Analysis of Technical Efficiency and Varietal Differences in Pistachio Production in Iran Using a Meta-Frontier Analysis[1]

Hossain Mehrabi Boshrabadi
Department of Agricultural Economics
Shahid Bahonar University, Kerman, Iran

Renato A. Villano and Euan Fleming
School of Economics
University of New England, Armidale, NSW, Australia

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Abstract

This paper reports on an analysis of technical efficiency and varietal differences in pistachio production in Iran. A random sample of 475 farmers was selected from the province of Kerman in 2003 and 2004. In this study, farmers are classified into three groups according to the variety of tree they planted. The three main varieties of pistachio trees planted are *Kalleh-Ghuchi*, *Fandoghi* and *Akbari*.

The technical efficiency indices are computed using three approaches. First, a standard stochastic production frontier was employed using pooled data. Secondly, stochastic frontier production functions were estimated for each variety (separately). Lastly, the meta-frontier approach was used because production varieties and technologies are expected to differ between the three varieties. Use of this method enabled technical efficiency scores to be corrected by the coefficient of the variety-technology gap ratio (VTGR). Estimates of the frontier were obtained assuming a translog functional form.

Results indicate that the mean values of technical efficiency in 2003 and 2004 for the pooled frontier, variety group frontiers and meta-frontier across all data are 54 per cent, 55 per cent and 62 per cent, respectively. The mean value of VTGR in 2003 and 2004 varies from 0.58 for the *Kalleh-Ghuchi* variety to 0.68 for the *Fandoghi* variety. These results show the importance of taking into account the differences in frontiers imposed by different tree varieties.

Keywords: pistachio; stochastic meta-frontier; production function; technical efficiency; Iranian agriculture;

JEL classifications: C21; Q12; Q16, Q55, R58

1. Introduction

This paper reports on an analysis of technical efficiency and what we term the 'variety-technology gap' in pistachio farming in the province of Kerman in Iran. This is the first study of which we are aware in which an estimate is made of differences in production frontiers of different crop varieties using the meta-frontier approach. Our aim is to distinguish technical efficiency caused by the production practices of farmers from that arising from differences in production capacity imposed by the tree variety grown.

Iran is the largest producer of pistachio at the world, accounting for about two-thirds of global planted area and slightly more than one-half of world production in recent years. It follows that pistachio is considered an important horticultural crop in Iran, being grown on 16.5 per cent of the total horticultural area and 2 per cent of the total agricultural area on average between 1995 and 2003. Production of dry pistachio averaged about 243 000 tonnes over the same period (Ministry of Jihad-e-Agriculture, 2004). The Iranian government has funded national research to expand pistachio output for export by increasing farm productivity and one important way to achieve this outcome is through variety improvement.

Earlier productivity and efficiency studies of pistachio production in Iran focused on the estimation of technical efficiency assumed technologies are similar across farms and tree varieties. The purpose of this paper is to re-estimate the frontier production models by tree variety using a more flexible functional form, a larger data set and a methodology that would accommodate the possibility of heterogeneity in production technology by tree variety in Kerman province. Technical efficiencies of pistachio production are derived from these estimated models.

The paper is organized as follows. Section 2 contains a brief discussion of the study area, and is followed by an exposition of the method of analysis in section 3. In section 4, the results are presented and discussed, and concluding comments are made in section 5.

2. The study area

This study is conducted using a pooled data set collected on the production of pistachio on farms in the province of Kerman in Iran in 2003 and 2004. Kerman is the largest province of

Iran, located in the south-eastern part of the country. Agriculture is the dominant sector in Kerman province, accounting for almost 50 per cent of its gross domestic product (Mehrabi Boshrabadi, 2003).

Pistachio is the most important crop grown in Kerman, which is the largest producer of pistachio in Iran, accounting for 82.5 per cent of fruit area and 74.2 per cent of pistachio output on average between 1995 and 2003. The dry pistachio yield averaged 0.839 tonnes per hectare over the same period, below the national average of 0.933 tonnes (Ministry of Jihad-e-Agriculture, 2004). The three pistachio varieties grown in the province are *Kalleh-Ghuchi*, *Akbari* and *Fandoghi*.

