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Analysing the traceability system in herbal product industry by game theory

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Abstract: The agricultural traceability system provides information transparency throughout the agricultural supply chain. This paper applies game theory to analyse the traceability system used by the herbal product industry in order to elucidate the strategic choices made by government authorities, farmers (e.g. producers), certification agencies, and consumers. This paper clarifies how relevant variables affect the traceability system employed in the herbal product industry. The analysis yields strong results and indicates a superior equilibrium; the observed strategic choices comprise active traceability system promotion by authorities, development of a comprehensive traceability system by farmers, maintenance of independence by certification agencies, and purchase of herbal products by consumers. The traceability system and existing herbal product safety programs must be refined because they are crucial to consumers, farmers, and people who support agricultural communities. These results contribute to the literature in the field, serving as a reference for members of the herbal product industry, government authorities, and academics.

Keywords: certification agencies; consumers; farmers; game theory; government authorities; herbal product industry; traceability system

The European Union defined an "agricultural traceability system" as a system that traces information on processed agricultural products, raw materials, and animal-derived agricultural products at the stages of seeding, planting, cultivation, production, processing, and circulation. Data on various types of processed products from farms and fisheries, concerning production, processing, distribution, and sales, may be recorded for consumer inquiries, promoting consumer awareness and mitigating concerns over unethically obtained foods and foods of unknown origin. After the second mad cow disease crisis occurred in Europe in 1996, the European Union promoted an agricultural traceability system to ensure food safety. In recent years, countries such as the United States, Australia, New Zealand, South Korea, Thailand, India, and China have been gradually fostering the development of agricultural traceability systems. Since 2003, Taiwan has been gradually developing an agricultural traceability system that has become a crucial safety regulation tool for agricultural products. The primary purpose of the agricultural traceability system is to provide information transparency throughout the agricultural supply chain; however, this is challenging because of the complexity and changing environments of the agricultural supply chain. The agricultural traceability system requires substantial resource investments and must provide immediate and accurate information for the various stakeholders in the agricultural supply chain; the agricultural traceability system has sufficient value to such stakeholders and consumers, and has therefore been widely recognized and accepted (European Commission 2007; Gu et al 2009; Tsai et al. 2012).

The implementation of traceability systems has substantial positive benefits on the environment and consumers; however, producers bear the costs of preparing the records for certified work, including certification fees and labour, and further bear the related quality and quantity risks in the production process and must account for the uncertainty element of whether supply

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chains and selling price reflect input costs. Because of the complexity of supply chains, information asymmetry among government authorities, farmers, certification agencies, and consumers is critical. For example, the balance between cost and revenue is crucial for farmers, and authorities must consider the tradeoffs between the interests and policies of all stakeholders in the agricultural traceability system (Caswell and Mojduszka 1996; Hobbs 2004; Wilson et al. 2008; Pan et al. 2009; Wang et al. 2009; Dani and Aman 2010).

The herbal product industry has gradually emerged in the global mainstream pharmaceutical market in recent years. Herbal products are manufactured using plants, algae, fungi, lichen, and plant exudates as starting materials. The herbal product industry has a growth rate of over 10% per year, and its market value is estimated at USD 60 billion in the world; this industry is one of the fastest-growing Taiwanese agricultural biotechnology industries (TAFTS 2016). This paper applies game theory to analyse the traceability system used by the herbal product industry in order to elucidate the strategic choices made by government authorities, farmers (e.g. producers), certification agencies, and consumers.

MATERIALS AND METHODS

The primary purpose of the agricultural traceability system is to provide information throughout the agricultural supply chain; however, this is challenging because of the complexity and changing environments of the agricultural supply chain. These challenges are as follows: (i) information complexity: because agricultural product manufacturers consider both cost efficiency and convenience, the agricultural products in a specific batch may have been sourced from various suppliers; (ii) information asymmetry: sellers are likely to overemphasise the characteristics of high-quality products and provide incomplete information for lower-quality products, misleading consumers through certain methods of packaging and marketing practices; (iii) cost-benefit tradeoff: supply chain firms must provide resources, such as information technology or manufacturing equipment, to ensure safety and information traceability in transporting agricultural products; therefore, firms must consider the balance between capital expenditures and the benefits of improved effectiveness; (iv) authority compromise: government policies and standards must balance the interests of all involved parties (Caswell and Mojduszka 1996; Hobbs 2004; Wilson 2008; Pan et al. 2009; Wang et al. 2009; Dani and Aman 2010).

