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A mathematical framework for assessing food fraud intentions

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Abstract

This work presents a framework for assessing subjects' intentions to engage in food fraud. The model demonstrated that the decision to commit fraud arises from psychological mechanisms of malicious intent (Π) and ethical fading-bounded ethicality (Ω). Based on these psychological processes, the framework utilises a survey tool to generate finite sets of binary responses, f_T (theorised response set derived from governing moral notions) and f_A (actual response set given by subjects). The similarity function, $f_T \multimap f_A$, maps a dichotomous variable, with arguments (p, q), to a continuous variable, $f\ [(p,\ q) \mapsto f]$. The model metrics have Jaccard index characteristics with a range of 0.0-1.0, where fraud intention is low when $f \to 0.0$ and high when $f \to 1.0$. The number of questions used in a survey indicates special characteristics of the model, for instance, its rate of change (R_f) and the number of possible response patterns (Γ). Survey data (N=54) was used to validate the model. The results show that the f values for respondents range from 0.21-0.69 with a mean of 0.44. Indicating that the respondents have moderate to neutral inclinations towards fraud. The statistical difference between f-values obtained from Π and Ω data indicates that they have the same effect on food fraud intention ($p > 0.05$). The model is essential when assessing the fraud intention of an individual or population by examining and understanding factors contributing to fraud and their numerical impacts. This is a significant step towards developing a fraud prevention framework.

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1. Introduction

The prevailing global food perception is based on availability, quality, safety, and authenticity. This outlook has popularised the ideologies of food safety, food defence, food quality, and food fraud in both the food research and processing domains. Food fraud is considered an unethical behaviour (an aspect of actions and intentions) and has resulted in many devastating risks to human health and economic growth [1–3]. Various sources indicate that the primary factor for food fraud is the deliberate intent to deceive for monetary gain [1, 4, 5]. This definition suggests the malicious intent (unethicality) of an individual in committing fraud. Nonetheless, Bazerman and Tenbrunsel [6], Chugh and Kern [7] and Kim *et al.* [8] mentioned that fraud intentions can emerge from inadvertent concepts of ethical fading or bounded ethicality due to irrational (or unintentional) actions.

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In this study, we developed a mathematical framework for assessing fraud intentions using the concepts of malicious intent (Π) and ethical fading-bounded ethicality (Ω) as determinants. Malicious intentions regard the perpetrator as the designer of the fraudulent conduct, deliberately driven by economic gain and rationally looking for unguarded opportunities [3]. The individual must be aware of their unethical behaviour before, during, and after committing fraud. In contrast, ethical fading and bounded ethicality suggest that individuals do not engage in fraud intentionally; rather, they are influenced by environmental and societal pressures, self-serving biases, and self-deception [6, 9]. We anticipate that a person engaging in fraud via ethical fading and bounded ethics (1) may not have any economic motivation; (2) any financial benefits will be realised post-act; and (3) if they acknowledge their unethical behaviour, they may experience feelings of humiliation and distress.

We further considered notions from the reasoned action theory, which established that an individual's attitude and general social interactions influence behaviour and intentions [10–12]. We ascertain that both the attitude and social interactions define the malicious intentions and ethical fading-bounded ethicality of individuals. However, how these factors (attitude and social interactions over a pool of choices) are distributed will show whether a food fraud intention or action is driven by malicious intentions or ethical fading-bounded ethicality.

The mathematical model recognises that for every behaviour or activity to be classified as ethical or unethical, it should be measured against a standard framework (f_T), which can be theoretical or based on a combination of experiences. The validity of the theoretical framework is not based on an individual but on norms put forward through societies and social interactions. This contextualises the theoretical framework to a particular social group. In agreement, van Ruth and Nillesen [13] and Gussow and Mariët [14] have shown that food fraud activities differ with regions and cultures. What some individuals perceive as fraud may not be considered as such in a given context. This study imagined a decision frame with two extremes, one that is pulled toward unethicality (food fraud) and the other toward ethicality. An observer can then employ the framework to determine the fraud intention (f) of the subject S under specific conditions deployed in a survey.

Current efforts to detect and reduce food fraud differ from our approach in that they are based on vulnerability assessment, data analytics and chemical analysis [3, 15]. Though these methods are effective, they barely assess the behavioural intentions of fraudsters. Understanding the quantitative impact of factors that lead to the fraud intention of individuals can be of paramount significance as a preventive measure towards food fraud.