The production data set method was collected from five producing area in the province, using two-stage cluster random sampling and a structured survey questionnaire of 475 farmers in 2003 and 2004. Parcels of land producing one tree variety were selected for data collection on each farm. A summary of the information on pistachio production collected from these farmers is presented in Table 1. The number of samples of *Kalleh-Ghuchi*, *Akbari* and *Fandoghi* varieties were 80, 100 and 71, respectively, in 2003 and 80, 100 and 34, respectively, in 2004.

[Table 1 here]

Rafsanjan is the largest pistachio-producing area in Kerman province, with about 51 per cent of pistachio farmers producing 44 per cent of the pistachio output. Farm size in the sample varies greatly within and between regions in Kerman province. Similarly, the average area planted to pistachio varies greatly between varieties. The average area planted to pistachio is highest for the *Fandoghi* variety and lowest for the *Kalleh-Ghuchi* variety. The average yield for the sample was about 1.25 tonnes per hectare in 2003 and 0.95 tonnes per hectare in 2004, above the provincial average in recent years. The *Akbari* variety achieved the highest, and the *Kalleh-Ghuchi* variety the lowest, average yield.

Table 2 presents the share of each input in the cost of production by variety. On the whole and for all varieties, water accounts for about 30 per cent of the total cost, followed by labour, animal fertilizer and the rental cost for machinery. Production of the *Akbari* variety is more labour-intensive than the other varieties.

[Table 2 here]

3. Method of Analysis

3.1 Analytical framework

The application of parametric frontiers in the estimation of technical efficiency in agriculture is demonstrated in a number of empirical studies. In recent years, the stochastic frontier approach has proved to be the most popular method because of its ability to take into account measurement error in the output and stochastic elements of production, thereby distinguishing the effect of noise from the effect of inefficiency. Technical efficiency is measured on the basis of the ratio of the realised to expected maximum output, given inputs and existing technologies and variety influences.

The original model developed by Aigner, Lovell and Schmidt (1977) and Meeusen and van den Broeck (1977) has been extended and modified to accommodate different circumstances. Some examples are Pitt and Lee (1981), Jondrow et al. (1982), Battese and Coelli (1992, 1995) and Kumbhakar (2002). One of the most recent extensions of the original model is the estimation of technical inefficiencies to accommodate differences in technologies across firms in the industry. The stochastic meta-frontier framework proposed by Battese and Rao (2002) and Battese, Rao and O'Donnell (2004) not only allows an examination of the technical inefficiencies of firms but also provides a measure of the technology gap.

Suppose we have *k* groups in the industry. We can estimate the stochastic group-*k* frontier using the standard stochastic frontier model defined as:

$$Y_{it(k)} \equiv f(X_{it(k)}, \beta_{(k)}) e^{V_{it(k)} - U_{it(k)}} \qquad i = 1, 2, \ldots, N_k \qquad (1)$$

where $Y_{it(k)}$ denotes the output of the *i*-th firm in the *t*-th period for *k*-th group; $X_{it(k)}$ denotes a vector of functions of the inputs used by the *i*-th firm in the *k*-th group; $\beta_{(k)}$ is the vector of unknown parameters to be estimated associated with the *k*-th group; $V_{it(k)}$ represent statistical noise assumed to be independently and identically distributed as $N(0, \sigma_{Vk}^2)$ random variables; and $U_{it(k)}$ are non-negative random variables assumed to account for technical inefficiency in production and assumed to be independently distributed as truncations at zero of the $N(\mu_{it(k)}, \sigma_{U(k)}^2)$ distribution.

The technical efficiency of the *i*-th firm with respect to the group-*k* frontier can be obtained using the result:

$$TE_{it}^{k} = \frac{Y_{it}}{e^{Xi\beta^k + V_{ti}}} = e^{-U_{ti(k)}} \tag{2}$$

Equation (2) allows us to examine the performance of the *i*-th firm relative to the individual group frontier. In order to examine the performance of the *i*-th firm relative to the meta-frontier, the stochastic meta-frontier production function approach is used. The meta-frontier is a function that envelops the stochastic frontiers of the different groups such that it is defined by all observations in the different groups in a way that is consistent with the specifications of a stochastic frontier model (Battese and Rao, 2002, p. 89).