Tsai et al. (2012) showed that government management, producer and manufacturer operational oversight, and consumer perception are the three most crucial factors. Wu et al. (2012) indicated that income level and the degree of concern over food safety are the only two factors exerting significant effects on the premiums that consumers are willing to pay. Wang and Yang (2015) applied game theory to the organic tea certification process and traceability system used by the Taiwanese tea industry to elucidate the strategic choices made by tea farmers and organic tea certification agencies.

Heinrich (2015) evidenced the need for examining the links between producers and consumers and indicated that plant metabolomics offer a novel means of assessing the chemical variability along a value chain. Saak (2016) considered a complementary environment with upstream and downstream efforts to provide quality, imperfect, lagged signals of intermediate and final quality, and repeated interaction. Mattevi and Jones (2016) showed that UK small and medium-sized enterprises are aware of the main purposes of traceability systems such as recall cost reduction, rapid recalls, and the improvement of food safety and quality.

This study references and extends the game theory models of Tirole (2001), Wang and Chiu (2013), and Wang and Yang (2015) and is based on the following assumptions: Government authorities can choose to either actively or passively promote a traceability system; farmers can choose whether to develop a comprehensive traceability system; certification agencies can choose to either maintain their independence or collude with farmers to issue false certification for products labelled as "traceable agricultural products"; and consumers can choose whether to purchase herbal products. Firstly, authorities choose whether to actively or passively promote the traceability system. The revenue and cost of actively promoting the traceability system are S_h and E_h, respectively, and the revenue and cost of passively promoting the traceability system are S_n and E_n, respectively; $S_h > S_n$ and $E_h > E_n$. When the herbal products are falsely labelled as "traceable agricultural products" and the authorities passively promote the traceability system, the damage compensation and quasi-rent imposed on authorities is W_g. The managerial accounting cost to farmers of developing the comprehensive traceability system is F_a. The certification fee of farmer application for the traceability system is F_b. The certification revenue of the certification agency is F_b.

The farmers' revenue generated from sales of herbal products labelled as "traceable agricultural products"

https://doi.org/10.17221/102/2018-AGRICECON

is R_a. The farmers' revenue generated through sales of herbal products not labelled as "traceable agricultural products" is R_b; $R_a > R_b$. If the farmers do not develop a comprehensive traceability system, the cost of farmer collusion with certification agencies to falsely obtain the "traceable agricultural products" label is C_a, and the damage compensation and quasi-rent imposed on the farmers when the herbal products are falsely labelled "traceable agricultural products" are denoted as W_n. The revenue of the certification agencies generated by colluding with the farmers is C_a, and the damage compensation and quasi-rent imposed on certification agencies for issuing false labels are denoted as W_a. If the certification agencies in the traceability system do not collude with the farmers to issue false certifications, the cost to the farmers in switching certification agencies is Q_n. When the original certification agency refuses to issue false certifications, the cost to this agency in finding a new farmer client is Q_a. The consumer revenue from purchases of the herbal products labelled as "traceable agricultural products" is U_a. The consumer revenue from purchases of the herbal products not labelled as "traceable agricultural products" is U_b; $U_a > U_b$. The consumer cost in purchasing the herbal products labelled as "traceable agricultural products" is R_a. The consumer cost of purchasing the herbal products not labelled as "traceable agricultural products" is R_b; $R_a > R_b$. If the farmers do not develop a comprehensive traceability system and instead collude with the certification agencies, the damage compensation provided to the consumers is W_t.

Figure 1 illustrates the game model design, showing an example of authorities, farmers, certification agencies, and consumers. Figure 1 also shows 16 strategic combinations used in the game.

Figure 1 illustrates the game model design, showing strategy choice of the authority, farmer, certification agency and consumer, and demonstrating 16 strategic combinations. Table 1 displays the payoffs of the authority, farmer, certification agency and consumer.

Backward induction was used in the game model, and the forward derivations began at decision point 4 to achieve the final equilibrium (Fudenberg and Tirole 1991; Gibbons 1992). Because the farmer payoffs of strategic combinations *b, d, f, h, j, l, n* and *p* were all less compared with those of strategic combinations *c* and *k;* and the farmer payoffs of strategic combinations *e* and *m* were all less compared with those of strategic combinations *a* and *i*, these combinations prevented the final equilibrium and are not discussed herein. Table 2 indicates each decision point in the game after performing a derivation and comparing Figure 1 and Table 1. Table 3 presents the six subperfect equilibrium results and conditions of the complete extensive game.

