Effects of technological progress on consumers' and producers' welfare: a case study for Pakistan Punjab

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Abstract

While there is no dearth of regression analyses or linear programming models reviewing the agricultural performance of Pakistan, hardly any study has used a price endogenous mathematical programming model to simulate the ex ante effects of new policies on consumers and producers simultaneously. Responding to this need this paper simulates the crop sector of Pakistan considering price-quantity interrelationships. In its present form, the model is restricted to the Pakistan Punjab which successfully replicates the observed cropping pattern in the base year (2006). The model assumes an aggregate representative farmer who allocates the resources in such a way that the optimal quantities supplied at market prices are consistent with the farm-gate demands at those prices. The model is then solved by altering the yield and cost parameters from India's Punjab, to analyze the new market equilibrium that would occur in the crops sector of Pakistan Punjab under a technologically enhanced agricultural system.

Keywords: price endogenous, sector model, historical mixes, Pakistan
JEL: C61, Q11, Q18

1. Introduction

There exists several linear programming models reviewing, planning and predicting the impacts of agricultural policies in Pakistan (GOTSCH and FALCON, 1975; CHAUDHRY and YOUNG, 1989; HASSAN, RAZA, KHAN and ILAHI, 2005; ARIFULLAH, 2007; KIANI, 2008). A linear programming model assumes fixed prices and costs for the activities and a competitive market where individual producers are price takers and allocate their resources to maximize the total net returns from cropping activities. This approach neglects the interrelationship between market prices and the aggregate quantities supplied by all farmers. The aggregate sector model, on the other hand, integrates the supply and demand sides of agricultural markets by taking into account the interaction between consumers and producers as well as input and output markets, in a partial equilibrium setting. Therefore, a price endogenous sector model has better simulating properties and provides a more powerful tool for policy analysis allowing the policy makers to predict the impacts of a policy change at sectoral level (MCCARL and SPREEN, 1980).

SAMUELSON (1952) was the first who recognized the use of mathematical programming to capture the equilibrium in spatially separated markets through the artifice of the "net social payoff", defined as the sum of producers' and consumers' surplus. Extending on his work, TAKAYAMA and JUDGE (1964) developed a nonlinear (quadratic) programming framework to endogenously determine prices, quantities and resource allocation assuming linear demand and supply functions. Following the framework pioneered by TAKAYAMA and JUDGE, numerous agricultural sector models have been used for more than half a century now to understand 'the market demand structures', resource bases and workings of overall economic systems and to predict the effects of agricultural policies. FAJARDO, MCCARL and THOMPSON (1981), APLAND and JONASSON (1992), HORNER et al. (1992), MCCARL et al. (1993), HELMING (1997), and JONASSON and APLAND (1997) are some examples for those studies. MCCARL and SPREEN (1980) and NORTON and SCHIEFER (1980) provide excellent theoretical overviews and a summary of the mathematical programming sector models that are used for empirical analyses of diverse policy and resource allocation issues faced by agricultural economies.

For Pakistan's agriculture sector the use of mathematical programming models to simulate the effects of newly introduced policies has been very few. DAVIES et al. (1991) developed a linear programming model to simulate the Pakistan's agricultural sector. Later DAVIES et al. (1996) studied the effects of Uruguay round on Pakistan domestic equity and resource base being one of the major exporters of cotton in the world. They used an Almost Ideal Demand System approach to incorporate nonlinear supply and demand functions which were then incorporated into a spatial equilibrium model by imposing income distribution effect and quantitative trade restrictions. QUDDUS, DAVIES and LYBECKER (1997) extended the Pakistan Agricultural Sector Model (PASM) developed by DAVIES et al. (1991) by incorporating the livestock sector. The modified model highlighted the need for incorporating inter-relationships between the crop and livestock sub-sectors. Their analysis recommended an increase in fodder acreage to meet the livestock sector's feed requirement and demonstrated the potential for increased production of various crops and other livestock products.

