Turk J Agric For
26 (2002) 303-309

Game Theory and its Application to Field Crops in Antalya Province

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Received: 22.08.2001

Abstract: The purpose of this paper is twofold. The first aim is to present briefly game theory and to illustrate the relationship between game theory and linear programming. The other aim is to apply game theory to field crops. The game theory model was used for main field crops, namely wheat, barley, maize, chickpea, sesame, cotton and groundnut, in Antalya province in Turkey. The data included time series of gross product values of the investigated crops for the period 1980-1999. The Wald decision-making criterion was applied to the game theory model to determine the highest income under the worst conditions. The results of the model indicated that groundnut and cotton were the most risky crops for the research area. As groundnut and cotton provide the highest expected income under the worst conditions these crops enter into the optimum plan. Furthermore, these two crops have the highest variation coefficients compared to the other crops. It can be concluded that the game theory model is a good indicator for growers selecting alternative management strategies.

Key Words: Game theory, Risk programming, Field crops, Agriculture and risk

Oyun Teorisi ve Antalya İli Tarla Bitkilerine Uygulanması

Özet: Bu çalışmanın iki amacı bulunmaktadır. Çalışmanın birinci amacı oyun teorisini açıklamak ve oyun teorisinin doğrusal programlama ile ilişkisini göstermektir. Çalışmanın diğer amacı ise oyun teorisinin tarla ürünlerine uygulanmasıdır. Bu amaçla, Antalya ilinde yetiştirilen başlıca tarla ürünlerinden buğday, arpa, mısır, nohut, susam, pamuk ve yerfıstığı ürünlerine oyun teorisi uygulanmıştır. İncelenen ürünler için 1980-1999 dönemine ait brüt üretim değeri verileri kullanılmıştır. Wald karar alma kriteri en kötü koşul altında en yüksek geliri belirlemek için oyun teorisi modeline uygulanmıştır. Oyun teorisi modeli sonuçlarına göre yerfıstığı ve pamuk araştırma bölgesi için en riskli ürünlerdir. Yerfıstığı ve pamuk en kötü koşullar altında en yüksek beklenen geliri sağladığı için optimum planda yer almışlardır. Ayrıca pamuk ve yerfıstığı incelenen ürünler içinde en yüksek varyasyon katsayısına sahiptir. Bu sonuçlara göre oyun teorisi modelinin, üreticilerin alternatif yönetim stratejileri seçiminde iyi bir gösterge olduğu söylenebilir.

Anahtar Sözcükler: Oyun teorisi, Risk programlama, Tarla bitkileri, Tarım ve risk

Introduction

Growers must take risks if they are to have any chance of obtaining profit. It is not possible for a management strategy to be potentially profitable and free from risk. Growers must balance the risks of loss against the potential for profit among alternative management strategies. In these structures, management of farms has become more important than in previous years.

Farmers have to manage risk and uncertainty. The sources of these risks and uncertainties for agriculture are marketing, production, financing, technological level, political events and climatic conditions. In agriculture in particular, uncertainty is greater for long term plans (Aras, 1988). Besides the main characteristics of agriculture, the dynamic of today's agriculture requires continuing adjustments to changing technological and economic conditions. In such situations it is necessary to study different planning methods such as game theory .

Little attention has been paid to the management of farms and farm planning so far in Turkey. Generally linear programming has been used in the planning of agricultural enterprises. However, linear programming determines the maximum profit according to given data, but risk and uncertainty are not taken into consideration. Other planning methods covering risk and uncertainty conditions such as game theory are not used in Turkey. Therefore, this study is important for two reasons. First, this is the first study about the research region with respect to farm planning, and second game theory was used in order to take risk and uncertainties into account.

The first aim of this paper is to explore the game theory model and to illustrate the relationship between game theory and linear programming. The other aim is to determine the highest expected income under the worst circumstances for the investigated crops. To achieve this aim, game theory was applied to the main field crops of Antalya province.

Materials and Methods

Game theory was used to analyse gross product value data obtained from the State Institute of Statistics, Prime Ministry, Republic of Turkey. Gross product values of wheat, barley, maize, cotton, groundnut, chickpea and sesame were used in the game theory model. Gross production value was calculated by multiplying crop yield and prices received by farmers. The share of these seven crops is 84.6% in the total gross product value of field crops of the province in 1996 values. The data included time series of gross product value covering the period 1980-1999. It was assumed that the effects of climate, price and other factors belonging to the past years will be valid for the next years in the model (McInerney, 1967; Agrawal and Heady, 1968; Hazell, 1970; Miran and Dizdaroglu, 1996; Akcaoz, 2001). In the game theory model, Wald's criterion (maximin) was used and 35 different farm plans were obtained. Payoff coefficients represent changes in the farmer's gross product value associated with the various alternatives of the plans (player) in the model. According to the maximin strategy the player, in this case the farmer, tries to choose 'the best of the worst'.