2. Development of the food fraud mathematical framework

The model for determining the food fraud intention (f) of subject S requires categorical dichotomous data from a survey concerning the respondent's views on questions related to food fraud. We can then convert the pattern in which subject S responds to the questions into a continuous metric scale. The framework makes the following assumptions:

1. The subjects are purely unbiased and are responding to the items truthfully.
2. The subjects who are inclined to food fraud traits will show a distinct response pattern, which is different from those who are not.
3. All questions or items have equal weights.
4. The framework does not measure the presence or absence of a subject's fraudulent behaviour; it assesses whether they intend to commit fraud when given specific scenarios or conditions.
5. The respondents will answer all questions or items in the survey tool.
6. The food fraud intention is defined by malicious intentions or ethical fading-bounded ethicality.

2.1. Data characteristics

A questionnaire that contains dichotomously scaled items with only two options, p and q, for responding was considered. For example, p and q can represent responses such as Good or Bad, True or False, and Yes or No, respectively. The items (ϵ) are typical questions that test subjects' desires, judgements, knowledge, and notions regarding food fraud intentions under specific conditions. The research tool should be designed in such a way that one of the responses, p or q, demonstrates inclination or aversion to food fraud tendencies; hence, $p \neq q$. For every item, subject S should choose either q or p.

2.2. Defining food fraud response sets

Let's assume we have a question or item ϵ in a survey that tests for food fraud. Then, ϵ_N is the total number of questions or items (ϵ), i.e., $\epsilon_N = \sum_{i=1}^{n} \epsilon_i = \epsilon_1 + \epsilon_2 + \cdots + \epsilon_n$. Given that the items focus on discerning the typical intentions of fraudsters vs. non-fraudsters, two response sets (f_T and f_A) can be obtained, which are dichotomous and contain a series of alternating values of p and q. Precisely, f_A or f_T takes the dichotomous arguments (p, q) and has a finite sequence of binary outcomes $(p, q, \cdots, q, p)$.

2.2.1. Theoretical response set, f_T

Theoretical response set (f_T) is a finite set of responses inclined towards food fraud generated using theoretical concepts. Consequently, we can denote f_T as the idealised motivation towards food fraud intentions. Depending on how the questions are designed, f_T is a set of p and q values, which can respectively be denoted by p_T and q_T for differentiation.

2.2.2. *Inverse set, f_T^{-1}*

The inverse of the theoretical response set is f_T^{-1}, which is a theorised response set for an ideal non-fraudster. For every element in a theorised set, if $f_T = \{p,\ q\}$, then $f_T^{-1} = \{q,\ p\}$.

2.2.3. *Actual food response set, f_A*

The actual response set, f_A, is a set of actual responses given by subject S in a survey that contains a total number of items, ϵ_N. In f_A, we also expect the response set to contain q and p values; however, we will not have an inverse set (f_A^{-1}) since subject S chooses one response (p or q) for each item, ϵ. The total number of items (ϵ_N) in f_A and f_T is equal and identical. Thus, if the subject S answers all items, $n(f_T) = n(f_A)$.

2.3. *Determining the food fraud intention f*

Given items ϵ_N from the survey tool, the response sets f_T and f_A can be used to determine or measure how likely subject S will engage in food fraud. The f-value is based on the degree of similarity or dissimilarity between the actual food fraud activity, f_A, and the ideal food fraud behaviour, f_T, i.e., the distance, $d(f_T, f_A)$. The similarity function of f was expressed as the degree of similarity between f_A and f_T using Eq. (1),

$$f = f_T \ominus f_A. \tag{1}$$

The operator $\ominus$ can be used to find the similarity between the f_A and f_T and can be solved in three steps.

