefits of IIAD, they have not conducted any sensitivity analysis of long-term benefits in the context of commodity markets. This is especially important when addressing the resulting distributional issues of relatively large-scale irrigation projects in the long-run. These issues are the primary focus of the present study.

3 Theoretical model and data used

In this study the basic model developed by Hayami and Hert (1977), Sampath (1983), and Ahmed and Sampath (1992) to explain the benefits of irrigation developments are used. However, the approach used in this study is different from these studies for at least three reasons. First, a more dynamic model is used to capture the long-run distributional effects in the economy, including consumers and two types of producers. Second, the study attempts to explain the magnitude, sensitivity and distribution of the benefits of irrigation developments rather than merely showing benefits of such developments. Third, the long-run welfare changes of IIAD are empirically investigated in a semi-subsistence economy.

Let $D(P)$ represent the demand for an agricultural commodity at price P and $S(P, k)$ be the supply schedule derived from profit maximization[2] where k is the price of

[1] Studies in this field implicitly assume zero value for water in the water market. If a government (water selling agency) does not gain revenue from the water market, it permits the government to increase distortionary taxes elsewhere in the economy. This may increase income disparities between different regions of the economy.

[2] $S(P, k) = \partial\pi(P, k)/\partial P$ (Hotelling's lemma) where $\pi(P, k)$ is profit as a function of P and k.

water. Assume market demand and supply curves with constant price elasticity where α and β are the price elasticity of demand and supply, respectively. A and B are the demand and supply shifters determined by exogenous factors and v is the price of water.

$$\text{Demand function } \; Q_0 = D_0 = AP_0^{\alpha} \quad \text{with } \alpha < 0 \tag{1}$$

$$\text{Supply function } \; Q_0 = S_0 = vBP_0^{\beta} \quad \text{with } \beta > 0 \tag{2}$$

$$v = k^{\tau} \; \tau < 0$$

Initial equilibrium price and quantity in the market are as follows:

$$P_0 = \left(\frac{vB}{\mathrm{A}}\right)^{\frac{1}{\alpha-\beta}} \tag{3}$$

$$Q_0 = (vB)^{\frac{\alpha}{\alpha-\beta}} A^{\frac{-\beta}{\alpha-\beta}} \tag{4}$$

Now assume that the commodity supply curve can be shifted with IIAD and the demand curve for agricultural commodity can be shifted with population and income changes. This situation is graphically presented in Fig. 1. The initial situation of the market for an agricultural commodity and the first stage change of the supply and demand schedules are shown in Fig. 1a.

In Fig. 1a, lines $Q'Q_{0r}$ and $Q''Q_{1r}$ represent rice retained by producers for home consumption ‘before ‘and ‘after’ irrigation development. Irrigation development will most likely increase the retention of rice for home consumption. This is because ‘before’ irrigation development, some of the farmers faced a home consumption shortage. These farmers are likely to retain more if their production increased as a result of irrigation development. Population growth and the growth of per capita income can both contribute to a shift in the demand curve, increasing the retention of rice for home consumption.

According to Fig. 1a the initial demand curve is given by $Q'D_0$. This demand curve has shifted to the right and a new demand curve is given by $Q''D_1$. The difference between the new aggregate demand curve and the household’s home

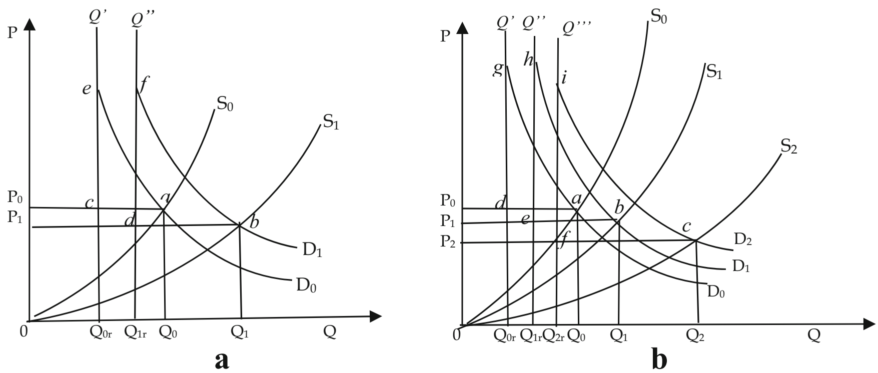

Fig. 1 Effects of irrigation development on commodity supply

consumption demand curves represent the shift in demand of the rice-buying consumers. The horizontal distance between $Q'Q_{0r}$ (demand curve for household home consumption) and the market demand curve (eD_0) represents what the deficit farmers and non-rice producers buy from the rice market.[3] The supply curve $0S_1$ represents the aggregate supply shift from $0S_0$ as a result of adopting modern irrigation technology with IIAD.