Following Battese and Rao (2002) and Battese, Rao and O'Donnell (2004), a stochastic meta-frontier production function model in the industry is defined as:

$$Y_{it} = f(X_{it}, \beta^*) \equiv e^{X_{it}\beta^*} \tag{3}$$

where $i = 1, 2, \ldots, N_k$, $t = 1, 2, \ldots T$; Y_{it}^* is the meta-frontier output that dominates all group frontiers, and β^* denotes the vector of meta-frontier parameters satisfying the constraints:

$$X_{it}\beta^* \geq X_{it}\beta^k \text{ for all } k = 1,2,\ldots K \tag{4}$$

The observed output defined by the stochastic frontier for the *k*-th group in equation (1) can be alternatively expressed in terms of the meta-frontier function in equation (3), such that

$$Y_{it} = e^{-U_{it(k)}} \times \frac{e^{X_{it}\beta(k)}}{e^{X_{it}\beta^m}} \times e^{X_{it}\beta^m + V_{it(k)}} . \tag{5}$$

The first term on the right-hand side of equation (5) is the same as that in equation (2), which denotes the technical efficiency of the *i*-th firm in the *t*-th period relative to the group-*k* frontier. The second term is what Battese and Rao (2002) term the technology gap ratio (TGR), which is expressed as

$$TGR_{it} = \frac{e^{X_{it}\beta_{(k)}}}{e^{X_{it}\beta^{*}}}. \qquad (6)$$

The TGR measures the ratio of the output for the frontier production function for the *k*-th group relative to the potential output that is defined by the meta-frontier function, given the observed inputs (Battese and Rao, 2002; Battese, Rao and O'Donnell, 2004). The TGR has values between zero and one.

The technical efficiency of the *i*-th firm, given the *t*-th observation, relative to the meta-frontier, is denoted by TE_{it}^{*} and is defined in similar way to equation (2). It is the ratio of the observed output relative to the last term on the right-hand side of equation (5), which is the meta-frontier output, adjusted for the corresponding random error, such that

$$TE_{it}^{*} = \frac{Y_{it}}{e^{X_{it}\beta^{*} + V_{it(k)}}}. \qquad (7)$$

Accordingly, following equations (2), (5) and (6), TE_{it}^{*} can be expressed as

$$TE_{it}^{*} = TE_{it}^{k} \times TGR_{it}. \qquad (8)$$

3.2 Variety-technology gap ratio

The notion of a TGR, defined in equation (6), is that of a gap between the production frontier for a particular group in an industry and the meta-frontier for the industry. It is helpful to expand this definition to the variety-technology gap ratio (VTGR). This specific definition suits our purpose in this study in that it describes the constraints placed on the potential output by a pistachio tree variety, and the interactions between production technology and that variety. Its importance for researchers of pistachio production lies in the fact that it enables us to assess the potential of the production system according to variety.

Characteristics of the three pistachio tree varieties that are the focus of analysis differ significantly. In particular, the *Kalleh-Ghuchi* variety is sensitive to frost damage and is also sensitive to water salinity. Yields of the *Fandoghi* variety fluctuate widely from year to year because it is strongly alternate-year-bearing nature. Finally, the *Akbari* variety is sensitive to heat stroke in summer and to water stress. Statistics reported above suggest that yield, input use and area planted differ between varieties.