1. Subtraction. Eq. (2) provides the difference (Λ) between f_T and f_A,

$$f_T \ominus f_A \Rightarrow |f_T - f_A| = \Lambda. \tag{2}$$

   The sign of the difference is of little importance; hence, all values of $|f_T - f_A| = \Lambda$ can be expressed as absolute or positive. Since each item in the ideal set f_T contains a q_T or p_T value, and each item in the response set f_A contains a q or p-value. Then Λ is equal to either of these solutions: $|q_T - q| = 0$, $|p_T - p| = 0$, $|p_T - q| = x$, and $|q_T - p| = x$; where $x \in \mathbb{N} : x > 0$. A case where $\Lambda = 0$ (Λ_0) suggests that the subject's response on an item ϵ was the same as that from the ideal set f_T. When $\Lambda = x$ (Λ_x), then the responses from the items are different since in a dichotomy scale $q_T \neq p$ and $p_T \neq q$.
2. Counting. Thus, after obtaining the difference Λ in Eq. (2), all instances where $\Lambda = 0$ can be added or counted as

$$count\ if : \Lambda = 0, \tag{3}$$

   and the number of zeros $n\Lambda_0$ can be found by

$$n\Lambda_0 = \sum_{i=1}^{n} (\Lambda_0)_i, \tag{4}$$

   where

$$\Lambda(q_T, p_T, q, p) = \begin{cases} 0, & |q_T - q|, |p_T - p| \\ x, & |q_T - p|, |p_T - q|. \end{cases} \tag{5}$$

3. Division. The intention of subject S to fraud can then be obtained after dividing $n\Lambda_0$ by the total number of items ϵ_N,

$$f_T \ominus f_A = \frac{\sum_{i=1}^{n} (\Lambda_0)_i}{\epsilon_N} = \frac{n\,(\Lambda_0)}{\epsilon_N} = f. \tag{6}$$

2.4. *Expressing f using Π and Ω*

In Section 1, it was established that unethicality (fraud) is usually motivated by malicious intent, Π (for instance, greed) and ethical fading-bounded ethicality, Ω (for example, bad working conditions and unawareness). In general, this means that a person's actual food fraud intention, f_A, can either be caused by malicious intent, Π, or ethical fading-bounded ethicality, Ω. The actual food fraud intention f_A can then be expressed in terms of Π and Ω as

$$f_A = \begin{pmatrix} \Pi \\ \Omega \end{pmatrix}. \tag{7}$$

Similarly, we can create a complementary set for the ideal food fraud intention, f_T, by looking at the theoretical or ideal malicious intent, Π^t, and the ideal ethical fading-bounded ethicality, Ω^t. These are based on the theoretical idea of how fraud can happen. Thus, f_T should also be explained by Π^t and Ω^t such that

$$f_T = \begin{pmatrix} \Pi^t \\ \Omega^t \end{pmatrix}. \tag{8}$$

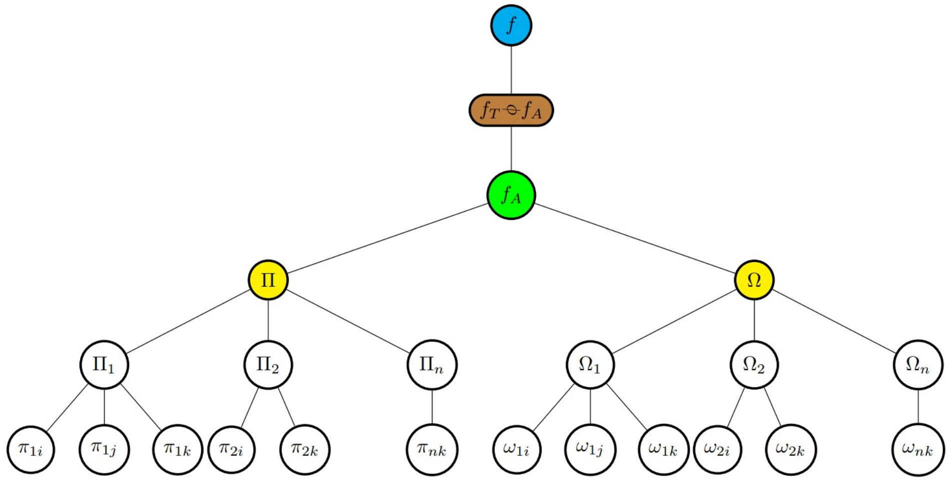

Figure 1. Systematic model showing the relationship among the food fraud variables.

The psychological processes, Π and Ω, represent different categories or subsets of the items ϵ_N used in the survey tool. The sum of items in Π and Ω should give the total number of items ϵ_N in the questionnaire, i.e., $n\Pi + n\Omega = \epsilon_N = nf_T = nf_T$. However, $n\Pi$ may be equal to or not equal to $n\Omega$, depending on the structure of the questionnaire. The proportion of Π and Ω can be represented as Π/ϵ_N and Ω/ϵ_N, respectively.