The consumer surplus 'before' the changes is given by the area *eca* while after the changes, it is *fdb*. Accordingly, the change of consumer surplus is represented by *fdb-eca*. When measuring the change in producer welfare, it is important to note that all the production is not sold and traditional producer surplus measurements cannot be used here. Following Sampath (1983), and Ahmed and Sampath (1992), changes in the cost of production and changes in revenue are used to measure the changes in producer surplus in this analysis. The change in revenue is shown by $Q_{1r}Q_1$bd-$Q_{0r}Q_0$ac and the change in costs is shown by $0Q_1$b-$0Q_0$a. Accordingly, the net change in producer cash income can be calculated by taking the difference between the change in cash income and the change in cost$\{(Q_{1r}Q_1\text{bd} - Q_{0r}Q_0\text{ac}) - (0Q_1\text{d} - 0Q_0\text{a})\}$. A more general situation relating to this scenario is shown in Fig. 1b. It shows how the benefits change with several supply and demand shifts. However, this figure shows only one possibility where the supply shift is greater than the demand shift. However, when analysing different periods, demand shifts can be equal or greater than the supply shifts. In this dynamic setting consumer and producer surpluses can also change with time. The mathematical model showing this relationship is explained below.

Assume a λ per cent shift in the supply schedule due to irrigation development in the first period (where λ is a positive constant). New supply function can be algebraically expressed as follows:

$$\text{New supply curve } S_1 = (1+\lambda)vBP_1^{\beta} \tag{5}$$

Assume that the rate of increase of demand for rice depends on the rate of population growth and the growth of per capital income. Let z represent the proportional shift in the aggregate demand curve in the first period. Accordingly, the modified demand curve for the first period can be represented as $z = f(n, Y)$ where n is the rate of change in population and Y is the proportional change in per capita income of the consumer (Ahmed and Sampath 1992). With this new demand curve the equilibrium price and quantity can be explained as follows:

$$\text{New demand curve } D_1 = A(1+z)P^{\alpha} \tag{6}$$

New equilibrium price and quantity can be derived as Eqs. 7 and 8.

$$P_1 = P_0\left[\frac{(1+\lambda)}{(1+z)}\right]^{\frac{1}{\alpha-\beta}} \tag{7}$$

$$Q_1 = Q_0(1+z)^{\frac{-\beta}{\alpha-\beta}}(1+\lambda)^{\frac{\alpha}{\alpha-\beta}} \tag{8}$$

[3] This quantity can be termed as the gross marketable surplus that is supplied by the surplus producers.

The change in consumer surplus (see Fig. 1) can be mathematically represented as:

$$\Delta \mathrm{CS} = \Delta \mathrm{CS}_1 - \Delta \mathrm{CS}_0 \tag{9}$$

$$\Delta \mathrm{CS} = \left[\int_{Q_{1\mathrm{r}}}^{Q_1} D_1 \mathrm{d}q - P_1(Q_1 - Q_{1\mathrm{r}})\right] - \left[\int_{Q_{0\mathrm{r}}}^{Q_0} D_0 \mathrm{d}q - P_0(Q_0 - Q_{0\mathrm{r}})\right] \tag{10}$$

Assume that the gross marketable surplus is equal to the total output produced minus home consumption by a household and m represents the ratio of gross marketable surplus to total output.

$$\mathrm{m} = \{(\text{Equilibrium quantity} - \text{home consumption})/\text{equilibrium quantity}\}$$

According to Fig. 1a Q_0 and Q_1 are the initial and new equilibrium quantities, $Q_{0\mathrm{r}}$ and $Q_{1\mathrm{r}}$ are the initial and new home consumption quantity of rice. If m_0 and m_1 are the initial and new marketable surpluses, they can be expressed as follows:

$$m_0 = \left(\frac{Q_0 - Q_{0r}}{Q_0}\right) \rightarrow Q_{0r} = Q_0(1 - m_0) \tag{11}$$

$$m_1 = \left(\frac{Q_1 - Q_{1r}}{Q_1}\right) \rightarrow Q_{1r} = Q_1(1 - m_1) \tag{12}$$