3.3 Empirical model and variables

We estimated the model using a translog functional form of equations (1) and (3), specified by:

$$LnY_{it(k)} = \beta_{0(k)} + \sum_{j=1}^{6} \beta_{j(k)} LnX_{itj(k)} + \frac{1}{2}\sum_{j=1}^{6}\sum_{s=1}^{6} \beta_{js(k)} LnX_{itj(k)} LnX_{its(k)} + \eta D_{it(k)} + V_{it}^{k} - U_{it}^{k} \qquad (9)$$

where j represents the j-th input (j = 1, 2, …6) of the i-th firm (1,2,…N_k) in the t-th time period (t = 1,2) in the k-th group (k = 1,2,3); $\beta_{ij(k)} = \beta_{ji(k)}$ for all j and k; Y_i represents the physical products of dry pistachio (in kilograms); X_{it1} is the total area planted to pistachio (in hectares); $X_{it2(k)}$ represents total use of water(in m^3); $X_{it3(k)}$ represents total use of labour, including family labour (in man-days); $X_{it4(k)}$ represents total other costs (in Toman). $X_{it5(k)}$ represents tree age (in years); $X_{it6(k)}$ represents density (trees per hectare); and D is a dummy variable for year.

$Y_{it(k)}$ and all $X_{it(k)}$s are mean-corrected to zero in the translog functional form, which implies that the first-order coefficient estimates of the model represent the corresponding elasticities.

4. Results and discussion

Stochastic frontier estimates for the individual varieties were estimated using *FRONTIER* 4.1c (Coelli, 1996) while the meta-frontier was estimated using *SHAZAM* following O'Donnell, Rao and Battese (2005). The results are summarized in Table 3. An examination of the results of a likelihood-ratio test using a mixed chi-squared distribution confirms the presence of technical inefficiency for all varieties. We thus conclude that the technical inefficiency term is a significant addition to the individual variety and pooled models. The pooled stochastic frontier was estimated to test for differences in group (variety) frontiers. The generalized likelihood ratio test statistic for the null hypothesis that the group frontiers are the same was strongly rejected. Accordingly, the estimation of the meta-frontier production model is justified.

[Table 3 here]

Estimates of technical efficiencies and VTGRs are presented in Table 4 and the distributions of VTGRs by variety are presented in Figure 1. In the estimated pooled frontier model, mean technical efficiencies are fairly uniform across varieties and years. By averaging the 2003 and 2004 estimates, we estimated that farms growing the *Akbari* variety achieved the highest mean technical efficiency (0.58) with minimum variation. Farms growing the *Kalleh-Ghuchi* variety had the lowest mean technical efficiency (0.52) and farms with plantations of the *Fandoghi* variety had the highest variation. The mean technical efficiency across all varieties is estimated at 0.55. Estimates of mean technical efficiencies differ much more between varieties in the estimated group frontier models. Farms growing the *Akbari* variety again achieved the highest mean technical efficiency (0.61), and farms growing the *Fandoghi* variety had the lowest mean technical efficiency of 0.49. The mean technical efficiency across all varieties is estimated at 0.55, similar to the estimate for the pooled frontier.

[Table 4 here]

[Figure 1 here]

However, these results can be misleading in that insufficient allowance is made for differences in production technology arising from the use by farmers of different tree varieties. There is also a shortcoming in the estimation of individual group frontiers in that their efficiency levels cannot be compared; nor can VTGRs be estimated. Both of these problems are overcome by estimating the meta-frontier model where, as expected, technical efficiency estimates are lower but much less dispersed. On average across 2003 and 2004, farms with the *Kalleh-Ghuchi* variety achieved the highest mean technical efficiency (relative to the meta-frontier) of 0.35 and those with the *Fandoghi* variety had the lowest mean technical efficiency of 0.33. The mean technical efficiency across all data is estimated at 0.34. The key finding here is that there is little difference in technical efficiency between varieties when using the meta-frontier, suggesting that the individual group estimates exaggerate differences in technical efficiency between farms growing different varieties.

The reason for this result is that estimates of the mean values of VTGR in 2003 and 2004 vary more widely than the mean technical efficiency estimates in the meta-frontier model, from 0.58 for the *Kalleh-Ghuchi* variety to 0.69 for the *Fandoghi* variety. The estimated VTGR averaged only 0.62 in both 2003 and 2004 across all varieties, indicating that choice of variety is playing a major role in preventing individual farmers from operating on or near the meta-frontier. That is not to say that a producer cannot be located on the meta-frontier because of the tree variety that has been planted. The maximum estimated VTGR is unity for all varieties, which means that the three group frontiers are tangent to the meta-frontier. But more of the producers who planted the *Fandoghi* variety are located on or close to the meta-frontier than producers who planted the other two varieties.