RESULTS AND DISCUSSION

This section provides a review and discussion of the findings concerning the government authorities, farmers, certification agencies, and consumers in our game model.

Factors influencing government authorities to actively promote the traceability system at the beginning

(i) Increased S_h, E_n, *and* W_g values indicate a high possibility of authorities actively promoting the traceability system.

(ii) Increased S_n and E_h values indicate a low possibility of authorities actively promoting the traceability system.

Analysis and evidence

According to the model derivation results and each decision in the game (Table 2), the various situations in which authorities actively promote the traceability system are represented in the following inequalities.

The certification agencies are not independent, and the farmers do not develop a comprehensive traceability system: $S_n - E_n - S_h + E_h - W_g < 0$.

The certification agencies are not independent, and the farmers develop a comprehensive traceability system: $S_n - E_n - S_h + E_h < 0$.

The certification agencies are independent: $S_n - E_n - S_h + E_h < 0$.

We determine positive and negative relationships among the various parameters that affect whether the authorities actively promote the traceability system. The authorities' revenue when actively promoting the traceability system is S_h; the authorities' cost in passively promoting the traceability system is E_n; when the herbal products are falsely labelled, and the authorities passively promote the traceability system, the damage compensation and quasi-rent imposed on the authorities W_g. Increased S_h, E_n, and W_g values indicate a high possibility of authorities actively promoting the traceability system. The authorities' revenue when passively promoting the traceability system is S_n; the authorities' cost in actively promoting the traceability system is E_h. Increased S_n and E_h

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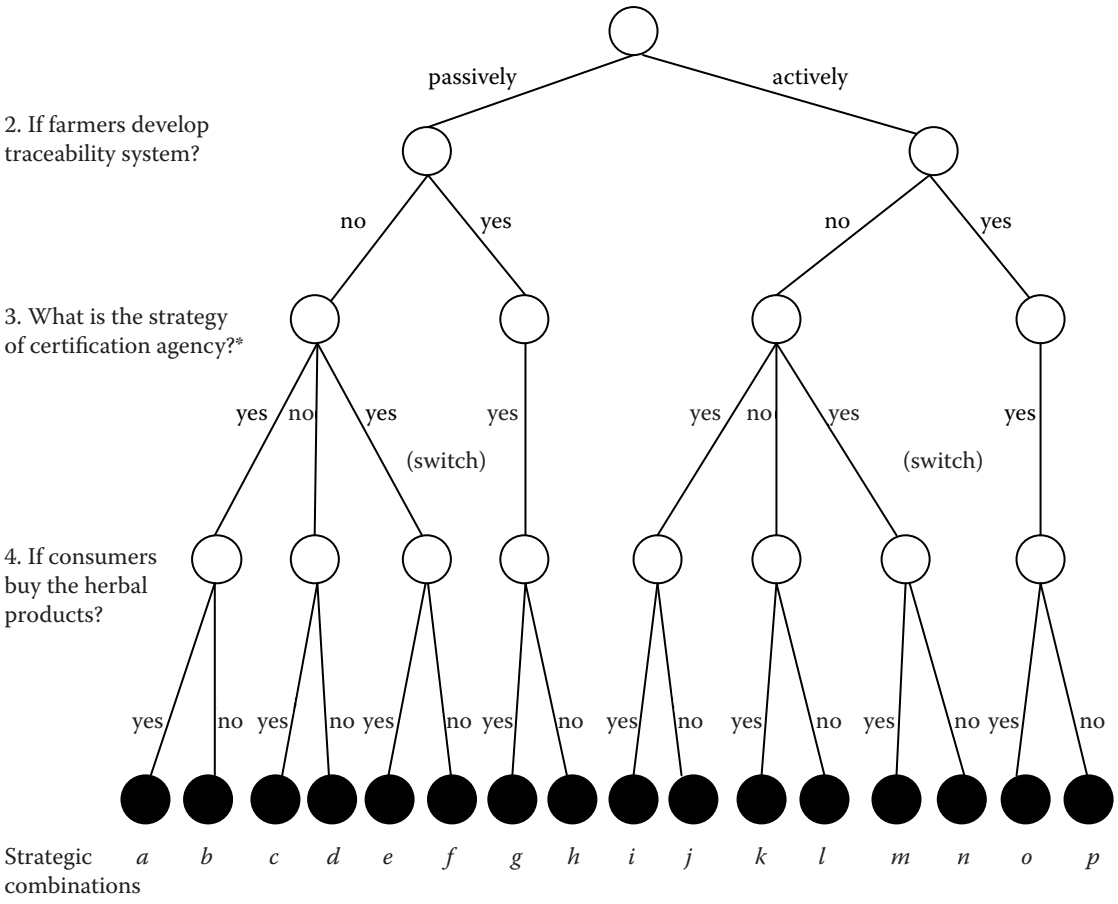