When considering food fraud, several factors can explain the malicious intent or ethical fading of the subject, S. For example, greediness and selfishness are factors that promote food fraud through malicious intent, whilst work pressure, intimidation, and toxic work environments are factors that may lead to fraud through ethical fading-bounded ethicality. Thus, Π and Ω can be extended to various factors n, for instance, $\Pi = (\Pi_1, \Pi_2, \cdots, \Pi_n)$ and $\Omega = (\Omega_1, \Omega_2, \cdots, \Omega_n)$, Figure 1.

We can think of Π_n and Ω_n factors as synonymous with latent variables. This indicates that they rely on the behavioural traits or determinants rather than being directly measured from the questionnaire. So, the latent variable Π_1 can be explained by different items or behaviours (determinants) for malicious intent $(\pi_{1i}, \pi_{1j}, \pi_{1k})$ and Π_2 as $(\pi_{2i}, \pi_{2j}, \pi_{2k})$ and so on (Figure 1). The same can also be applied to the latent variables Ω for ethical fading-bounded ethicality. The actual food fraud intention, f_A, can therefore be represented in terms of Π and Ω, as in Eq. (9). We also expect the f_T response set to contain the same variables, denoted as Π_n^t and Ω_n^t, for distinction. To find out if someone has intentions to commit food fraud, Π and Ω can be used to evaluate the similarity function $f_T \ominus f_A$ and the difference $|f_T - f_A| = \Lambda$ as shown in Eq. (10). The expression, Eq. (10), indicates that the difference $|f_T - f_A| = \Lambda$ can be represented by $\Lambda_{1i}, \Lambda_{2j}, \cdots, \Lambda_{nk}$, for factors $(1, 2, \cdots, n)$ and behavioural traits $(i, j, \cdots, k)$. Where $\Lambda_{1i} = \pi_{1i}^t - \pi_{1i}$; $\Lambda_{2j} = \pi_{2j}^t - \pi_{2j}$; $\Lambda_{nk} = \pi_{nk}^t - \pi_{nk}$. The same also applies to the Ω variable.

The concept suggests that there are two levels of latent variables. Variables Ω_n and Π_n, where $n = 1, 2, \cdots, k$, represent Level 1 latent variables that are explained by ω_{nk} and π_{nk} behavioural traits (Figure 1). The Level 2 latent variables can be represented by Ω and Π, which are explained by variables Ω_n and Π_n. In a practical example, a Level 2 psychological process of having malicious intentions, Π, can be explained by Level 1 factors $(\Pi_1, \Pi_2, \cdots, \Pi_n)$ like being greedy or self-serving. Whilst traits (π_{nk}), such as purposefully altering the rules to gain attention or an incentive, explain Level 1 factors.

$$f_A = \begin{pmatrix}\Pi \\ \Omega\end{pmatrix} = \begin{pmatrix}\Pi_1 \\ \Pi_2 \\ \cdot \\ \cdot \\ \cdot \\ \Pi_n \\ \Omega_1 \\ \Omega_2 \\ \cdot \\ \cdot \\ \cdot \\ \Omega_n\end{pmatrix} = \begin{pmatrix}\pi_{1i} \\ \pi_{1j} \\ \pi_{1k} \\ \pi_{2i} \\ \pi_{2j} \\ \pi_{2k} \\ \cdot \\ \cdot \\ \cdot \\ \pi_{nk} \\ \omega_{1i} \\ \omega_{1j} \\ \omega_{1k} \\ \omega_{2i} \\ \omega_{2j} \\ \omega_{2k} \\ \cdot \\ \cdot \\ \cdot \\ \omega_{nk}\end{pmatrix}, \tag{9}$$