Farms with the *Fandoghi* variety have the highest estimated mean VTGR while those with the *Kalleh-Ghuchi* variety have the lowest estimated mean VTGR among the three tree varieties. It is clear from Figure 1 that the *Fandoghi* variety has a more compact distribution of VTGRs and a larger proportion of observations towards the higher end of the range; only about 10 per cent of farms growing this variety recorded a VTGR below 0.5. This variety tends to be less sensitive to frost damage, water salinity and heat stroke in summer.

In contrast, almost 30 per cent of the farms growing the *Kalleh-Ghuchi* variety had a VTGR below 0.5. Farms with the *Akbari* variety had a distribution of VTGRs that was closer to a bell curve. While 7 per cent of them were close to the meta-frontier, only a small proportion of farms had a VTGR above 0.8 and most were grouped in the range from 0.5 to 0.75. A higher proportion of these farms had VTGRs below 0.5 than for farms growing the *Fandoghi* variety but a smaller proportion had VTGRs below 0.5 than for farms with the *Kalleh-Ghuchi* variety.

5. Conclusion

Our analysis of technical efficiency and what we term the variety-technology gap in pistachio farming in Kerman province in Iran is, to our knowledge, the first study to estimate a meta-frontier in crop production based on crop variety. This recently developed method has the advantage of allowing us to take specific account of the production technologies of three varieties of pistachio trees in estimating farm-level technical efficiencies. Two other, more familiar, estimation methods were employed: the standard stochastic production frontier using pooled data for the province and individual stochastic frontier production functions for the three varieties. Estimates of the frontier were obtained assuming a translog functional form.

Technical efficiency indices were computed using data in 2003 and 2004 from a random sample of 475 farmers. Use of the meta-frontier method enabled technical efficiency scores to be corrected by the coefficient of the VTGR, leading to results that showed that very little difference exists in technical efficiency between farms growing the different varieties. However, results indicate that farms growing the three varieties differ in the use they make of inputs and their VTGRs. Ignoring the limits placed on increasing technical efficiency because of constraints imposed by variety choice could lead to incorrect conclusions about the scope for farmers to improve their technical performance by adopting better farming practices.

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Table 1: Summary of basic characteristics of the sampled farmers, by variety

Item	Tree variety			
	Kalleh-Ghuchi	*Fandoghi*	*Akbari*	Total
Number of samples	160	200	115	475
Average area planted 2003-2004 (hectares)	1.74 (2.27)	2.68 (4.29)	1.90 (6.67)	2.18 (4.51)
Yield 2003 (kg/hectare)	1060 (805)	1218 (1093)	1480 (932)	1251 (973)
Yield 2004 (kg/hectare)	799 (632)	931 (733)	1383 (1175)	955 (824)

Note: Figures in parentheses are standard deviations.

Table 2: Average share of inputs in total variable cost by variety, Kerman province, 2003 and 2004

Input	*Kalleh-Ghuchi*	*Fandoghi*	*Akbari*	Total
	%	%	%	%
Water	28.67	31.33	28.17	29.67
Labour	26.15	24.15	27.78	25.70
Animal fertilizer	22.28	19.35	19.33	20.33
Chemical fertilizer	4.16	5.46	3.74	4.60
Pesticide	4.65	4.04	5.40	4.58
Machinery	11.18	12.42	14.61	12.54
Other inputs[a]	2.91	3.25	0.97	2.58
Total	100.00	100.00	100.00	100.00

[a] Includes packing and transport of inputs and products.