Figure 1. Game model

*yes – the certification agency issues "traceable agricultural products" labels; no – the certification agency does not issue "traceable agricultural products" labels; switch – switching certification agency; for further explanation of variables see chapter Materials and methods and Table 1

Source: drawn according to the assumptions in this paper

values indicate a low possibility of authorities actively promoting the traceability system.

Factors influencing farmers to develop a comprehensive traceability system

(i) Increased R_a, C_a, and W_n values indicate a high possibility of farmers developing a comprehensive traceability system.

(ii) Increased F_a and R_b values indicate a low possibility of farmers developing a comprehensive traceability system.

Analysis and evidence

According to the model derivation results and each decision in the game (Table 2), the various situations in which the farmers develop a comprehensive traceability system are represented in the following inequalities.

The certification agencies are not independent:
$F_a - C_a - W_n < 0$.

The certification agencies are independent:
$R_b - R_a + F_a < 0$.

We determine positive and negative relationships among the various parameters that affect whether the farmers develop a comprehensive traceability system. The farmers' revenue from sales of the herbal products labelled as "traceable agricultural products" is R_a; the cost of farmer collusion with certification agencies is C_a; the damage compensation and quasi-rent imposed on the farmers when the herbal products are falsely labelled is W_n. Increased R_a, C_a,

https://doi.org/10.17221/102/2018-AGRICECON

Table 1. Payoff matrix of game model

Strategic combination	Authority	Farmer	Certification agency	Consumer
a	$S_n - E_n - W_g$	$R_a - F_b - C_a - W_n$	$F_b + C_a - W_a$	$U_b - R_a + W_t$
b	$-E_n$	$-(F_b + C_a)$	$F_b + C_a$	0
c	$S_n - E_n$	$R_b - F_b$	F_b	$U_b - R_b$
d	$-E_n$	$-F_b$	F_b	0
e	$S_n - E_n - W_g$	$R_a - F_b - C_a - Q_n - W_n$	$F_b - Q_a$	$U_b - R_a + W_t$
f	$-E_n$	$-(F_b + C_a + Q_n)$	$F_b - Q_a$	0
g	$S_n - E_n$	$R_a - F_a - F_b$	F_b	$U_a - R_a$
h	$-E_n$	$-(F_a + F_b)$	F_b	0
i	$S_h - E_h$	$R_a - F_b - C_a - W_n$	$F_b + C_a - W_a$	$U_b - R_a + W_t$
j	$-E_h$	$-(F_b + C_a)$	$F_b + C_a$	0
k	$S_h - E_h$	$R_b - F_b$	F_b	$U_b - R_b$
l	$-E_h$	$-F_b$	F_b	0
m	$S_h - E_h$	$R_a - F_b - C_a - Q_n - W_n$	$F_b - Q_a$	$U_b - R_a + W_t$
n	$-E_h$	$-(F_b + C_a + Q_n)$	$F_b - Q_a$	0
o	$S_h - E_h$	$R_a - F_a - F_b$	F_b	$U_a - R_a$
p	$-E_h$	$-(F_a + F_b)$	F_b	0