This paper develops a price endogenous nonlinear programming model for the crop sector of Punjab province incorporating regional resource availability and production technology pertaining to the region. Punjab represents the most developed agricultural region in Pakistan, accounting for a large portion (80% of wheat and cotton, 65% of maize and sugarcane and 90% of potato and pulses etc.) of the national agricultural production for commercial purposes. Therefore, although being a regional model, the price endogenous framework used in this study is well justified since output changes in this region directly affect the national agricultural markets. The model considers price-quantity interrelationships when determining the optimal resource allocation of an aggregate representative farm assuming that the representative farmer is a rational profit optimizer.

The crop sector of Punjab, Pakistan, is considered as the food basket of the country. However, although the area under crops and production of major crops has increased convincingly, the total factor productivity in the region is argued to be much lower than its real potential (BYERLEE, 1992; ALI and VELASCO, 1994; PINGALI and HEISEY, 2001; ALI and BYERLEE, 2002; GOVERNMENT OF PAKISTAN 2006). The total factor productivity growth in Pakistan's Punjab over the period 1970-2003 was estimated as 1.3% annually, compared to 1.9% for the India's Punjab over the same period (GOVERNMENT OF PUNJAB, 2009). This suggests that there is room for improving the productivity in the region by appropriate incentive mechanisms, improved technology, and infrastructure development. By establishing appropriate mechanisms improved crop productivity can be achieved and the regional crop sector would respond to these changes by allocating agricultural production factors (mainly land) differently, which in turn would lead to a new equilibrium in agricultural markets. Investigating the new state of the regional agricultural system and the resulting market equilibrium is the research issue addressed in this paper.

The cropping activities considered in the study include cereal crops (wheat, maize, rice, millets, guar seed), cash crops (cotton, sugarcane), legume crops (chickpea and mung dry bean), vegetable (potato), oilseeds (rapeseed and canola), and feed crops (winter and summer fodders). These cropping activities occupy more than 90% of the total cropland in the region and generate above 95% of the crop production value period (GOVERNMENT OF PUNJAB, 2009).

2. The model

The objective function of the price endogenous nonlinear sector model developed here incorporates price dependent product demand and factor supply functions and measures the consumer's and producer's surplus, which will be referred to as the 'social surplus'. The consumer surplus is defined as the area between the demand functions and the endogenous price levels, while the producers' surplus is the crop returns computed at endogenous crop prices and the cost of supply summed across multiple commodities (SAMUELSON, 1952; TAKAYAMA and JUDGE, 1971).

On the demand side we assume a linear demand function for commodity *i*, expressed by

$$P_i = \alpha_i - \beta_i Q_i ,$$

where α_i and β_i are known (estimated) scalars which represent the price intercept and the slope of the demand functions. On the supply side, we assume linear production technologies (Leontief or input-output production functions) and constant input prices. Let c_j denote the cost of production per unit of j^{th} crop production activity and X_j be the amount of land allocated to that activity. The social surplus (objective function of the model) is then given by:

$$\sum_i Q_i(\alpha_i - 0.5\beta_i Q_i) - \sum_j c_j X_j .$$

The model constraints include land use and availability[1] and market equilibrium (or material balance) constraints. The land availability constraint restricts the total use of land by all crop production activities to the availability of cropland. Due to favorable climatic conditions and soil quality, in Punjab multiple use of cropland in a given production year is possible as long as the crop calendars (i.e. growth periods) do not overlap. To allow this in the model, instead of an annual land use/availability constraint that restricts the use of land by all cropping activities in a given year to the total availability of land, we define a land balance constraint for each month where production calendars (planting and harvesting months) of individual crops are incorporated. To explain this, suppose crop *j* can be planted in month t_1 and harvested in month t_2. Then, if X_j hectares are allocated to crop *j*, in any month between t_1 and t_2.that piece of land is covered by crop *j* and cannot be allocated to any other crop. The same land can be used, however, if a crop can be planted and harvested outside the time window $[t_1, t_2]$. This is formulated in the model as follows:

$$\sum_j \delta_{jt} X_j \le l \quad \text{for all } t ,$$

[1] Land availability is considered as the only restrictive factor in this particular application. The model can be extended to incorporate the use and availability of other resources by imposing a linear constraint for each input, namely $\sum_j \delta_{jtk} X_j \le b_{kt}$ for all *k,t* where δ_{jtk} represents the amount of input *k* required per unit of X_j in period *t* and b_{kt} is the availability of input *k* in month *t*.

where δ_{jt} is 1 if crop activity *j* occupies the land during month *t* and zero otherwise. Therefore, the constraint implies that the total acreage of all crops whose crop calendars do not overlap cannot exceed the available land, which is denoted by *l* in the above equation and assumed to be the same for all months.

The material balance constraint requires that the demand for each commodity cannot exceed the total amount supplied by all farms i.e.

$$Q_i \leq \sum_j y_{ij} X_j \quad \text{for all } i ,$$

where y_{ij} is the contribution (yield) of j^{th} crop activity to the supply of i^{th} product.

The mathematical model is expressed in algebraic form below:

$$\begin{aligned}
&Max \quad \sum_i Q_i(\alpha_i - 0.5\beta_i Q_i) - \sum_j c_j X_j \\
&s.t.: \\
&\qquad Q_i \leq \sum_j y_{ij} X_j \quad \text{for all } i \\
&\qquad \sum_j \delta_{jt} X_j \leq l \quad \text{for all } t \\
&\qquad Q_i, X_j \geq 0
\end{aligned}$$

The solution of the above model endogenously generates the market equilibrium quantities and optimal land use patterns that maximize net farm returns at the endogenous commodity prices. Although the market equilibrium prices of individual commodities are not defined as endogenous variables in the model described above, they are determined endogenously through the shadow prices (Lagrange multipliers) associated with the material balance constraints. This issue is well documented in the literature (see for example MCCARL and SPREEN, 1980, or NORTON and SCHIEFER, 1980), therefore for the sake of space we do not elaborate on mathematical proofs.

3. Data

The base year (2006) data on crop yields, quantities demanded and the government procurement prices for wheat, cotton, sugarcane and rice have been adopted from The Agriculture Statistics of Pakistan (GOVERNMENT OF PAKISTAN, 2007). The producer prices for the remaining crops were obtained from www.fao.org. The costs of production of all crops for Punjab Pakistan have been adopted from ARIFULLAH (2007), by updating for the rate of inflation for the province level data and cross checking with the various studies for the Punjab province of Pakistan (AHMED and

MARTINI, 2000). The Indian Punjab's cost of cultivation were found at GOVERNMENT OF INDIA (2007) for some of the major crops planted in the region, including wheat, rice, maize, millets, cotton, sugarcane, rapeseed, etc.

The national demand elasticities of all thirteen crops are obtained from various studies, including BOUIS and SCOTT (1996), ALI and ABEDULLAH (1998), AHMED and MARTINI (2000), ALI and BAREELY (2002). The demand elasticities characterizing the farm-gate demand faced by Punjab producers are assumed to be the same as the national elasticity estimates given that the region supplies much of the commercial agricultural output[2].

4. Results

When using mathematical programming models for sector analyses, the first step is to examine how closely it replicates (validates) the observed situation prevailed in a selected base year, which is 2006 in the present study. Therefore to test the empirical validity of the mathematical model developed here we first ran the model to simulate the performance of agricultural sector of Punjab in 2006.

Table 1 presents the base year observed crop acreage, quantity demanded and market prices for the thirteen cropping activities and the results obtained from the model. The acreage allocations, quantities demanded and prices of all cropping activities generated by the model are within a close range to the actual situation that prevailed in the base year.