$$|f_T - f_A| = \begin{pmatrix}\Pi \\ \Omega\end{pmatrix} - \begin{pmatrix}\Pi^t \\ \Omega^t\end{pmatrix} = \begin{pmatrix}\Pi_1 \\ \Pi_2 \\ \cdot \\ \cdot \\ \cdot \\ \Pi_n \\ \Omega_1 \\ \Omega_2 \\ \cdot \\ \cdot \\ \cdot \\ \Omega_n\end{pmatrix} - \begin{pmatrix}\Pi_1^t \\ \Pi_2^t \\ \cdot \\ \cdot \\ \cdot \\ \Pi_n^t \\ \Omega_1^t \\ \Omega_2^t \\ \cdot \\ \cdot \\ \cdot \\ \Omega_n^t\end{pmatrix} = \begin{pmatrix}\pi_{1i} - \pi_{1i}^t \\ \pi_{1j} - \pi_{1j}^t \\ \pi_{1k} - \pi_{1k}^t \\ \pi_{2i} - \pi_{2i}^t \\ \pi_{2j} - \pi_{2j}^t \\ \pi_{2k} - \pi_{2k}^t \\ \cdot \\ \cdot \\ \cdot \\ \pi_{nk} - \pi_{nk}^t \\ \omega_{1i} - \omega_{1i}^t \\ \omega_{1j} - \omega_{1j}^t \\ \omega_{1k} - \omega_{1k}^t \\ \omega_{2i} - \omega_{2i}^t \\ \omega_{2j} - \omega_{2j}^t \\ \omega_{2k} - \omega_{2k}^t \\ \cdot \\ \cdot \\ \cdot \\ \omega_{nk} - \omega_{nk}^t\end{pmatrix} = \begin{pmatrix}\Lambda_{1i} \\ \Lambda_{1j} \\ \Lambda_{1k} \\ \Lambda_{2i} \\ \Lambda_{2j} \\ \Lambda_{2k} \\ \cdot \\ \cdot \\ \cdot \\ \Lambda_{nk}\end{pmatrix}. \tag{10}$$

2.5. *Determination of food fraud intention strength, β_f*

Let $n\Lambda_0/\epsilon_N$ represent the ratio of similar cases and $n\Lambda_x/\epsilon_N$ the ratio of non-similar cases, then β_f can be defined as the difference between these ratios. We termed β_f the fraud intention strength or ratio difference, which roughly indicates the strength of the subject's desire to commit food fraud. The higher values of the ratio difference (β_f) suggest that subject S scored more towards fraud ($n\Lambda_0$) than non-fraud ($n\Lambda_x$). β_f is expressed in two ways. We first consider the simple ratio difference,

$$\beta_f = \left[\frac{(n\Lambda_0 - n\Lambda_x)}{\epsilon_N}\right]. \tag{11}$$

Given that $n\Lambda_0 + n\Lambda_x = \epsilon_N$, solving Eq. (11) for a range of values will show that β_f decreases as $n\Lambda_0 \to 0$, that is, when $n\Lambda_x \to \epsilon_N$ (Figure 2). The magnitude of β_f ranges from -1.0 to +1.0. It can be established that $\beta_f \to 0$ when $n\Lambda_0 \to n\Lambda_x$ and $\beta_f = 0$ when $n\Lambda_0 = n\Lambda_x$. Below these values, when $n\Lambda_0 < n\Lambda_x$, β_f will be negative (Figure 2). If we subtract Λ_x from Λ_0, the negative values could indicate a shift in the subjects' intentions from fraud to non-fraud. This will sort of provide the direction of the intention, i.e., positive values will suggest an inclination towards fraud intentions, whilst negative values will show an inclination towards non-fraud

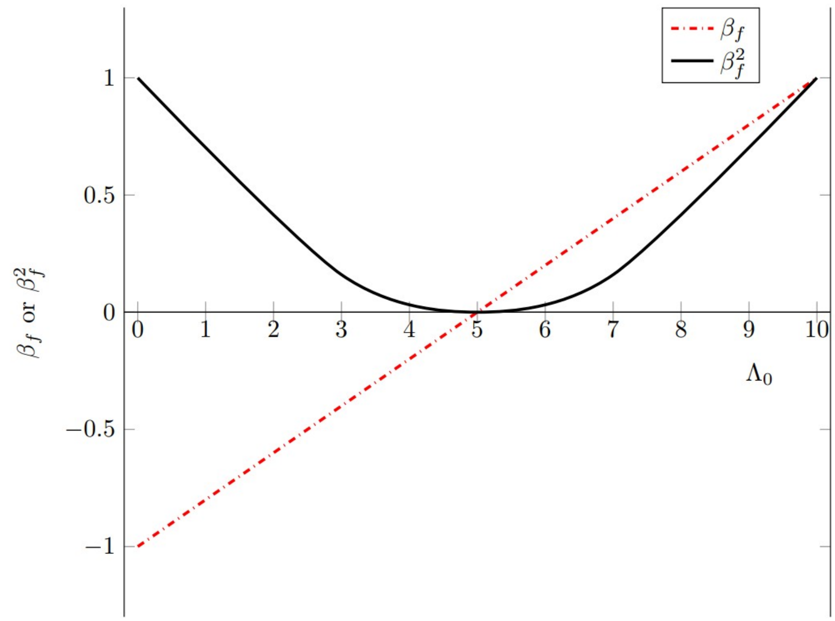

Figure 2. The relationship between Λ_0 and β_f.