for further explanation of variables see chapter Materials and methods

Source: derived from this article

Table 2. Each decision point conditions of the game

Decision point	Strategy	Conditions
4. If consumer purchases the herbal products?	purchase	(1) certification agencies are not independent: $U_b - R_a + W_t > 0$ (2) certification agencies are independent: $U_b - R_b > 0$ (non-developing comprehensive traceability system) $U_a - R_a > 0$ (developing a comprehensive traceability system)
3. What is the strategy of certification agency?	issue the labels	$C_a - W_a > 0$ (non-developing comprehensive traceability system)
	non-issue the labels	$C_a - W_a < 0$ (non-developing comprehensive traceability system)
2. If farmers develop comprehensive traceability system?	non-develop	(1) certification agencies are not independent: $F_a - C_a - W_n > 0$ (2) certification agencies are independent: $R_b - R_a + F_a > 0$
	develop	(1) certification agencies are not independent: $F_a - C_a - W_n < 0$ (2) certification agencies are independent: $R_b - R_a + F_a < 0$
1. If authority actively promotes traceability system?	passively	(1) certification agencies are not independent: $S_n - E_n - S_h + E_h - W_g > 0$ (non-developing comprehensive traceability system) $S_n - E_n - S_h + E_h > 0$ (developing a comprehensive traceability system) (2) certification agencies are independent: $S_n - E_n - S_h + E_h > 0$
	actively	(1) certification agencies are not independent: $S_n - E_n - S_h + E_h - W_g < 0$ (non-developing comprehensive traceability system) $S_n - E_n - S_h + E_h < 0$ (developing a comprehensive traceability system) (2) certification agencies are independent: $S_n - E_n - S_h + E_h < 0$

for further explanation of variables see chapter Materials and methods

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Table 3. Complete extensive game sub-perfect equilibrium results and conditions

Equilibrium results		Equilibrium conditions
I (strategic combination *a*)	decision point 4:	$U_b - R_a + W_t > 0$
	decision point 3:	$C_a - W_a > 0$
	decision point 2:	$F_a - C_a - W_n > 0$
	decision point 1:	$S_n - E_n - S_h + E_h - W_g > 0$
II (strategic combination *c*)	decision point 4:	$U_b - R_b > 0$
	decision point 3:	$C_a - W_a < 0$
	decision point 2:	$R_b - R_a + F_a > 0$
	decision point 1:	$S_n - E_n - S_h + E_h - W_g > 0$
III (strategic combination *g*)	decision point 4:	$U_a - R_a > 0$
	decision point 2:	$R_b - R_a + F_a < 0$ (certification agencies are independent) or $F_a - C_a - W_n < 0$ (certification agencies are not independent)
	decision point 1:	$S_n - E_n - S_h + E_h > 0$
IV (strategic combination *i*)	decision point 4:	$U_b - R_a + W_t > 0$
	decision point 3:	$C_a - W_a > 0$
	decision point 2:	$F_a - C_a - W_n > 0$
	decision point 1:	$S_n - E_n - S_h + E_h - W_g < 0$
V (strategic combination *k*)	decision point 4:	$U_b - R_b > 0$
	decision point 3:	$C_a - W_a < 0$
	decision point 2:	$R_b - R_a + F_a > 0$
	decision point 1:	$S_n - E_n - S_h + E_h - W_g < 0$
VI (strategic combination *o*)	decision point 4:	$U_a - R_a > 0$
	decision point 2:	$R_b - R_a + F_a < 0$ (certification agencies are independent) or $F_a - C_a - W_n < 0$ (certification agencies are not independent)
	decision point 1:	$S_n - E_n - S_h + E_h < 0$

for further explanation of variables see chapter Materials and methods

Source: derived from this article

and W_n values indicate a high possibility of farmers developing a comprehensive traceability system. The managerial accounting cost to farmers in developing a comprehensive traceability system is F_a; the farmers' revenue from sales of the falsely labelled herbal products is R_b. Increased F_a and R_b values indicate a low possibility of farmers developing a comprehensive traceability system.

Factors influencing the decision of the certification agencies to maintain independence and deny traceability system certification (when the farmers do not develop a comprehensive traceability system)

(i) An increased W_a value indicates a high possibility of the certification agencies maintaining independence and denying traceability system certification.

(ii) An increased C_a value indicates a low possibility of the certification agencies maintaining independence and denying traceability system certification.

Analysis and evidence

According to the model derivation results and each decision in the game (Table 2), when the farmers do not develop a comprehensive traceability system, the conditional inequality denoting certification agency maintenance of integrity and denial of traceability system certification is $C_a - W_a < 0$.

We determine positive and negative relationships among the various parameters, pertaining to the condition that the certification agency maintains its integrity and refuses to issue certification. If the certification agencies collude with the farmers, the damage compensation and quasi-rent imposed on the agencies is W_a. An increased W_a value indicates a high possibility of the certification agencies maintaining independence and denying traceability system certification. The revenue generated by certification agencies colluding with the farmers is C_a. An increased $C_a$value indicates a low possibility of the certification agencies maintaining independence and denying traceability system certification.

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Factors influencing consumers to purchase the herbal products

(i) Increased U_a, U_b, and W_t values indicate a high possibility of consumer purchase of herbal products.