For the four major commercial crops, wheat, cotton, rice, and sugarcane, the simulation performance of the model is remarkable. The largest discrepancy between the observed and simulated acreage variables is 10.8%, which is usually considered as a satisfactory level for simulation models. The model overestimates the equilibrium acreage variables for most crops. Note that the total acreage of all crops in the actual column and the model simulation column do not match. This is not an error, rather it is caused by multiple uses of the land in the optimal solution that results in a larger total crop acreage in the model solution. This implies that if the crop calendars we used in the model are truly representative, the land is underutilized by Punjab farmers.

[2] KUTCHER (1983) presents a method for calculating demand elasticities for a region based on national demand elasticities and the region's share in the total supply of individual products. Also see HAZELL and NORTON (1986).

Table 1. Actual and model simulated acreage, production and prices of the selected crops produced in Punjab, Pakistan

	Base year acreages (1,000 Ha.)		Base year quantities (1,000 tons)		Base year prices (PK. Rs.)**	
Crops	**Actual**	**Model***	**Actual**	**Model***	**Actual**	**Model***
Wheat	6,433	6,622 (2.9)	17,853	18,544 (3.9)	12,130	11,369 (-8.4)
Cotton	2,463	2,608 (5.9)	9,605	1,0170 (5.9)	8,804	7,769 (-11.8)
Rice	1,728	1,826 (5.7)	3,076	3,287 (6.9)	1,6320	14,000 (-14.2)
Sugarcane	625	575 (-8.0)	28,969	26,636 (-8.1)	1,500	1,648 (8.9)
Chickpea	911	828 (-9.1)	865	786 (-9.1)	12,803	14,046 (9.7)
Potato	105	108 (2.9)	1,390	1,438 (3.5)	8,730	8,080 (-8.1)
Rapeseed	138	142 (2.9)	123	128 (4.1)	2,1804	20,957 (-7.6)
Winter Fodders	1,032	1,046 (1.4)	22,807	23,019 (0.9)	1,850	1,772 (-6.0)
Maize	493	530 (7.5)	1,428	1,537 (7.6)	11,028	9,650 (-12.5)
Millet	367	380 (3.5)	217	228 (5.1)	10,793	11,385 (5.5)
Guarseed	104	113 (8.7)	81	91 (11.8)	3,000	2,731 (-9.0)
Mung	195	216 (10.8)	125	130 (4.4)	12,980	10,178 (-21.6)
Summer Fodders	966	993 (2.8)	21,775	22,351 (2.6)	1,840	1,579 (-14.2)

* Figures in parentheses represent the percentage deviations between the model results and the observed base year values of acreage, production and commodity prices.

** PK. Rs: Pakistan Rupees. In 2007 the exchange rate was 1US$=62.65 Pk. Rs.

Source: GOVERNMENT OF PAKISTAN (2007)

The overestimations in crop acreages are also reflected in the overestimation of crop production values. Consequently, with the exception of sugarcane, chickpeas and millets the crop prices endogenously generated by the model are generally lower than the observed base year prices. Given the simplicity of the model and having obtained the data from different sources, such discrepancies are considered normal.

The model estimates for the consumer's surplus, producer's surplus and the social surplus calculated using the base year production and price estimates are presented in table 3. These values will be compared against the corresponding values obtained under the 'technological change' scenario which will be elaborated on below.

