EVALUATION OF RISK FACTORS IN AGRICULTURE: AN APPLICATION OF THE ANALYTICAL HIERARCHICAL PROCESS (AHP) METHODOLOGY

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ABSTRACT

Risk in the agricultural sector has multiple dimensions or factors and prioritization of these can support decision making. On the other hand, knowing the importance of these risk factors for distinct agricultural activities and how they vary according to geographic zone constitutes relevant information for agricultural development. The objective of this study was to prioritize risk factors that are highly relevant for farmers in Central South Chile. The multi-criteria Analytical Hierarchical Process (AHP) methodology was used to define a decision structure with four risk factors or criteria: climate, price and direct cost variability, human factor, and commercialization. In general, results obtained showed that there are no important imbalances in the weightings of different risk factors. Price and cost variability was the most important factor (0.30) whereas climate was the least important (0.20). It also confirmed that there are spatial differences in the weightings obtained for the distinct risk factors which determine distinct risk levels for the respective agricultural activities according to geographic region.

Key words: Risk analysis, AHP, multi-criteria decisions.

INTRODUCTION

Risk is present in all agricultural management decisions as a result of different sources of uncertainty, and as long as farmers have different preferences with respect to risk, the choices he/she makes will be conditioned to a lower or higher degree by a risk-minimizing process (Gomez-Limon *et al.*, 2003). Moreover, the increasing role of uncertainty from climate change and globalization creates a greater need for tools to efficiently manage different sources of uncertainty (Ritchie *et al.*, 2004; Stigter, 2008; Hansen *et al.*, 2009).

Agricultural economics literature has provided several studies to estimate farmer risk preferences (Gomez-Limon *et al.*, 2003; Isik and Khanna, 2003; Toledo and Engler, 2008), or generate models to understand how a farmer decides among a set of random choices (Hardaker *et al.*, 2004; Bradshaw, 2004), or to model a specific

source of risk (Di Falco and Chavas, 2006; Hansen *et al.*, 2009). In general, all these studies focus on a limited set of risk sources, excluding several measurable and non-measurable risk factors from the analysis. To this effect, measuring the importance of different risk sources influencing farmers' decisions, as well as constructing management tools to assist the decision process have received less attention in the literature.

According to Baquet *et al.* (1997), there are five distinct risk factors in agriculture: productive risk, marketing risk, financial risk, human risk, and environmental risk. Each of these plays a role in the farmer's decision, but the relative importance of each factor has not been analyzed in recent literature. This article tries to narrow this gap by providing an estimate of weightings that measure the importance of different risk factors on farmer risk ranking of a set of productive alternatives. A multi-criteria optimization methodology was adopted to achieve these objectives by including factors that intervene in the decision of establishing an agricultural activity. To this effect, Saaty (1980) proposes the Analytical Hierarchical Process (AHP) that decomposed a final objective into a hierarchical criteria and sub-criteria structure. This structure allows resolving a complex decision by a series of binary comparisons which finally lead to a decision. In this case, the final objective was to establish a ranking

of agricultural activities as a function of risk level. To prioritize the activities, four factors or risk criteria were considered as a first level of decision criteria, while each one was made up of two sub-factors considered in a second hierarchical level.

The versatility offered by AHP allows s for a wide application in the empirical field covering diverse areas of decision making where a series of decision criteria intervenes. Some applications of these areas are the establishment of research priorities (Braunschweig and Janssen, 1998; Braunschweig, 2000), credit evaluation (Xu and Zhang, 2009) public policy evaluation and decision (Gerber *et al.*, 2008), selection of new product development (Chin *et al.*, 2008), and evaluation and selection of productive area management systems (Parra-Lopez *et al.*, 2008).

The objective of this study was twofold. A primary objective was to estimate the relative weightings of four different risk factors on the farmer's choice of productive alternatives. A second objective was to provide a ranking of a set of productive alternatives according to the farmer's perceived risk level.

MATERIALS AND METHODS

The AHP methodology has three important advantages (Martínez and Escudey, 1998): i) its application in empirical problems leads to an intuitive solution; ii) results are not easily manipulated; and iii) it allows establishing the relative importance of the sub-criteria considered in the decision problem. This methodology has been widely disseminated due to the great flexibility achieved in structuring decision problems, as well as the explicit consideration of the subjective judgments of different experts generating results that sustain an objective base for decision making (Braunschweig and Janssen, 1998; Escobar *et al.*, 2004). Likewise, it allows establishing an inconsistency level in the expert judgments that is used as an indicator for the quality of the information revealed in the exercise.