intentions. The use of the differences (Λ_0 - Λ_x) -intentions towards fraud and (Λ_x - Λ_0) -intentions towards non-fraud can be allowed; however, caution should be taken when interpreting the data.

The introduction of positive and negative values in Eq. (11) may make one suggest that the signs represent positive and negative intentions towards fraud. Though such notions may exist, it will be a misconception to use them here, since these polarities are just showing inclinations to either fraud or non-fraud and not moral standpoints (e.g., good intentions vs. bad intentions). To avoid such a misconception, we may choose to express the value with the same polarity and then consider the magnitude of β_f to determine strength. This was obtained in Eq. (12) by squaring the simple ratio difference (β_f^2). Thus, the strength of the intention of both the fraudsters and non-fraudsters will be expressed equally, i.e., all positive (Figure 2). However, to address the direction of the intention of subject S (i.e., inclination to fraud or non-fraud), Eq. (12) uses the inequalities of Λ_0 and Λ_x, that is, $\Lambda_0 > \Lambda_x$ (inclination to food fraud) and $\Lambda_0 < \Lambda_x$ (disinclination to food fraud),

$$\beta_f^2 = \left[\frac{(n\Lambda_0 - n\Lambda_x)^2}{\epsilon_N^2}\right], \quad (\Lambda_0 > \Lambda_x). \tag{12}$$

Just as in β_f, the quadratic relationship showed that the vertex for the $\beta_f^2 - \Lambda_0$ graph (Figure 2) occurred when $\beta_f^2 = 0$. Before the vertex, when $\Lambda_0 < 5$, β_f^2 will decrease as Λ_0 increases. However, after the midpoint ($\Lambda_0 > 5$), β_f^2 will increase since the difference ($\Lambda_0 - \Lambda_x$) will become larger. This distribution (Figure 2) suggests that at lower values of $n\Lambda_0$, the intention strength decreases $\beta_f \rightarrow 0.0$, whereas at higher values of food fraud intention, the intention strength increases $\beta_f \rightarrow 1.0$. The expression, Eq. (12) and Figure 2, illustrates that the values of β_f^2 are always positive because of the difference $[(n\Lambda_0 - n\Lambda_x)^2 = (n\Lambda_x - n\Lambda_0)^2]$. Squared ratio difference (β_f^2) values will be lower than those of β_f. However, this will also be good by reducing non-significant cases where $n\Lambda_0 \rightarrow n\Lambda_x$ close to zero. The other case could have expressed the strength as a modulus or an absolute value, $|\beta_f|$, giving positive values with the same magnitude as β_f. However, in this study, we focused on the simple and squared ratio difference.

3. Characteristics of the f-scale

3.1. Scale limits

The values of f are expected to be within the interval of 0.0 - 1.0 (Figure 3). The value of 0.0 indicates the minimum food fraud intention (f_T^{-1} response set), while 1.0 indicates the maximum intention (f_T response set). The different f values can, therefore, depend on the difference in the number of similarity instances (Λ_0) from the respondents. The greater the number of Λ_0, then $f \rightarrow 1.0$, i.e., more inclined to food fraud, and the lower the number of Λ_0, then $f \rightarrow 0.0$, i.e., disinclined to food fraud. Thus, the parameter Λ_0 can be regarded as the unit for f, which affects its magnitude. Theoretically, we expect the relationship of f and Λ_0 to be linear, as illustrated in Figure (3) and Eq. (13), since $f \propto \Lambda_0$. Thus,