Substituting Eqs. (11) and (12) into Eq. (10), the following equations can be obtained:

$$\Delta CS = \left[\int_{Q_{1r}}^{Q_1} D_1 dq - P_1 Q_1 + P_{0r}\{Q_1(1 - m_1)\}\right] - \left[\int_{Q_{0r}}^{Q_0} D_0 dq - P_0 Q_0 + P_0\{Q_0(1 - m_0)\}\right] \tag{13}$$

$$\begin{aligned} \Delta \mathrm{CS} = P_0 Q_0 \Bigg[& \left(\frac{\alpha}{(1+\alpha)}\Phi\right)\left(1 - (1 - m_1)^{\frac{1+\alpha}{\alpha}}\right) \\ & - \left(\frac{\alpha}{(1+\alpha)}\right)\left(1 - (1 - m_0)^{\frac{1+\alpha}{\alpha}}\right) - (\Phi m_1 - m_0) \Bigg] \end{aligned} \tag{14}$$

where $\Phi = (1 + z)^{\left(\frac{-1-\beta}{\alpha-\beta}\right)}(1 + \lambda)^{\left(\frac{1+\alpha}{\alpha-\beta}\right)}$.

We also need to know the changes of producer surplus (changes in producers' cash income). This is equal to changes in revenue, less changes in cost. According to Fig. 1a, producers' total revenue (TR) with and without IIAD are represented by areas $Q_{0\mathrm{r}}Q_0$ac and $Q_{1\mathrm{r}}Q_1$bd. This area can be expressed mathematically as follows:

$$\Delta \mathrm{TR} = [P_1(Q_1 - Q_{1r}) - P_0(Q_0 - Q_{0r})] \tag{15}$$

$$\Delta \mathrm{TR} = P_0 Q_0[\Phi m_1 - m_0] \tag{16}$$

Next, the change in the cost of production with the new irrigation technology should be calculated. This can be done using the initial and new supply curves in

Eqs. 2 and 5 respectively. This change is given by the difference between $0bQ_1$ and $0aQ_0$ in Fig. 1a. The total cost (TC) change can be represented as:

$$\Delta \mathrm{TC} = [0bQ_1 - 0aQ_0] = \int_0^{Q_1} S_1 dq - \int_0^{Q_0} S_0 \mathrm{d}q \tag{17}$$

$$\Delta \mathrm{TC} = \frac{\beta}{(\beta + 1)} P_0 Q_0 (\Phi - 1) \tag{18}$$

Accordingly, cash income of surplus producers will change as follows:

$$\Delta \mathrm{PS} = [\Delta \mathrm{TR} - \Delta \mathrm{TC}] \tag{19}$$

$$\Delta \mathrm{PS} = P_0 Q_0 \left[(\Phi m_1 - m_0) - \left(\frac{\beta}{\beta + 1} \right) (\Phi - 1) \right] \tag{20}$$

This study will use the changes of consumer and producer surpluses shown by Eqs. 14 and 20 to analyse the distributional issues of IIAD under a semi-subsistence economy. We first analyse changes in surpluses under a dynamic setting, allowing for a change in supply as well as demand schedules. Second, we explain the possible benefit changes under different types of producers. Third, we discuss the sensitivity of the benefits derived to changes in relevant parameters.

4 Defining variables and the estimation procedure

The parameters for the aggregate demand and the supply function of rice are obtained by using the simultaneous equation approach. The demand and supply functions are estimated using the 2SLS method. It is assumed that per capita quantity demanded for rice is a function of its own real price and real per capita income. To estimate the rice demand function for the country, annual data from 1960 to 2006 are used. Using the same period annual data, we estimate a rice supply function for the country. Rice supply is assumed to be a function of its own real price and real irrigation expenditure.[4] Irrigation expenditure is used as the instrument, when estimating the demand function. Per capita real income is used as the instrument in the supply function. The demand and supply equations were estimated using log–log functional forms as they produced satisfactory results in terms of signs of the estimated coefficients and statistical/diagnostic tests.

To identify two groups of farmers, we use farmers who started cultivating under the Mahaweli development project (‘modern’ farmers)[5] and farmers who cultivate

[4] In the model estimation, marginal costs are assumed as a function of quantity produced and irrigation expenditure.

[5] This is the largest irrigation development project in Sri Lanka. It’s main development tasks were completed during the period, 1980–1989, under the accelerated Mahaweli development Program. Initially, it was expected to develop approximately 365,000 hectares of irrigable land in the Dry Zone which including several projects for stepwise implementation. However, by the end of 2006, the project was able to open up approximately 100,000 hectares of irrigable lands, constructing approximately 9478 km of canal networks.

land outside the Mahaweli development project area ('traditional' farmers). It was first hoped to estimate separate supply functions for rice for modern farmers and traditional farmers. Since separate data for rice demand are not available in the country, it is not possible to use a simultaneous equation method for this purpose. Instead, we used time series data analysis, namely through co-integration and error correction to estimate short-run as well as long-run price elasticities of rice supply. Annual data from 1960 to 2006 were used for estimating price elasticities of supply for 'traditional' farmers. When estimating parameters for 'modern' farmers, data from 1980 to 2006 are used. In both cases, rice supply is assumed to be a function of its own real price and real irrigation expenditure.