Materials

The study was applied to a panel of qualified informants made up of eight leading producers and seven agricultural consultants. Those interviewed were distributed in the Bío Bío, La Araucanía, and Los Lagos Regions in such a way as to cover the central southern zone of the country. Agriculture is considered to be a traditional activity in the study area although farming systems vary throughout the zone. The most important activities are cereals, dairy and cattle farming. The three regions account 82% of the production of sugar beet, 71% wheat, and 49% of bovine meat (INE, 2009).

Methods

The central objective of the problem was to rank productive activities as a function of their risk level. To do this, a list of seven productive alternatives was established. Option ranking established a hierarchy with four criteria that corresponded to four different risk factors each made up of two sub-criteria. Each informant was asked to compare pairs of productive alternatives using each of the criteria and sub-criteria which were used as parameters to evaluate the distinct pairs of productive alternatives being considered without repeating any combination. The final step consisted in comparing the sub-criteria and criteria in pairs using the main objective of the decision problem as the comparison parameter.

Comparisons were made with the numerical scale proposed by Saaty (1980) which goes from 1 to 9, where the value 1 implies that both alternatives are equal and 9 indicates the highest degree of preference for the first alternative. When the second alternative is preferred, the number is preceded by the negative sign.

Responses from those interviewed are summarized in a matrix $A = (a_{ij})$, where each element $a_{ij} = w_i/w_j$, represents the weightings of the alternative *i* with regard to *j*, and where *w* is the priority vector constructed from the informant responses. Hence, the matrix is expressed as:

$$A = (a_{ij}) = \begin{bmatrix} 1 & w_1/w_2 & \cdot & w_1/w_n \\ w_2/w_1 & 1 & \cdot & w_2/w_n \\ \cdot & \cdot & \cdot & \cdot \\ w_n/w_1 & w_n/w_2 & \cdot & 1 \end{bmatrix} \quad [1]$$

Matrix A is repeated for each criterion, then again for each sub-criterion, and for the objective of the problem, which in this case resulted in the construction of 13 matrices.

The dimension of matrix A is *n x n* and corresponds to the total of the productive alternatives being compared. Some properties of matrix A are: a) It is reciprocal, that is, $a_{ij} = 1/a_{ij}$ for all *i,j* = 1, 2, …., *n*; b) From the former, we also have $a_{ii} = 1$ for all *i* = 1, 2, …., *n*; c) If all judgments are perfectly consistent, then $a_{ij} = a_{ik}a_{kj}$. If (c) is satisfied, then the elements of matrix A do not contain errors of judgment, therefore $a_{ik}a_{kj} = w_iw_k/w_kw_j = w_i/w_j = a_{ij}$ for all *i,j,k* = 1, 2, ….., *n* must be satisfied.

In the case that there are inconsistencies in the judgments, AHP methodology considers the eigenvector method to estimate weightings. The eigenvector allows correcting the inconsistency by calculating *w* as the main correct eigenvector of matrix A:

$$A_w = \lambda_{max} W \quad [2]$$

where λ_{max} is the maximum eigenvector of matrix A. The eigenvector method calculates the final weightings as a mean of all the possible ways to compare the alternatives considered in the decision problem. This method has the quality of providing a measurement of inconsistency calculated as the difference between $\lambda_{max} - n$, given that $\lambda_{max} \geq n$ in the general case and is equal only when matrix A is perfectly consistent.

Thus $\lambda_{max} - n$ is a useful measurement to evaluate the degree of inconsistency. If we later consider the normalization of this measurement for the size of A, we can define the Consistency Index as:

$$CI = \frac{(\lambda_{max} - n)}{(n-1)} \qquad [3]$$

The software used in the estimation shows the Consistency Ratio (CR) as the index of inconsistency that put in relative term CI with the Random Inconsistency (RI) index that corresponds to the level of inconsistency of a set of random matrices, the same set used to obtain λ_{max}. This value is automatically calculated by the software (Expert Choice Inc, version 11, Arlington, USA).

$$CR = \frac{CI}{RI} \qquad [4]$$

According to Martínez and Escudey (1998), the maximum inconsistency level should be 10%.