As stated at the outset, the total factor productivity (TFP) growth in Pakistan's Punjab between 1970 and 2003 has been 1.3% annually. This rate is significantly lower than in several other Asian agriculture systems, in particular the comparable estimate for the Indian Punjab (1970–95), which is 1.9% annually. The TFP growth rates for other countries in this part of the world are 2.2% for China (1965–85), 1.9% in Taiwan (1951–80), 1.8% in Thailand (1971–2002), and 2.1% in Vietnam (1985–203) (GOVERNMENT OF PUNJAB, 2009). Analyzing the reasons for the low TFP growth in Pakistan Punjab is beyond the scope of this paper. Our interest lies in the crop pattern and new market equilibrium and the resulting social welfare changes that would be achieved if Pakistan Punjab had the same productivity (crop yields) as India Punjab. Because of their homogenous socio-economic conditions and similarity in production environments, such a scenario is highly likely if appropriate measures could be taken in Pakistan Punjab. The specific question we address here is the following: 'how the market equilibrium, crop pattern (land use), crop prices and social welfare in Pakistan Punjab would change if the productivity in the region could be enhanced by appropriate incentive mechanisms (increasing crop yields simultaneously with production costs) to the level of Indian Punjab; how would the benefits (if any) be distributed among the consumers and producers?'

Assuming that by establishing appropriate mechanisms improved crop productivity can be achieved and the regional crop sector would respond to these changes by allocating agricultural production factors (mainly land) differently, the technological progress would lead to new market equilibrium. We used the model to analyze this scenario by replacing the yields and production costs of the major crops listed in table 1 (specifically wheat, cotton, rice, sugarcane, chickpea and rapeseed) with the respective data from India's Punjab region while retaining the consumer behavior (crop demand functions faced by Pakistan Punjab producers). The new market equilibrium and optimal resource allocation that would occur under this scenario are presented in table 2. The results show significant increases both in the acreages and production quantities (thus demand) of major crops like wheat, rice, sugarcane, maize, millet and guar-seed.

The areas allocated to potato and summer fodder have also increased, but marginally, whereas the production quantities for these crops increased significantly compared to the base case reported in table 1. On the other hand, the areas of cotton, chickpea, mung, and rabi fodders have dropped since more profitable crops have taken over some of the lands that were allocated to those crops in the base run. Rapeseed and mung being the efficiently crops are producing increased quantity despite decrease area allocated to these crops in new scenario. To facilitate the comparison of the model results *vis-a-vis* the base run results, the percent changes are reported in parentheses in the table.

The production increases for three major crops, rice, sugarcane and maize are enormous. This indicates that Pakistan has much room to improve the productivity of these crops, and if this is done substantial output increases would occur for these crops despite that their prices would fall dramatically. On the other hand, dropped acreage and production of cotton implies that Pakistan Punjab has already achieved a sufficient productivity level. The technological progress would not alter the attractiveness of this crop, which is mainly because of the high demand for cotton.

Table 2. Model simulation results and comparison of the acreage, production and market prices of some major crops produced in Pakistan Punjab under enhanced technology

Crops	Acreages (1,000 ha)		Production (1,000 tons)		Price (PK. Rs.)	
	Base Run	Scenario	Base Run	Scenario	Base Run	Scenario
Wheat	6,574	7,016 (6.7)*	18,408	29,433 (59.9)	11,369	9,034 (-20.5)
Cotton	2,608	2,416 (-7.4)	10,170	6,765 (-33.5)	7,770	9,139 (17.6)
Rice	1,826	2,175 (19.1)	3,287	8,418 (156.1)	14,000	5,760 (-58.9)
Sugarcane	569	664 (16.7)	26,360	4,5717 (73.4)	1,648	1,400 (-15.2)
Chickpea	889	397 (-55.3)	844	269 (-68.1)	14,046	41,076 (196.8)
Potato	108	114 (5.6)	1,435	1,978 (37.8)	8,080	6,772 (-15.2)
Rapeseed	140	133 (-5.0)	126	158 (25.4)	20,957	23,979 (13.7)
Winter Fodders	1,042	998 (-4.2)	23,018	21,943 (-4.7)	1,772	2,132 (19.8)
Maize	530	628 (18.5)	1,537	1,883 (22.5)	9,650	6,008 (-37.7)
Millet	380	457 (20.3)	228	448 (96.5)	11,385	9,011 (-20.9)
Guarseed	113	160 (41.6)	91	125 (37.4)	2,731	1,391 (-49.1)
Mung	216	212 (-1.9)	130	185 (42.3)	10,178	10,675 (4.9)
Summer Fodders	993	1,048 (5.5)	22,351	25,171 (12.6)	1,579	1,051 (-33.4)

* Figures in parentheses represent percent changes with respect to the base run solution.