Some published estimates of price elasticity of demand and supply for rice in Sri Lanka were identified (Gunawardana 2000; Rafeek and Samarathunga 2000). However, the price elasticity estimates in this study are lower compared to previous work conducted in Sri Lanka.[6] This study used the value −0.30 and 0.30 as the central estimates of the price elasticity for demand and for supply in Sri Lanka, respectively. To analyse the sensitivity, higher values of −0.5 and 0.5 were used for demand and supply elasticities, respectively. These estimates are consistent with most of the estimates of price elasticity for rice in Asian countries (Vanichjakvong 2002; Choeun et al. 2006). The same demand elasticity was used for dividing the producer surplus between modern and traditional farmers. However, a lower value of supply elasticity ($\eta = 0.2$) was used for traditional farmers as their supply elasticity was found to be relatively lower than for modern farmers. In the analyses, it was assumed that 1970 was the base year and its price and quantity data were used as the equilibrium price and quantity for the base year. This is because most of the irrigation sector transformation, including land opening and new dam construction were started during the 1970s in Sri Lanka.

The supply shifts in the country for each decade starting from 1970 were calculated using data of the changes in rice supply as a ratio of the respective years. According to the Sri Lankan Department of Census and Statistics, the total rice production in Sri Lanka has increased from 1,099, 545 MT in 1970 to 2,972,833 MT in 2006 (Department of Census and Statistics in Sri Lanka 2007). This implies that percentage shifts in the aggregate rice supply schedule were 170.3 ($\lambda = 1.703$) for the entire period. First, the magnitude of the supply shifts for the period, 1970 and 1980, 1970 and 1990, 1970 and 2000, and 1970 to 2006 were calculated and incorporated into the first part of the analysis. Second, the magnitude of the supply shift for every decade was calculated to capture how consumer, producer and total surplus have changed for the respective decades. For this purpose, average rice production for the 10-year period was calculated and used to estimate what percentage it has changed relative to the previous 10-year average. Supply shifts for 1980, 1990, 2000 and 2006 were calculated in this manner. These supply shifts help us to estimate the welfare changes during each decade.

[6] Previous studies show that price elasticity of demand and supply is between 0.1 and 0.6. However, most of the previous work in the rice market in Sri Lanka use OLS without considering the endogeinity problems in their analyses.

The shift in aggregate demand for rice was calculated from the estimated change in population, per capita income and income elasticity of demand for rice for 1980, 1990, 2000 and 2006. On average, the contribution of the change in population to shift aggregate demand was significantly higher (92 %) than that of per capita income and price changes. Change in demand between 1970 and 2006 was approximately 1,341,726 MT.

The national data on the quantity of marketable surplus of rice is not available. It was, therefore, necessary to calculate the marketable surplus using secondary information. For example, if an average family consists of four members and the rice requirement per person per year is 96 kg (Food Balance Sheets 2007), then the family rice requirement is 384 kg/year. This is equivalent to 548 kg of paddy per year (assuming a conversion ratio of 0.7). The average yield of paddy is approximately 4.137 metric tons/ha in 2006 and hence a 0.066 ha (0.163 acre) is sufficient to meet the family needs if two seasons were cultivated with paddy. Those farmers who produce more than 548 kg of paddy per year are the net-sellers of paddy. Accordingly, marketable surplus for the country in 2006 is 51 %.[7] Weerahewa (2004) shows that average marketable surplus of rice in Sri Lanka is approximately half of their total production. However, this marketable surplus has been changing dramatically over time. For example, the calculated marketable surplus in 1970 was 12 % of total production. This means that home consumption was 88 %. This marketable surplus has increased to 21, 37 and 44 % by 1980, 1990 and 2000, respectively. There are at least three reasons for the increase in the marketable surplus during this period. The most important reason was the emergence of commercialised rice producers as a result of introducing modern irrigation technology. Second, average family size decreased to 4 from 6 in the 1970s. Third, average yield has increased to 4.137 metric tons/ha in 2006 from 2.930 metric tons/ha in the 1980s.