RESULTS AND DISCUSSION

Choice of activities, criteria, and decision problem structure

In 2006, a survey of a sample of producers in the central southern zone of Chile identified the most important activities and the most relevant risk factors. Table 1 shows the frequency with which the activities selected for this study appeared as the main activity in the sample. In addition, Table 2 shows the prioritization of the farmers of an extensive group of risk factors. In accordance with Table 2, the selected factors or risk criteria were climate, price and cost variability, human risk, and commercialization.

Two sub-criteria were determined for each criterion with the central element of the choice being representativity, relevance, and the possibility of future objective information about them. The sub-criteria were defined in accordance with a panel of agricultural consultants. The decision problem structure was constructed from this information. Figure 1 shows the decision problem structure giving details of the respective sub-criteria.

In this way, the decision model was structured with four criteria and eight sub-criteria. The interviews with informed agents collected the comparisons between pairs of activities for each sub-criterion to construct the matrices. Questions were asked sequentially, that is, always starting with the lower limit sub-criterion. Once the comparisons for each set of sub-criteria were finalized, the person being interviewed was asked for the relative comparison of each pair of sub-criteria. Finally, comparisons between criteria were made as the last step in the interview.

Prioritization results
The decision problem structure allows establishing the weighting for each one of the risk factors used as criteria and sub-criteria, the main objective of this study. Weightings for each factor are shown in Table 3. It can be seen that weightings fluctuated between 20 and 30% without any important imbalance between them. This implies that the importance assigned to each risk factor was similar. The reported weighting is relative to the set of risk factors submitted in the exercise. However, considering that these risk factors were selected from the ranking of a wide sample of farmers, it can be assumed that they correspond to those repeatedly chosen in decision making. Moreover, it could be feasible to extrapolate the results in real decision making. To this effect, the weighting obtained can be interpreted as the percentage that each factor influences the total risk perception of the activity. In this case, it can be said that the most relevant risk factor was the price and cost variability that represented 30% of the total risk perception, while climate showed the lowest risk with 20%. This result contradicts

Table 1. Activities used for binary comparisons.

Nº	Group	Description	Frequency as main activity (%)
1	Fruit trees	Apple and cherry trees	0.3
2	Berries	Blueberry, raspberry, strawberry, and blackberry	2.8
3	Cereals	Wheat, oat, corn, barley, triticale, and candeal wheat	22.4
4	Cattle	Bovine and ovine	15.9
5	Dairy	Bovine	47.4
6	Crops for industrial use	Sugar beet, canola, lupine, chicory, legumes, and freezing corn	7.5
7	Vegetables	Potatoes, asparagus, onion, and tomatoes	3.7

Table 2. Producer perception of major risk factors in the agricultural sector.

Risk factors in the agricultural sector	Percentage of responses in accordance with importance of score[1]				Mean	Ranking
	1	**2**	**3**	**4**	**Mean**	**Ranking**
Climatic factors	66	29	3	3	1.43	1
Product price variability	54	43	2	1	1.49	2
Variability of farm inputs	50	45	3	2	1.57	3
Market access for the sale of products	43	46	7	4	1.73	4
Labor costs	37	50	8	6	1.82	5
Duty and phytosanitary barriers	38	41	14	8	1.91	6
Government policies and regulations	39	38	14	9	1.94	7
Fluctuations in the value of the U.S. dollar	38	36	14	11	1.99	8
Variability of fuel prices	28	50	14	8	2.01	9
Concentration of the industry that I supply to	30	46	13	10	2.03	10
Variability of interest rates for financing	26	46	17	12	2.14	11
Free trade agreements and globalization of markets	27	43	18	12	2.15	12
Environmental regulations	21	52	15	11	2.17	13

[1]1 = Very important, 2 = important, 3 = undecided, and 4 = not important.

the relevance that climatic change is acquiring in the general literature (Stigter, 2008; Hansen *et al.*, 2009). Human risk is perceived as the second most important risk factor, leaving commercialization in the third place in the ranking with 24%.