Table 3: Parameter estimates for the translog stochastic frontier models and meta-frontier

Parameter	Group frontier						Pooled frontier		Meta-frontier coefficient
	Kalleh-Ghuchi		*Fandoghi*		*Akbari*				
	Coeff.	SD	Coeff.	SD	Coeff.	SD	Coeff.	SD	
β_0	0.78	0.20	0.96	0.20	0.61	0.07	0.89	0.08	1.05
β_1	0.77	0.18	0.45	0.11	0.42	0.15	0.53	0.08	0.49
β_2	-0.09	0.14	0.19	0.12	0.29	0.11	0.03	0.08	0.05
β_3	0.14	0.10	0.23	0.10	0.11	0.06	0.22	0.05	0.39
β_4	0.02	0.08	0.06	0.07	-0.07	0.06	0.03	0.04	0.02
β_5	0.35	0.16	-0.12	0.16	-0.18	0.23	0.21	0.10	-0.11
β_6	0.02	0.25	0.05	0.25	0.19	0.24	0.19	0.12	0.08
β_{11}	-0.86	0.56	-0.29	0.30	-0.48	0.31	-0.44	0.17	-0.06
β_{12}	0.08	0.45	0.20	0.29	1.04	0.25	0.17	0.15	-0.06
β_{13}	0.40	0.25	-0.31	0.23	-0.57	0.25	0.04	0.12	-0.37
β_{14}	0.24	0.19	0.14	0.14	0.21	0.21	0.18	0.08	0.26
β_{15}	-0.99	0.41	0.55	0.25	0.45	0.66	0.20	0.17	0.0005
β_{16}	0.44	0.39	-0.20	0.54	-0.10	0.48	-0.21	0.18	-0.38
β_{22}	0.35	0.39	0.10	0.30	-1.73	0.55	0.05	0.16	0.37
β_{23}	-0.19	0.19	0.32	0.22	1.07	0.23	0.03	0.11	0.22
β_{24}	-0.25	0.14	-0.25	0.14	0.12	0.24	-0.25	0.08	-0.24
β_{25}	0.62	0.37	-0.13	0.27	0.09	0.49	-0.10	0.19	-0.03
β_{26}	0.24	0.47	0.15	0.49	1.86	0.56	0.24	0.20	0.13
β_{33}	-0.41	0.22	0.02	0.20	-0.27	0.38	-0.15	0.12	0.64
β_{34}	0.20	0.11	0.18	0.12	-0.58	0.15	0.17	0.07	-0.07
β_{35}	0.53	0.24	-0.40	0.28	-1.75	0.34	-0.14	0.16	-0.81

β_{36}	-0.50	0.31	-0.26	0.22	-1.60	0.32	-0.06	0.13	-0.46
β_{44}	0.00	0.11	-0.02	0.02	-0.05	0.17	-0.02	0.01	0.02
β_{45}	0.29	0.20	0.06	0.20	1.09	0.17	0.00	0.12	0.66
β_{46}	-0.07	0.23	0.07	0.20	-0.20	0.39	0.03	0.10	0.38
β_{55}	-0.03	0.98	-1.65	1.02	0.66	0.79	-0.12	0.43	1.07
β_{56}	0.65	0.71	-0.60	0.45	1.24	0.65	-0.16	0.29	0.29
β_{66}	0.83	0.85	-0.38	0.77	-0.20	0.46	-0.21	0.24	-0.14
η	-0.28	0.10	-0.22	0.10	-0.17	0.12	-0.23	0.07	-0.21
σ^2	0.76	0.18	1.42	0.26	0.75	0.09	1.08	0.12	
γ	0.76	0.14	0.94	0.05	1.00	0.00	0.82	0.05	
Log-L	-149.8		-215.5		-68.54		-507.6		

Table 4: Estimates of technical efficiencies and variety-technology gap ratios

Variety		Year	Pooled efficiency	Group efficiency	VTGR	Meta-frontier efficiency
Kalleh-Ghuchi	Mean	2003	0.530	0.603	0.597	0.356
		2004	0.504	0.595	0.563	0.341
		Total	0.517	0.599	0.580	0.349
	SD	2003	0.164	0.145	0.274	0.184
		2004	0.191	0.174	0.260	0.201
		Total	0.178	0.159	0.267	0.192
Fandoghi	Mean	2003	0.549	0.485	0.694	0.338
		2004	0.547	0.485	0.675	0.327
		Total	0.548	0.485	0.685	0.333
	SD	2003	0.186	0.225	0.209	0.192
		2004	0.201	0.239	0.204	0.202
		Total	0.193	0.231	0.206	0.197
Akbari	Mean	2003	0.576	0.635	0.564	0.343
		2004	0.579	0.557	0.621	0.337
		Total	0.577	0.612	0.581	0.341
	SD	2003	0.146	0.266	0.201	0.181
		2004	0.171	0.272	0.245	0.201
		Total	0.153	0.269	0.216	0.186
Total	Mean	2003	0.552	0.568	0.624	0.345
		2004	0.534	0.555	0.617	0.340
		Total	0.545	0.554	0.624	0.340
	SD	2003	0.168	0.227	0.235	0.186
		2004	0.194	0.227	0.237	0.201
		Total	0.180	0.228	0.236	0.192