The base year marketable surplus of 12 % ($m_0 = 0.12$) and 20 % change was allowed when analysing the sensitivity of the parameters. Estimated marketable surpluses for 1980, 1990, 2000 and 2006 are 0.21, 0.37, 0.44 and 0.51, respectively. There was a clear difference of the marketable surplus between 'traditional' farmers (wet zone farmers) and 'modern' farmers (dry zone farmers). The analysis looked at the changes of PS between modern farmers and traditional farmers whose marketable surpluses (as well as supply shifts) are different from each other. Next, it was important to differentiate farmers according to the land size they cultivate. Accordingly, land size cultivated was categorised into small-scale farmers, medium-scale farmers and large-scale farmers.[8] According to this classification, it was found that existing land holdings follow the distribution of 20, 48 and 32 % among large, medium and small farmers, respectively. Their marketable surpluses were 67, 48, and 35 %, respectively. This analysis was conducted for the period, 1970–2006.

[7] We use the number of paddy farmers and estimate their total rice requirements for the year. Then, we deduct it from the total annual production to obtain the marketable surplus for the respective year.

[8] If the cultivated land size is less than 0.5 hectare, the farmers are categorised as small-scale land holders. Land size for the medium size farmers is between 0.5 and 1 hectares. Farmers who cultivate more than one hectare are defined as large-scale farmers.

5 Results and discussion

The percentage change of the important variables relative to the base year (1970) is shown in Table 1. According to Table 1 the per capita real income growth was much greater than the population growth during this period. The change in the marketable surplus is remarkable and it is mainly due to increasing productivity, as well as decreasing family size. Productivity change is a direct result of IIAD.

As a first step in the analysis, changes in the consumer, producer and total surpluses were calculated by using 1970 as the base year against 1980, 1990, 2000 and 2006. For example, the first changes only capture the changes of CS, PS and TS until 1980. Then the benefit changes for 1990, 2000 and 2006 were calculated. In this way, the time period was gradually extended in analysing the results. The purpose was to look at how long-term benefits of IIAD can change with the population and GDP dynamics of the economy. The results of this analysis are shown in Table 2.

It is obvious that changes in supply shifts are significantly higher than the shifts in demand in each period. This implies that the country is still expanding its production capacity of rice, while reducing domestic demand and the supply gap and increasing the level of self sufficiency. According to Table 2, changes in consumer surplus are significantly higher than the changes in producer surplus. Another interesting result was the positive gains in producer surplus. Between 1970 and 1980, the PS is greater than the CS. This is because when demand is shifting, there are additional gains to the producer due to price changes. It becomes clear that

Table 1 Percentage change of the variables relative to the base year (1970)

Period	Population	Income (per ca.)	Marketable surplus	Shift in demand	Shift in supply	Average real price
1970–1980	17.8	36.3	0.75	0.15	0.42	−7.9
1970–1990	29.9	83.5	2.08	0.45	1.15	−20.8
1970–2000	47.5	196.4	2.66	0.56	1.31	−31.9
1970–2006	58.9	261.5	3.25	0.75	1.70	−38.6

Base year values of population and per capita real income are 12.5 million and Rs. 17,507, respectively. Marketable surplus for the same year is 194,280 MT which is 12 % of total production. Equilibrium real prices and quantities are Rs. 32,008 per metric ton and 1,099,545 MT, respectively

Table 2 Changes in CS, PS and TS under a semi-subsistence economy

From base year (1970) to:	Shift in supply	Shift in demand	Change in CS (Rs. Mn)	Change in PC (Rs. Mn)	Change in TS (Rs. Mn)
1980	0.425	0.153	2287.50	3239.87	5527.37
1990	1.158	0.459	13,978.63	8427.75	22,406.38
2000	1.319	0.565	26,490.50	11,189.49	37,679.99
2006	1.703	0.751	48,236.58	14,274.22	62,510.80

Equilibrium price and quantity in 1970 were used when calculating changes in CS, PS and TS

Table 3 Changes in CS, PS and TS in each period

Period	Shift in supply	Shift in demand	Change in CS (Rs. Mn)	Change in PC (Rs. Mn)	Change in TS (Rs. Mn)
1970–1979	0.425	0.153	2287.5 (2.9)	3239.9 (15.6)	5527.4 (5.6)
1980–1989	0.514	0.265	17,032.5 (22.2)	7558.1 (36.3)	24,590.6 (25.1)
1990–1999	0.074	0.073	23,130.2 (29.9)	5105.5 (24.5)	28,235.8 (28.8)
2000–2006	0.165	0.119	34,674.8 (44.9)	4918.7 (23.6)	39,593.5 (40.4)

Percentage change of CS, PS and TS for each period is shown in brackets. Real prices for base years, 1980, 1990 and 2000 are Rs. 29,479, 25,336 and 21,789 per metric ton, respectively. Equilibrium quantities for the same years are 1,567,100, 2,373, 600 and 2,550,100

the overall changes in consumer surplus was Rs. 48,236 million, while producer surplus change was Rs. 14,274 million between 1970 and 2006. As a result society has gained a total sum of Rs. 62,510 million as total welfare benefits from IIAD in the rice sector.