$$f = k_1 \cdot \Lambda_0 + k_0, \tag{13}$$

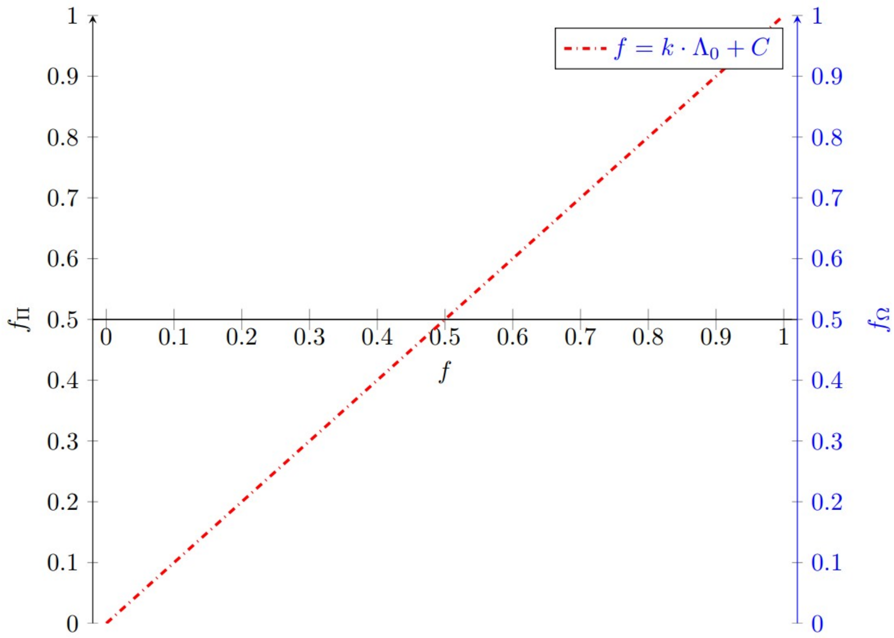

Figure 3. Shows the scales of f, f_Π, and f_Ω.

where k_1 represent the gradient, while k_0 represent the intercept. In essence, f is a continuous variable (with values ranging from 0.0 to 1.0) derived from categorical or dichotomous data (f_T and f_A). In the extreme condition where $f = 0.0$, it means that the responses from the f_A set given by the subject S do not match at all (dissimilar) with the ideal or theoretical response set f_T, i.e., $f_T \neq f_A$; hence, $f_T^{-1} = f_A$. In contrast, when $f = 1.0$, it means that f_A is the same or similar to f_T, i.e., $f_T = f_A$ (Figure 3).

According to the categories mentioned in Section 2.4 -namely, malicious intent (Π) and ethical fading -bounded ethicality (Ω) -the fraud intention f can be shown in two different ways: f_Π for items related to malicious intent and f_Ω for items related to ethical fading. As Λ_0 increases, so does the value of f, f_Π ($\Lambda_0^\Pi/n\Pi$) and f_Ω ($\Lambda_0^\Omega/n\Omega$), as shown in Figure (3) and Eq. (13). We can empirically establish the following

$$f = f_\Pi + f_\Omega. \tag{14}$$

3.2. The f-scale rate of change

If we assume that the weight of each item is the same, then the rate at which f changes (R_f) will depend on the total number of items ϵ_N. In general, a change in one response for a small sample size of ϵ_N can cause a greater change in the value of f, as compared to a large sample size of ϵ_N (Figure 4). The graph (Figure 4) shows that the curve is steep when ϵ_N is small and flattens out as ϵ_N increases. Therefore, Eq. (15) effectively expresses R_f as the reciprocal of ϵ_N,

$$R_f = 1/\epsilon_N. \tag{15}$$

We can also treat R_f as an error term (non-standardised) involved in selecting a response. The subject S may choose a response they did not wish to because of ambiguities or some other reason. In this case, a bias of $R_f = 1/\epsilon_N$ can be assumed (Figure 4). Figure (4) shows that as the values of ϵ_N increase, the value of R_f decreases. Hence, the smaller the value of ϵ_N, the greater the associated error, and the larger the value of ϵ_N, the smaller the associated error.

3.3. Number of response patterns, Γ

The number of response patterns, Γ, illustrates the possible patterns of response set, f_A, that a subject S can choose when answering the questionnaire. This can be important in identifying common patterns that a group of subjects S can choose. So, the number of patterns (Γ) defines the response set f_A, and it can be determined by considering the number of available options (p, q for a dichotomous scale) and the total number of items (ϵ_N). In general, the relationship between the number of patterns Γ and the number of options (i.e., 2 for a dichotomy scale) and the total number of items (ϵ_N) can be expressed as

$$\Gamma = 2^{\epsilon_N}. \tag{16}$$

We can establish the proof that Γ is true for all positive integers ($\mathbb{Z}^+$) in ϵ_N using the principles of mathematical induction. Logically, since ϵ_N represents the number of items in the questionnaire, we expect the values to always be integers and positive.