(ii) Increased R_a and R_b values indicate a low possibility of consumer purchase of herbal products.

Analysis and evidence

According to the model derivation results and each decision in the game (Table 2), the various situations in which consumers purchase the herbal products are represented in the following inequalities.

The certification agencies are not independent: $U_b - R_a + W_t > 0$.

The certification agencies are independent, and the farmers do not develop a comprehensive traceability system: $U_b - R_b > 0$.

The certification agencies are independent, and the farmers develop a comprehensive traceability system: $U_a - R_a > 0$.

We determine positive and negative relationships among the various parameters that affected whether the consumers purchase the herbal products. Consumer revenue from purchasing the herbal products labelled as "traceable agricultural products" is U_a; consumer revenue from purchasing the herbal products not labelled as "traceable agricultural products" is U_b; the damage compensation available to the consumers when the herbal products were falsely labelled is W_t. Increased U_a, U_b, and W_t values indicate a high possibility of consumer purchase of herbal products. The cost to consumers in purchasing the herbal products labelled as "traceable agricultural products" is R_a; the cost to consumers in purchasing the herbal products not labelled as "traceable agricultural products" is R_b. Increased R_a and R_b values indicate a low possibility of consumer purchase of herbal products.

Possibility of Result VI (strategic combination *o*)

Strategic combination *o* achieving an optimal equilibrium was determined by the following conditions:

(i) Increased U_a, C_a, W_n, E_n, and S_h values indicate a high possibility of Result VI achieving the optimal equilibrium.

(ii) Increased R_b, F_a, S_n, and E_h values indicate a low possibility of Result VI achieving the optimal equilibrium.

Analysis and evidence

Table 3 presents the extensive, suboptimal equilibrium results of the game and various conditions based on the model derivation results. Result VI achieves the optimal equilibrium; this result comprises the strategic combination *o*, shown in Figure 1. The conditions are presented as follows:

$U_a - R_a > 0$, $R_b - R_a + F_a < 0$ (i.e. the certification agencies are independent) or $F_a - C_a - W_n < 0$ (i.e. the certification agencies are not independent), $S_n - E_n - S_h + E_h < 0$.

We determine positive and negative relationships among various parameters, achieving the optimal equilibrium by using Result VI. Consumers revenue from purchasing the herbal products labelled as "traceable agricultural products" is U_a; the cost of farmer collusion with certification agencies is C_a; the damage compensation and quasi-rent imposed on the farmers when the herbal products are falsely labelled is W_n; the authorities' cost in passively promoting the traceability system is E_n; and the authorities' revenue when actively promoting the traceability system is S_h. Increased U_a, C_a, W_n, E_n, and S_h values indicate a high possibility of Result VI achieving the optimal equilibrium. Farmer revenue from sales of the herbal products not labelled as "traceable agricultural products" is R_b; the managerial accounting cost to farmers in developing a comprehensive traceability system is F_a; authorities' revenue when passively promoting the traceability system is S_n; and the authorities' cost in actively promoting the traceability system is E_h. Increased R_b, F_a, S_n, and E_h values indicate a low possibility of Result VI (strategic combination *o*) achieving the optimal equilibrium.

CONCLUSION

In summary, the optimal equilibrium is the situation whereby authorities actively promote the traceability system, farmers develop a comprehensive traceability system, certification agencies issue the "traceable agricultural products" label and consumers purchase herbal products. The increased relevant variables indicate a high possibility of achieving the optimal equilibrium, considering consumer revenue from purchasing the herbal products labelled "traceable agricultural products," the cost of farmer collusion with to the certification agencies in obtaining the "traceable agricultural products" label, the damage compensation and quasi-rent imposed on the farmers when the herbal products are falsely labelled, the authorities' cost inactively promoting the traceability system, and the authorities' revenue generated by actively promoting the traceability system. The

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increased relevant variables indicate a low possibility of achieving the optimal equilibrium, considering farmer revenue from sales of herbal products not labelled as "traceable agricultural products," managerial accounting costs to the farmers in developing the comprehensive traceability system, authority revenue generated by passively promoting the traceability system, and authorities' costs in actively promoting the traceability system. The traceability system and existing herbal product safety programs must be refined because they are crucial to consumers, farmers, and people who support agricultural communities. This research was unprecedented, applying an innovative model and providing a novel analysis structure for use in the herbal industry. These results contribute to the literature in the field, serving as a reference for members of the herbal product industry, government authorities, and academics.

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