In the second stage of the analysis, calculations were made of the changes in consumer and producer surplus for the years, 1980, 1990, 2000 and 2006 by assuming each previous year as the base year. This type of analysis helps to understand the changes in consumer, producer and total surpluses during each time period. For example, when calculating CS, PS and TS in 2000, the equilibrium price and quantity in 1990 are assumed as the base year price and quantity. The results show that the changes in CS and PS are positive in each period. Since the producers, as well as the consumer gains are positive, the overall welfare changes are positive for each period. This implies that the country is still experiencing positive welfare changes due to IIAD in the rice farming sector (Table 3).

The highest shift in supply is recorded between 1970 and 1980, which is 51 %. This is the period in which the highest priority was given by the Sri Lankan government to opening up land and investing in new irrigation projects. Since then the supply shifts have been decreasing gradually. However, shift in demand varies from time to time according to population and per capita income growth. The most important period for change in demand is the period between 1980 and 1990. The higher affordable ability of the Sri Lankan household with the liberalization of the Sri Lankan economy in 1978 may have significantly influenced the higher demand during this period. The highest percentage for changes of PS could be observed during the same period. However, changes in CS are significantly higher (45 %) between 2000 and 2006. The change in PS during this period is 23 %, while the change in TS is 40 %.

Average farm size as well as the productivity of modern irrigation technology areas is relatively higher than that of traditional farming areas.[9] For example, average farm size for dry zone farmers is approximately 0.8 ha, while the average farm size in the wet zone with no irrigation investment was 0.25 ha in 2006. Average productivity for dry zone farmers was 5.26 MT per hectare, while it was 3.81 MT per hectare for wet zone farmers. The average yield for most districts in the

[9] The dry zone is used as the modern farming sector, while the wet zone is used as the traditional farming sector. This is because irrigation development has taken place only in the dry zone of Sri Lanka.

Table 4 Changes in PS between 'modern' and 'traditional' farmers: 1970–2006

Period	Modern farmers (Rs. Mn)	Traditional farmers (Rs.Mn)	ΔPS
1970–1980	6461.40	−3221.53	3239.87
1970–1990	16,970.57	−8542.82	8427.75
1970–2000	21,625.74	−10,436.25	11,189.49
1970–2006	25,398.58	−11,124.36	14,274.22

The gains of the producer are calculated for the whole period, 1970–2006. The base year price is assumed as Rs. 32,008. Equilibrium quantities are 791,672 MT and 307,872 MT for 'modern' and 'traditional' sectors, respectively. Supply elasticity for modern farmers and traditional farmers are assumed as 0.4 and 0.2, respectively

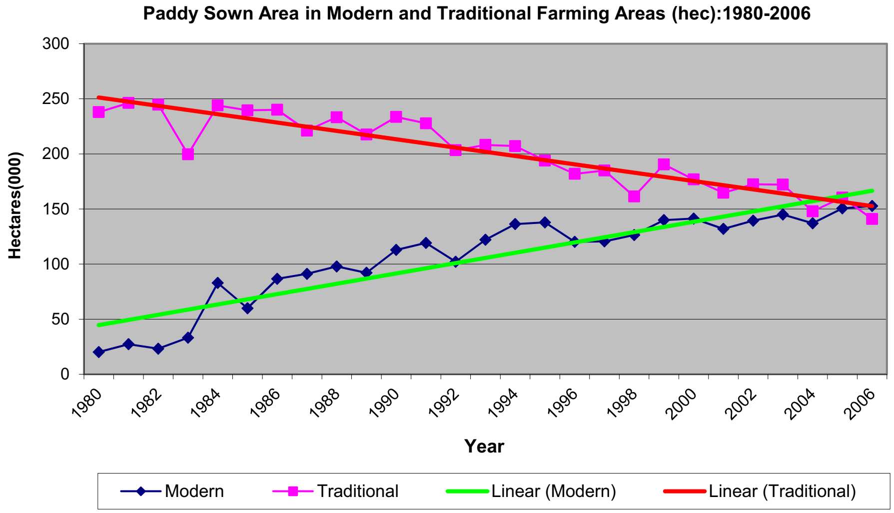

Fig. 2 Comparison of paddy sown area between 'modern' and 'traditional' agricultural areas

wet zone was less than 3.5 MT per hectare in 2006. This implies that marketable surplus in modem irrigation areas was higher than the rest of the country. The estimation reveals that an average of 67 % of production is sold by modern irrigation farmers, while the marketable surplus for traditional farmers was approximately 38 % of their total output.[10] Using this information it was possible to divide the changes in producer surplus of 'modern' farmers and 'traditional' farmers. The results are reported in Table 4.