The gross product values of crops are different from each other and fluctuate from year to year. For example, while gross product value per hectare of groundnut in 1980 was TL 656.6 million (Turkish Lira), it was TL 859.9 million in 1999. The gross product value of groundnut was higher than that of the other crops investigated. Groundnut has the highest variation coefficient with 5.39%, while the variation coefficient of chickpea was the lowest with 2.65%. The variation coefficients of gross product value of cotton, wheat, sesame, barley and maize were 4.92, 3.95, 3.91, 3.37 and 3.29% respectively.

The maximin criterion is used in the game theory model where

V Expected income,

$X_1,\ X_2,\ \ldots\ldots X_n$ Rate of production activities,

$a_{11},\ a_{21},\ \ldots\ldots a_{m1}$

$a_{12},\ a_{22},\ \ldots\ldots a_{m2}$

$\ldots\ldots\ldots\ldots$

$a_{1n},\ a_{2n},\ \ldots\ldots a_{m2}$

Gross product values per hectare of crops

Max = V denotes objective function

V explains maximin value and the coefficient of V is (-1).

Based on these explanations, the game theory model is given in Table 1.

Results and Discussion

Game Theory and Linear Programming

Linear programming problems must have three elements: objective function, constraints and non-negativity conditions. These three elements also exist in a two-person zero-sum game. A two-person zero-sum game can be converted into an equivalent linear programming problem. In a two-person zero-sum game, the objective of one player is to maximise the expected gain while the other player tries to minimise the expected loss. In other words the aim of the players in game theory is either to maximise or minimise gains. In short, the objective of the game is a linear function of the decision variables (Bierman et al., 1973; Kwak and Delurgio, 1980).

In linear programming the players wish to optimise their gain subject to given constraints and the variables must be always non-negative. When both players select the optimal strategies in a two-person zero-sum game, one player's highest expected gain is equal to the other player's lowest expected loss (Kwak and Delurgio, 1980). Therefore the value of the maximisation problem is exactly the same as that of the minimisation problem. This is the same as the primal/dual relationship in linear programming.

Kwak and Delurgio (1980) pointed out that game theory and linear programming have the following similar

Table 1. Game Theory Model.

```
1] MAX = V;
 2] X1*126615460 + X2*92598750 + X3*130879540 + X4*206021060 +
 3] X5*662513310 + X6*656587750 + X7*264920310 -V>0;
 4] X1*157086530 + X2*116982760 + X3*183070770 + X4*195984150 +
 5] X5*662038600 + X6*572204420 + X7*244981970 -V>0;
 6] X1*129831010 + X2*126260370 + X3*207381960 + X4*244442400 +
 7] X5*541045420 + X6*484953440 + X7*352061320 -V>0;
 8] X1*143457600 + X2*110729500 + X3*181853830 + X4*249708270 +
 9] X5*663164580 + X6*698089900 + X7*405123010 -V>0;
10] X1*146290350 + X2*145806140 + X3*231718790 + X4*200926650 +
11] X5*530159360 + X6*682476240 + X7*280787640 -V>0;
12] X1*164520060 + X2*156978680 + X3*289762340 + X4*300945010 +
13] X5*623849890 + X6*767318890 + X7*314222170 -V>0;
14] X1*144933650 + X2*122571080 + X3*254827310 + X4*314607430 +
15] X5*435122570 + X6*539951130 + X7*365662390 -V>0;
16] X1*116076710 + X2*100194180 + X3*217261240 + X4*117916680 +
17] X5*733428060 + X6*736447160 + X7*336435650 -V>0;
18] X1*115471230 + X2*89236680 + X3*262634730 + X4*128903350 +
19] X5*668282700 + X6*487654170 + X7*232587340 -V>0;
20] X1*110565750 + X2*59059030 + X3*281790160 + X4*118629520 +
21] X5*765408510 + X6*645064660 + X7*340617800 -V>0;
21] X1*123220830 + X2*72841190 + X3*284712010 + X4*135877890 +
22] X5*879120210 + X6*768309810 + X7*352023000 -V>0;
23] X1*118249790 + X2*67226030 + X3*241589070 + X4*84166510 +
24] X5*642346640 + X6*723640070 + X7*251745810 -V>0;
25] X1*160788880 + X2*148247880 + X3*365429390 +X4*109116340 +
26] X5*771270180 + X6*528446800 + X7*214523010 -V>0;
27] X1*178505350 + X2*146419980 + X3*438095950 + X4*123115820 +
28] X5*918279510 + X6*509784770 + X7*240328640 -V>0;
29] X1*145890430 + X2*105171920 + X3*281594990 + X4*176970720 +
30] X5*1036196060 + X6*425585570 + X7*257850920 -V>0;
31] X1*154110720 + X2*145664780 + X3*279843870 + X4*296315280 +
32] X5*952544530 + X6*581049680 + X7*395498290 -V>0;
33] X1*181391780 + X2*131763550 + X3*294968450 + X4*149354360 +
34] X5*800549510 + X6*561679210 + X7*369532850 -V>0;
35] X1*181929310 + X2*150183810 + X3*265608040 + X4*167525830 +
36] X5*792967840 + X6*559553530 + X7*405860300 -V>0;
37] X1*210896160 + X2*185564150 + X3*460869490 + X4*148055810 +
38] X5*828468680 + X6*694909990 + X7*503547360 -V>0;
39] X1*275800000 + X2*189760000 + X3*402675000 + X4*259200000 +
40] X5*728870000 + X6*859950000 + X7*506400000 -V>0;
41] X1+X2+X3+X4+X5+X6+X7=100;
42] X1*154281580 + X2*123163020 + X3*277828350 + X4*186389150 +
43] X5*731781310 + X6*624182860 + X7*331735490 =12300000000 ;
END
DIV INDEX1.SON
GO
QUIT
```