If sub-criteria weightings are analyzed for each criterion, the same tendency as in the previous case can generally be seen since there were no great imbalances in the weightings obtained. The weightings furthest from parity were obtained in the commercialization factor with the sub-criteria of
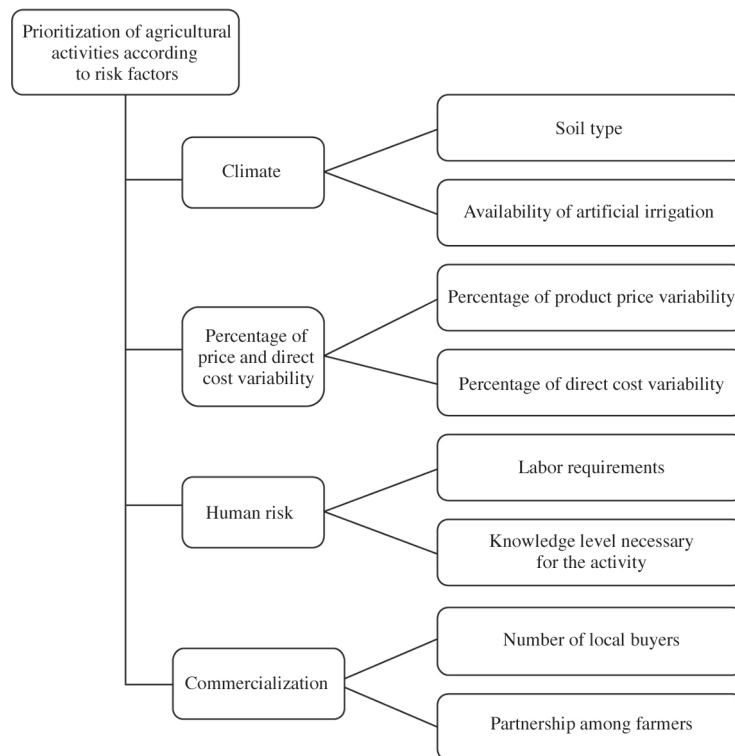

Figure 1. Structure of Analytical Hierarchical Process (AHP) decision model.

Table 3. General prioritization of criteria and sub-criteria.

Criteria	Priority	Sub-Criteria	Priority
Climate	0.200	Soil	0.464
		Availability of artificial irrigation	0.536
Percentage of price and direct cost variability	0.301	Percentage of product price variability	0.416
		Percentage of direct cost variability	0.584
Human risk	0.260	Labor needs	0.466
		Necessary knowledge level	0.534
Commercialization	0.239	Number of local buyers	0.397
		Partnership among farmers	0.603
CR (Inconsistency)	0.001		

CR: Consistency ratio.

number of local buyers and partnership among producers. It is relevant to emphasize that the exercise recorded an overall inconsistency index near 0, which allows concluding that the quality of the expert responses was quite high and results closely approximate an objective datum.

Despite the relative homogeneousness between weightings obtained for the different factors, there is a tendency to attribute a higher weighting to the criteria and sub-criteria in which the farmers can adopt a risk management strategy. For example, in percentage price and cost variability, a higher weighting was assigned to percentage price than cost variability, where the producer can generally manage substituting inputs or management practices to a greater degree. A policy recommendation is to implement mechanisms to reduce information asymmetry in local market. These mechanisms must generate information with a low cost for farmers and always be updated. This way, farmers could take better decision about when is the best moment to sell their production. On the other hand, in the human risk factor, the most relevant sub-criterion was necessary crop knowledge, an aspect that can be managed with training or consultancy. The problems related to human factor are two, training of farmers and workers in specific knowledge for some activities and availability of worker for crop. In this sense, the Chilean government can develop training programs for farmers and workers to reduce the uncertainty about how technology knowledge. In addition, it can support turning into a more mechanized agriculture, especially in fruit production. In the case of large farmers, the government can implement subsidies for specific machineries and equipment, desirables in the crop that can help to reduce labor uncertainty. On the other hand, for medium and small farmers a feasible alternative is to implement a machinery bank that provides a service of high technology machineries at a reasonable cost.

By analyzing the weighting of the different factors by region, it can be seen that the same ranking is maintained in the Bío Bío and La Araucanía Regions, although the weighting of price and cost variability in the Bío Bío Region rises to 36% as compared to 32% for the La Araucanía Region. This higher weighting is compensated by a reduction in the relative value of the climate in the Bío Bío Region falling to 18% versus 25% in the La Araucanía Region. This difference can be explained by the greater use of artificial irrigation in the Bío Bío Region reaching an area of 166.455 ha which is 3.3 times the area in the La Araucanía Region, thus establishing a very distinct scenario regarding climatic risk management (Resultados Censo Agropecuario, 2007). On the other hand, it is relevant to emphasize that the weighting of the risk factors in the Los Lagos Region was different from the other regions under study, and also altered the general ranking of the risk factors. In this region, the price and cost variability was third in the ranking with a 25% weighting, while commercialization risk was in the first place with 31%. The second place was human risk with 27%. Figure 2 shows the weighting of the different factors by region.