Table 4 clearly shows the magnitude of the crowding out effects in terms of losses in producer surplus to traditional farmers. It was Rs. 11,124 million by 2006. We also examined the trend of the cultivated land area for modern and traditional farming areas in the country. Figure 2 in appendix shows the trend of these variables between 1980 and 2006. There has been a significant reduction in the

[10] Our sample survey also clearly shows that the marketable surplus of the farmers who use modern irrigation technology is greater than farmers who practice traditional farming.

cultivated land of 'traditional' areas (approximately 62,000 ha). This area contributed approximately 98 % of the total paddy land in 1980 while it was 83 % in 2006 (Department of Census and Statistics 2007). On the other hand, land cultivation in the modern area has increased from 2 % in 1980 to 17 % by 2006 (Mahaweli Authority 2007). The total land area under paddy cultivation in the country increased marginally during this period.[11] The main reason for the decrease in cultivation land in 'traditional' areas is the competition from 'modern' farmers. This has led to rice farming being abandoned in these areas. The inevitable consequence of this pressure is that most of the traditional farmers are pushed towards cultivating short-term cash crops that are less competitive and need less water. This has significantly decreased the total area of paddy cultivated in the 'traditional' farming sector during this period. This can be termed as the crowding out effects of adopting IIAD in one part of the economy.

To investigate the changes of PS among small, medium and large-scale farmers it was assumed that the distribution followed the existing system which is 32 % small holders, 48 % medium holders and 20 % large farmers. The contribution of each farmer group to changes in the total producer surplus was 35, 64 and 39 %, respectively. Medium-scale farmers and large-scale farmers, who are the dominant categories in this classification, were the main beneficiaries of positive producer surplus resulting from technological change. The reason is that their marketable surplus was relatively higher than the small-scale farmers. Estimated initial marketable surplus for all groups was 12 %. However, this marketable surplus had increased to 35, 48 and 67 % for small, medium and large-scale farmers, respectively, by 2006.

As the last step the comparative statistic results are derived by changing the key parameters in the analysis. This type of comparative statistic results basically shows how marginal changes in policy parameters affect some key variables such as consumer surplus, producer surplus and total surplus. The policy parameters considered are the price elasticity of demand (α), price elasticity of supply (β), the initial value of the marketable surplus (m_0) and new marketable surplus (m_1). As it is evident, the size and distribution of gains from irrigation development not only depends on the elasticity of demand and supply for the product, but also on the size of the marketable surplus. The empirical results of the comparative statics are summarized in Table 5.

Table 5 shows the sensitivity of consumer surplus, producer surplus and total surplus to alternative values of demand and supply elasticities as well as the initial and new values of marketable surplus. These results were obtained using the initial equilibrium price and quantities in 1970 and allowing changes until 2006. Price elasticity of demand was relatively more sensitive than the price elasticities of supply to the CS, PS, and TS. For example, when the price elasticity of demand changes from −0.3 to −0.5 change of the CS, PS, and TS are −58.5, 26.8 and −39.0 %, respectively. In general, it can be concluded that whenever the demand curve is inelastic, the CS change will be smaller than under elastic demand for given values of supply elasticity

[11] It was 844, 000 hectares in 1980 and 910,000 hectares in 2006.