elements: linear objective function, linear side constraints, non-negativity condition and primal/dual relationship. However, there are some important differences between game theory problems and standard linear programming applications. Hazell and Norton (1988) listed these differences as follows:

i) A series of solutions will be obtained. The utility function of the decision-maker is affected a) positively on the level of expected income and b) negatively by an increase in the variability of income. Thus a series of solutions is obtained which trace out a V-Expected income frontier.

ii) The objective function contains a single coefficient for the variable V. V is constrained to be no greater than the lowest income for a specified expected level of income.

The optimal solution to a game problem may be stated by formulating it as a linear programming problem (Gordon and Ressman, 1978). Bierman et al. (1973) formulated a game problem as linear programming. They supposed that the game has two players, A and B. Player A has possible pure strategies A_1, A_2, ...A_m. Player B has strategies B_1, B_2, ...B_n, and a_{ij} is the payoff to player A when player A is using strategy A_i and player B is using B_j.

A mixed strategy for player A consists of a set of probabilities X_i (for i = 1 to m), such that $\sum_{i=1}^{m} X_i = 1$. Each X_i represents the probability of using pure strategy A_i. The objective for player A is to obtain an expected value V (the value of the game) as large as possible. He can only be sure of the expected value V if his strategy will guarantee that, regardless of what strategy his opponent adopts; he will obtain an expectation of V or more. For example, if player B were to adopt B1, then A's strategy must be such that

$$a_{11} X_1 + a_{21} X_2 + a_{31} X_3 + \dots\dots + a_{m1} X_m \geq V$$

Similarly if player B uses B_2, then to guarantee V, A must have

$$a_{12} X_1 + a_{22} X_2 + a_{32} X_3 + \dots\dots + a_{m2} X_m \geq V$$

A similar condition holds for any strategy B may play. Hence the linear programming problem for A is

$$\begin{aligned}
&\text{Maximize} \quad V \\
&\text{Subject to} \quad a_{11} X_1 + a_{21} X_2 + \dots\dots + a_{m1} X_m - V \geq 0 \\
&\qquad\qquad\quad a_{12} X_1 + a_{22} X_2 + \dots\dots + a_{m2} X_m - V \geq 0 \\
&\dots\dots\dots\dots\dots\dots\dots\dots\dots \\
&a_{1n} X_1 + a_{2n} X_2 + \dots\dots + a_{mn} X_m - V \geq 0 \\
&X_1 + X_2 + \dots\dots + X_m = 1 \\
&\text{all } X_i \geq 0
\end{aligned}$$

The last equation guarantees that the probabilities add up to one. The solution to this problem gives the equilibrium mixed strategy (X_1, X_2,..... Xm) for player A and the value of the game V. The dual of the linear programming problem for player A is the primal problem from player B's point of view. Let (U_1, U_2,..............U_n) be the mixed strategy probabilities for player B. He wishes to minimise the expected pay-off to his opponent. The solution gives the optimum strategy for B (U_1, U_2, ...U_n) and the value of the game W. Note that W must equal V.