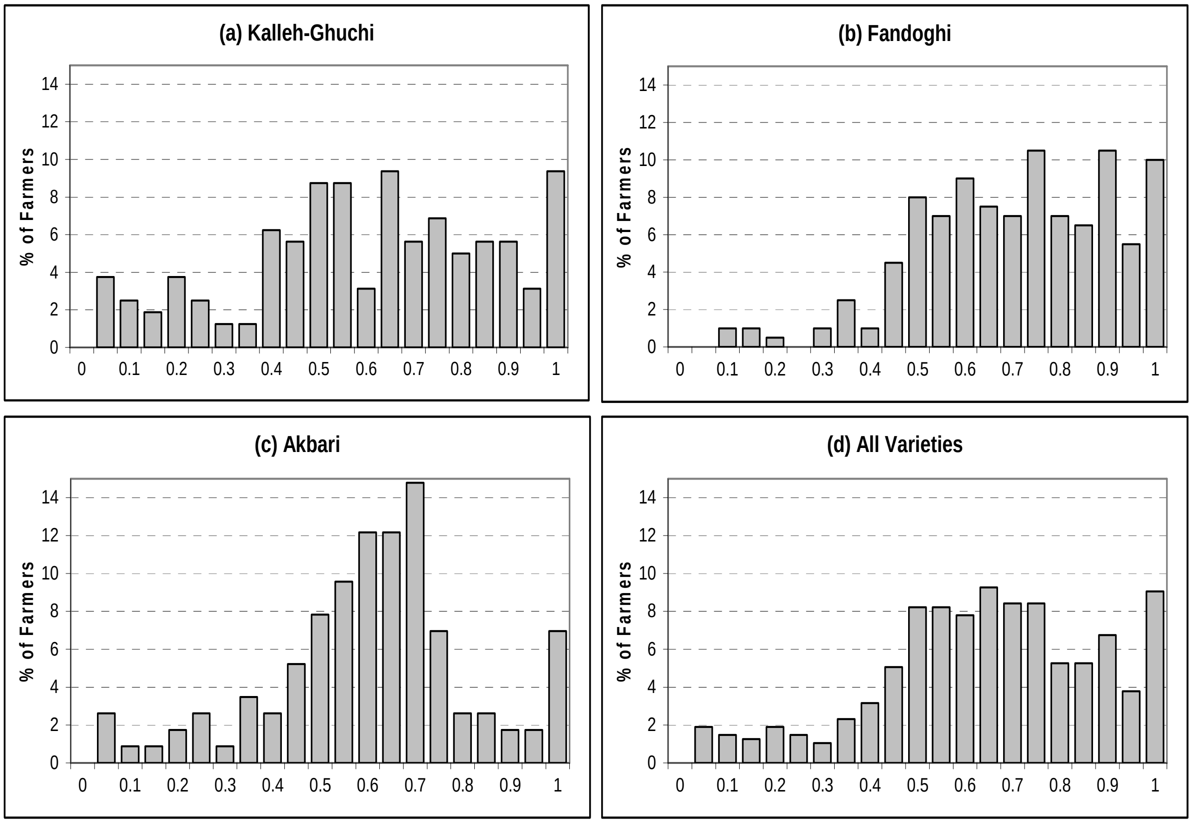

Figure 1: Distribution of the VTGRs of pistachio farmers in Kerman Province, Iran, 2003 and 2004.