The sector model incorporates price dependent product demand functions; therefore an output (thus demand) increase is accompanied by a price decrease, or vice versa. While producers would gain from output increases the falling prices may offset those gains and the net effect may be positive or not. An important policy issue is who benefits from the assumed technological progress and the resulting price movements in agricultural markets. To answer these questions we assess the welfare changes measured by the consumer's and producer's surplus, and the overall social surplus, table 3 shows the results.

The figures in table 3 clearly indicate a substantial social welfare increase (nearly 60%). This is mainly because of the dramatic increase in consumption and reduced commodity prices which together increase the consumers' surplus by 52%. Producers also enjoy a net gain from the technological progress. Although the relative change with respect to the base run seems very high (141%), the absolute change (94.7 million Rs) is only a quarter of the consumer's welfare gain (417.9 million Rs.).

Table 3. Comparison of the welfare gains under the existing and enhanced agricultural production technologies in Pakistan Punjab

	Base run (million Pak. Rs.)	New technology (million Pak. Rs.)	Net difference (million Pak. Rs.)
Consumer surplus	798.6	1216.6 (52.3)*	417.9
Producer surplus	67.1	161.7 (141.0)	94.7
Social surplus	865.7	1378.3 (59.2)	512.6

* Figures in parentheses indicate percent changes with respect to the base run.

Therefore, the model results answer the question stated at the outset: As a whole society benefits from the hypothesized agricultural technology enhancement (namely by achieving the Indian Punjab yields and costs of cultivation); both producers and consumers would benefit from increased productivity; but, the main beneficiary of the technological progress would be Pakistan consumers (in Punjab and elsewhere in Pakistan) who would enjoy a much greater surplus than the producers in Punjab.

5. Conclusions

Agriculture is considered the mainstay in the economy of Punjab, Pakistan with the major crops share of 46.7% in the value addition and livestock contribution of 39.1% in FY 2007 (PUNJAB ECONOMIC REPORT, 2007). The Government of Punjab is interested to optimize agricultural resource use through various measures. However, the existing cropping pattern is biased towards four major crops which neither conform to its comparative advantage nor to realities of national and international markets. Given the restricted resource base the optimality of the present cropping pattern is questioned by various reports (ADB, 2008; GOVERNMENT OF PUNJAB, 2009). A variety of technically feasible cropping patterns can be achieved in the four ecological zones (i.e. wheat-cotton, wheat-rice, mixed and rain-fed zone) in optimizing the use of valuable resources simply by adjusting area sown to these crops. Crop diversification is a subject of interest for the government of Indian Punjab as well, where crop diversification has been regarded as not simply to evolve a crop combination for stimulating growth but also optimizing on the wider dimension of resource use efficiency and sustainability of agriculture and its inter-linkages with rest of the economy (METHA, 2005).

This paper demonstrates that if appropriate mechanisms are introduced to improve crop productivity the region's crop sector would respond by allocating agricultural production factors (mainly land) much differently, creating the basis for a new market equilibrium. Except cotton, in which Pakistan Punjab has achieved a satisfactory productivity level, several major commercial crops would increase their share in land allocation (particularly wheat, rice and sugarcane), which would be accompanied by dramatic decreases in commodity prices, thus increasing both the producers' and the consumers' welfare. Often times farm policies including direct income transfers through price supports and input subsidies, infrastructure investments, and low taxation of the farm incomes are criticized particularly at times when a developing economy is experiencing hardships. These policies aim at increasing farm productivity along with farm incomes. The empirical results of this modeling exercise show that the main beneficiaries of such policies are actually consumers who gain much more welfare than the producers.

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