Game Theory Applications in Agricultural Economics

Although game procedures applied to agricultural problems may prove useful in making recommendations to farmers, game theory has still not been used in agricultural economics research. Therefore, the reported applications of game theory to agricultural problems are few indeed. Early studies related to game theory were conducted by Langham (1963), McInerney (1967), Agrawal and Heady (1968), McInerney (1969), Hazell (1970), Kawaguchi and Maruyama (1972), and Akcaoz (2001). The concept of game theory has caused agricultural economists to re-evaluate their view of management decisions and strategies pursued by farmers.

However, there are many kinds of agricultural problems which can be solved by game theory applications. Game theory has been applied to production and marketing issues, and landlord-tenant relationships on rented farms. In the framework of game theory the farmer plays a game against nature. Therefore the farmer may plant different varieties and use combinations of crop strategies. He can use fertiliser in different dosages and can develop a strategy against the climate conditions. Therefore, Heady and Candler (1969) point out that "there are numerous types of agricultural problems, which have characteristics defining them in the game theory framework".

Different strategies are possible for game theory depending on the farmer's personality and circumstances. There are four classic criteria: Wald's criterion (maximin), Laplace's criterion, Hurwicz's criterion and Savage's regret criterion, and each criterion requires different strategies.

In this research, Wald's criterion (maximin) was used. According to the maximin criterion the farmer tries to choose "the best of the worst". This means that the farmer selects the combination of activities which will maximise his minimum income. This strategy gives the farmer maximum security. The reasons behind this strategy for the farmer can be several. The farmer has only small equity in his farm; he has large and different family responsibilities and so on. If the farmer pursues the maximin strategy he can be regarded a pessimist or as ultra careful (Barnard and Nix, 1979).

The results of game theory are given in Table 2. Based on the gross product value of the investigated crops 35 different farm plans were explained for the period 1980-1999. The results of the game theory model showed that if expected income is higher than 731.0 million TL/ha or less than 125.0 million TL/ha a solution is not feasible. When the expected income is approximately 660.9 million TL/ha the optimum solution is found at plan 6. As the expected income increases after this level the average lowest income decreases. If expected income decreases after the optimum solution (plan 6), the lowest income decreases also.

It is seen from Table 2 that while expected income is 731.0 million TL/ha, the average lowest income is 435.9 million TL/ha, and cotton (99.27%) and groundnut are (0.73%) part of the plan (plan 1). When the expected income is level 650.0 million TL/ha, sesame is included in the farm plan (plan 7). In this plan, cotton (33.29%), groundnut (63.29%) and sesame (3.42%) are used. If the expected income level is 560.0 million TL/ha, the average lowest income is approximately 456.4 million TL/ha. Chickpea (3.39%), cotton (27.55%), groundnut (45.05%) and sesame (27.01%) are included in this farm plan (plan 13).

At a 460.0 million TL/ha expected income level, sesame is excluded from the plan and maize is included (plan 18). In this plan the lowest average income is 390.5 million TL/ha; the farm plan consists of maize (1.82%), chickpea (45.72%), cotton (39.31%) and groundnut (13.15%). If the expected income is 360.0 million TL/ha, barley is included in the farm plan (plan 23). Barley, maize, chickpea, cotton and groundnut will also be included. If the expected income is 280.0 million TL/ha, the average lowest income is 234.4 million TL/ha. In this case wheat is included in the farm plan (plan 28). The farm plan consists of 3.38% wheat, 52.98% barley, 15.55% maize, 5.45% chickpea, 13.8% cotton and 8.84% groundnut.

When the expected income level is 220.0 million TL/ha, chickpea and sesame are excluded from the plan and the average lowest income is about 17.95 million TL/ha. In this plan (plan 30) wheat, barley, maize, cotton and groundnut are included. The lowest income is 62.1 million TL/ha in the farm plan (plan 35) if the expected income is 125.0 million TL/ha. In this plan only barley (94.10%) and wheat (5.90%) are included.

With the game theory model, when expected income is at the highest level for the examined region, cotton and groundnut are in the farm plan. As the expected income decreases, the share of the cotton and groundnut decrease, and wheat, barley, maize, chickpea, sesame are included in the farm plans. At the lowest expected income level, wheat and barley, which are less risky crops, are in the farm plan.

Conclusions

Game theory is concerned with competitive situations. Farm planning problems conceive the farmer playing a game against nature. A two-person zero-sum game can be converted into a linear programming model due to several similarities between the two. Therefore, the optimal solution to game theory may be found by formulating it as a linear programming problem. The objective of the game theory model in agriculture is to find the highest income under the worst circumstances.