Table 5 Sensitivity analysis of the benefits: 1970–2006

		$\alpha = -0.30$	$\alpha = -0.50$	Percentage change of benefits/cost
$\beta = 0.30$	Cash revenue	14727.49	21,703.65	47.4
$\lambda = 1.704$	Production cost	453.27	3609.90	696.4
$z = 0.752$	Cash income (PS)	14,274.22	18,093.75	26.8
$m_0 = 0.8$	Consumer surplus	48,236.58	20,034.17	−58.5
	Total surplus	62,510.80	38,127.92	−39.0
		$\beta = 0.3$	$\beta = 0.5$	
$\alpha = -0.3$	Cash revenue	14,727.49	17,284.73	17.4
$\lambda = 1.704$	Production cost	453.27	2326.12	413.2
$z = 0.752$	Cash income (PS)	14,274.22	14,958.61	4.8
$m_0 = 0.8$	Consumer surplus	48,236.58	54,883.11	13.8
	Total surplus	62,510.80	69,841.72	11.7
		$m_0 = 0.12$	$m_0 = 0.32$	
$\beta = 0.30$	Cash revenue	14,727.49	7688.64	47.8
$\alpha = -0.30$	Production cost	453.27	453.27	0.00
$z = 0.752$	Cash income (PS)	14,274.22	7235.37	−49.3
$\lambda = 1.704$	Consumer surplus	48,236.58	38,506.32	−20.2
	Total surplus	62,510.80	45,741.69	−26.8
		$m_1 = 0.51$	$m_1 = 0.61$	
$\beta = 0.30$	Cash revenue	14,727.49	18,443.34	25.2
$\alpha = -0.30$	Production cost	453.27	453.27	0.00
$z = 0.752$	Cash income (PS)	14,274.22	17,990.07	26.0
$\lambda = 1.704$	Consumer surplus	48,236.58	103,695.29	115.0
	Total surplus	62,510.80	121,685.35	94.7

Equilibrium price and quantity of rice that are used to analyse sensitivity are Rs. 32,008 (per MT) and 1,099,545 MT, respectively

and supply shifts. Furthermore, the new marketable surplus is highly sensitive to CS (115 %), while the initial magnitude of the marketable surplus is relatively more sensitive to the producers' income (47 %). The sign of the benefit changes due to marketable surpluses implies that the assumption on the magnitude of the initial marketable surplus can underestimate the CS, PS and TS, while the assumption on the magnitude of the new marketable surplus can overestimate them.

6 Summary of findings and policy implications

This analysis showed the level of distribution of benefits among producers, consumers, and society as a whole due to the introduction of IIAD with population and per capita income growth. Accordingly, the major findings in this study are: (1) investments in IIAD has contributed to a positive gain in terms of changes of consumer surplus, producer surplus and total surplus; (2) consumer gains are higher than the producer gains during this period; (3) the magnitude of agricultural crowding out effects, in terms of losses to ‘traditional’ farmers is approximately Rs. 11,000 million and, in terms of cultivated area, the decrease is approximately 62,000 ha; (4) ‘modern’ farmers have acquired a positive benefit due to the change in producer surplus; and (5) of them, the relative gains of the large and medium-scale farmers are higher. However, the benefit calculations are relatively sensitive to the price elasticity of demand and supply as well as the estimators of new and initial marketable surpluses.

In a policy context, it becomes clear that any development project can result in detrimental outcomes to various stakeholders. If the project benefits only one sector (e.g., ‘modern’ sector) of society, the ‘traditional’ sector’s ability to compete with the ‘modern’ sector depends on productivity improvements and a reduction in production costs in the long-term. If the cost of the development project could be financed according to the benefits that different stakeholders gain from it, issues arising from competition could be addressed equitably. However, there are no such water service charges based on gains by various stakeholders in most developing countries, including Sri Lanka. In the absence of a water market, governments have to use tax revenue to finance its expenditure. This can result in more distortions since consumers, as well as all agricultural producers are subject to paying the same tax without any differentiation. This result has important policy implications. For example, when governments use public funds in promoting the interests of one group of producers which harm others, the long-term distributional outcomes can worsen the benefits to the economy of such policies.

It is also shown that the problem of distribution can be more severe if new technology is handled by a small number of large producers. To avoid such a possibility, efforts should be strengthened to facilitate the adoption of technological innovations among small farmers. A positive welfare change could be observed in farms as well as non-farm sectors due to the large-scale investments in irrigation development in the 1980s and 1990s. This has directly reduced rural poverty considerably during this period. Therefore, a large-scale investment with suitable policy instruments is needed in the future to eradicate poverty and enhance rural livelihoods.

This analysis particularly stresses the issues on the distributional aspects of irrigation development in the long-term exploring issues of consumer and producer gains in detail. However, it is important to be conscious of the possible limitations of the study. We are aware that in the analysis we have a few assumptions that can affect our results if they are relaxed. They include government intervention and international trade. Government intervention and international trade is likely to impact on the results of this analysis. However, to analyse the main issues mentioned above and to keep the model simple, the empirical methodology ignored the effects of government intervention or international trade on changes in social welfare. The study also did not distinguish between various consumer groups who are likely to gain or lose. However, we believe that the results provided in this study clearly demonstrate some of the distributional impacts of irrigation induced agricultural development in a semi-subsistence economy which has not been examined in this manner.

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