The difference between regions accounts for the difference in the type of agricultural practices in distinct zones. In general, in the Bío Bío and La Araucanía Regions, there is a greater diversification of activities than in the Los Lagos Region where some groups of activities stand out, such as cereals, industrial crops, and forage (Resultados Censo Agropecuario, 2007). The same structure was also seen in the survey carried out in the zone where the Los Lagos Region was mostly concentrated in dairy and cattle farming, and potatoes. In the particular case of milk and potatoes, commercialization plays a fundamental role for economic results. To this effect, in the case of milk, partnership among producers was valued as a strategy to improve the results of possible negotiations with the industry.

Another result of this study was a prioritization of agricultural activities shown in Table 4. This table shows the risk value assigned to each activity for which an indicator of relative risk can be considered. This shows
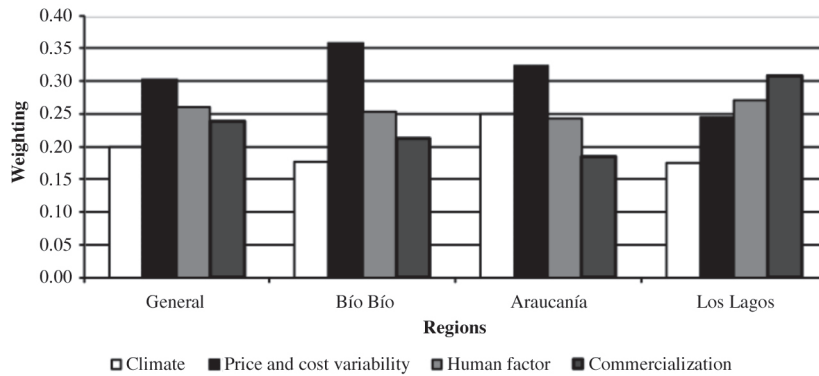
Figure 2. Relative importance of overall risk factors and by Region.

that the least risky activity in the central southern zone of the country was cattle farming followed by cereal crops, while the most risky was berries. Fruit trees and crops for industrial use presented similar risk levels in the three regions and the perceived risk level for these activities fell as we move southward. On the other hand, dairy farming increased its risk level in the southward regions, going from an intermediate risk level to the second agricultural activity with the highest risk in the Los Lagos Region. A possible explanation can be found in the fact that there is a greater presence of extensive dairy farms dependent on climatic conditions (Smith *et al.*, 2002).

The risk of a productive alternative only showed one dimension of the decision problem since the profitability of these alternatives is unknown. However, it is interesting to state some facts. For example, in the Bío Bío Region, berries were considered three times riskier than cattle farming. Likewise, fruit trees and crops for industrial use had almost twice the risk as cereals. On the other hand, in the Los Lagos Region, this difference tended to disappear, showing similar levels in all productive activities. Finally, Figure 3 shows the relative importance of each risk factor in the mean risk assigned to each activity. As can be seen in the figure, the four risk factors had a different relative importance in the perceived risk of the productive activities. It is important to emphasize that the relative weight of the

four risk factors used in the prioritization was different for each activity. This contrasts with the afore-mentioned result where the different risk factors appeared with a similar weighting. However, it can be observed that some tendencies are alike. In all cases, price and cost variability was shown as a factor with a high incidence in the risk level of the activities. This result complements Table 3 in which price variability had the highest weighting. On the other hand, fruit trees showed a more homogeneous weighting among the distinct risk factors. Results in Figure 3 show that the risk factors have different effects on distinct activities, and therefore, generalizations are complex. In addition, we know from Figure 2 that the importance of the risk factors presented variations among regions. These two results have implications for the decision that the farmer must take regarding the activity portfolio of his/her farm since different regions would weight differently the risk associated to each portfolio.

It can be concluded from the results that a farmer who is very adverse to risk should privilege activities such as cereals and cattle farming since they were the least risky, while those who more easily accept risk could pursue activities such as berries, vegetables, or dairy farming. On the other hand, the farmer's decision making should consider a parallel profitability analysis to gain knowledge about the potential compensations in terms of the profitability of each

Table 4. General prioritization of agricultural activities according to risk factors.