In this study the highest expected income level under the worst circumstances was determined using the game theory model. For this purpose gross product values of wheat, barley, cotton, maize, chickpea, groundnut, and sesame were used for the period of 1980-1999 in Antalya province. The results of the game theory model indicate that groundnut and cotton were the most risky crops in the research area. As groundnut and cotton

Table 2. Game Theory Results.

Farm Plan	Expected Income (1000 TL/ha)	Lowest Income (1000 TL/ha)	Crop Patterns (%) Wheat	Barley	Maize	Chickpea	Cotton	Groundnut	Sesame
1	731 000	435 883.7	0.00	0.00	0.00	0.00	99.27	0.73	0.00
2	730 000	436 858.0	0.00	0.00	0.00	0.00	98.34	1.66	0.00
3	720 000	446 600.6	0.00	0.00	0.00	0.00	89.05	10.95	0.00
4	700 000	466 085.7	0.00	0.00	0.00	0.00	70.46	29.54	0.00
5	680 000	485 570.9	0.00	0.00	0.00	0.00	51.88	48.12	0.00
6	660 960	504 123.9	0.00	0.00	0.00	0.00	34.18	65.82	0.00
7	650 000	499 081.7	0.00	0.00	0.00	0.00	33.29	63.29	3.42
8	630 000	489 877.8	0.00	0.00	0.00	0.00	31.69	58.64	9.67
9	620 000	485 275.8	0.00	0.00	0.00	0.00	30.89	56.32	12.79
10	610 000	480 673.8	0.00	0.00	0.00	0.00	30.08	54.00	15.92
11	600 000	476 071.8	0.00	0.00	0.00	0.00	29.28	51.68	19.04
12	580 000	466 867.9	0.00	0.00	0.00	0.00	27.67	47.04	25.29
13	560 000	456 362.9	0.00	0.00	0.00	3.39	27.55	42.05	27.01
14	540 000	443 439.2	0.00	0.00	0.00	13.07	30.18	36.42	20.33
15	520 000	430 515.4	0.00	0.00	0.00	22.75	32.81	30.80	13.64
16	500 000	417 591.6	0.00	0.00	0.00	32.43	35.45	25.17	6.95
17	480 000	404 667.8	0.00	0.00	0.00	42.11	38.08	19.54	0.27
18	460 000	390 525.1	0.00	0.00	1.82	45.72	39.31	13.15	0.00
19	440 000	374 359.9	0.00	0.00	9.58	42.99	34.61	12.81	0.00
20	420 000	357 669.4	0.00	0.00	16.27	41.15	30.03	12.55	0.00
21	400 000	340 978.8	0.00	0.00	22.97	39.29	25.45	12.29	0.00
22	380 000	324 288.2	0.00	0.00	29.65	37.44	20.87	12.04	0.00
23	360 000	307 375.9	0.00	1.98	34.69	34.77	16.84	11.72	0.00
24	340 000	289 131.2	0.00	15.82	29.80	27.20	16.12	11.06	0.00
25	320 000	270 886.5	0.00	29.67	24.90	19.62	15.41	10.40	0.00
26	300 000	252 641.8	0.00	43.52	20.00	12.04	14.70	9.74	0.00
27	280 000	234 388.9	3.38	52.98	15.55	5.45	13.80	8.84	0.00
28	260 000	216 105.4	19.37	46.11	12.77	2.52	12.20	7.03	0.00
29	240 000	197 818.5	36.75	37.44	10.17	0.00	10.52	5.12	0.00
30	220 000	179 510.5	62.80	17.54	8.72	0.00	8.35	2.59	0.00
31	200 000	161 137.2	86.19	0.00	7.43	0.00	6.07	0.31	0.00
32	180 000	142 022.5	87.53	1.46	8.10	0.00	2.32	0.59	0.00
33	160 000	118 490.9	95.37	0.00	4.63	0.00	0.00	0.00	0.00
34	140 000	86 927.2	54.11	45.89	0.00	0.00	0.00	0.00	0.00
35	125 000	62 099.6	5.90	94.10	0.00	0.00	0.00	0.00	0.00

provided the highest expected income under the worst conditions, these crops enter the optimum plan. While wheat and barley were less risky crops, they provided the least expected income under the worst conditions. The variation coefficients of the investigated crops were also calculated based on the gross product values of the crops. It was found that groundnut and cotton have the highest variation coefficients while chickpea has the lowest coefficient in terms of gross product value.

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