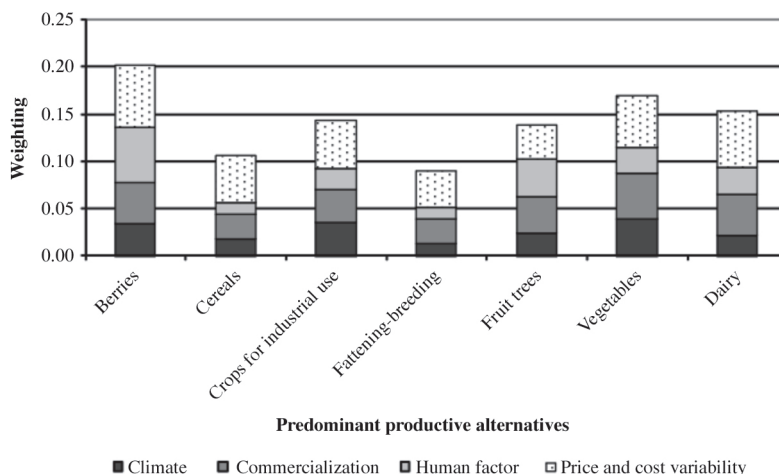| Nº	Agricultural activity	Priorities by Region			
		Bío Bío Region	La Araucanía Region	Los Lagos Region	General
1	Cattle farming	0.074	0.077	0.103	0.088
2	Cereals	0.09	0.116	0.107	0.106
3	Fruit trees	0.169	0.134	0.128	0.139
4	Crops for industrial use	0.165	0.0139	0.123	0.143
5	Dairy	0.128	0.142	0.178	0.154
6	Vegetables	0.154	0.194	0.166	0.169
7	Berries	0.221	0.198	0.195	0.201

Figure 3. Composition of risk factors insofar as total risk assigned to each activity.

activity. Furthermore, the farmer can reduce the total risk of the system, even including higher risk activities through an efficient diversification of his/her activities. According to Barbieri and Mahonay (2009), producers use diversification as a strategy to adapt their farms to the demands of today's agriculture. This study provide useful information to decide: a combination of activities that will result in a more efficient diversification portfolio; to make decision about which is the best strategy for hiring an insurance policy; and to take an insurance for exchange rate if production is destined to international markets.

CONCLUSIONS

Results indicated that a homogeneous relative importance was generally assigned to the four risk factors, however, the percentage price and cost variability had a higher weighting than human risk which was the next most important, 0.30 and 0.26, respectively. The climate factor had the lowest weighting of 0.20. In the percentage price and cost variability, cost was more relevant than price variability. On the other hand, prioritization of agricultural activities by region presented moderate variability despite the existence of great differences in actual productive systems, climate, and predominant productive orientations. It was observed that the berries activity was considered the most risky and cattle farming the least risky. If the results are analyzed by region, some differences can be observed. In the Los Lagos Region, perceived risk for dairy farming was higher than in the Bío Bío Region. On the contrary, fruit trees and crops for industrial use showed similar risk levels in the three regions, and the perceived risk for these activities decreased southward.

It can also be concluded that risk factors did not have the same relative importance in all activities, indicating

the particularities of each one. These results showed that risk factors have different effects on distinct activities, making generalizations complex. In the same way, it was observed that the relative importance of risk factors varies among regions, thus generating immediate effects on the prioritization of agricultural activities in the distinct regions.

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RESUMEN

Evaluación de factores de riesgo en la agricultura: Una aplicación de la metodología de Proceso Analítico Jerárquico (AHP). El riesgo en el sector agrícola tiene múltiples dimensiones o factores y la priorización de éstas puede apoyar la toma de decisiones. Por otra parte, resulta relevante conocer la importancia que tienen estos factores de riesgo para distintos rubros agrícolas y como varían según zona geográfica, pues es información valiosa para el diseño de políticas de desarrollo agrícola. El objetivo de este estudio fue priorizar factores de riesgo que son altamente relevantes para los agricultores del centro sur de Chile. Se utilizó la metodología multicriterio Proceso Analítico Jerárquico (AHP) para definir la estructura de decisión con cuatro factores de riesgo o criterios: clima, variabilidad de precios y costos, factor humano y comercialización. En general, los resultados obtenidos muestran que no existen importantes desequilibrios en las ponderaciones para diferentes factores de riesgo. La variabilidad de

precios y costos fue el factor de mayor importancia (0,30) mientras que el clima fue el menos importante (0,20). También se confirmó que existen diferencias espaciales en las ponderaciones obtenidas para los distintos factores de riesgo, lo cual determina distintos niveles de riesgo para los respectivos rubros agrícolas según la región geográfica.

Palabras clave: riesgo agropecuario, AHP, decisiones multicriterio.

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