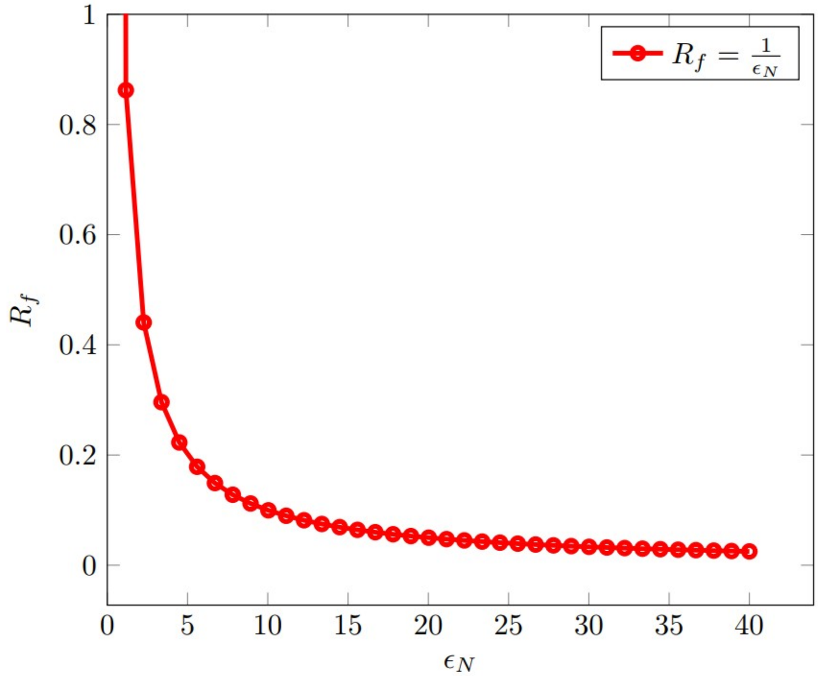

Figure 4. The relationship between R_f and ϵ_N.

We recognise the proof to be similar to that of 2^n and should satisfy the inequality $2^n > n$. Thus, according to the principles of mathematical induction's base step, we need to check if the statement $\epsilon_N = 1$ is true. The statement is true since $2^{\epsilon_N} = 2^1 = 2 > 1$. An inductive hypothesis can then be established: the statement is also true for some other integer P (another set of the number of items), such that $2^P > P$. The inductive step will prove that the statement is true for $P + 1$, that is, $2^{P+1} > P + 1$, and it is true since, when $P = 1$, $2^{1+1} = 2^2 = 4 > 2$.

4. Validation of the model using a survey instrument

4.1. Data collection

We created a research instrument, comprising 46 questions or items (ϵ_N), using Google Forms and distributed it online via a hyperlink. The respondents accessed the link through social media channels (WhatsApp, Facebook, and LinkedIn) and emails between November 2021 and February 2022. A pilot study was issued to 10 respondents to check for errors and ambiguities before distribution to the public as recommended by Guntzburger *et al*. [16]. The survey targeted respondents associated with food manufacturing (machine operators, packers, dispatch personnel, SHE offices, quality controllers, laboratory technicians, managers, buyers, etc.) and those in food research and academia (lecturers, researchers, and government authorities). The data was collected from some provinces in Zimbabwe, namely Bulawayo, Harare, Manicaland, Mashonaland East, Masvingo, and Midlands. Table A lists the 39 questions used for this study.

4.2. Sections of the questionnaire

The questionnaire comprises four sections: demographics, subject preview, general factors, and case studies. The demographics hold minimal significance in this study, even though they contain information concerning the respondents' general knowledge, such as age, sex (male or female, as designated at birth), work experience, location, and the specific sector of the food business in which they are employed. The remaining questions used in this study are included in Table A.

4.2.1. Section 2: Subject preview

The section tests if the respondents are aware of the definition of the term "food fraud," the general factors that encourage or promote it, and its impact. The section contains 6 questions.

4.2.2. Section 3: General factors

In scenario 1, participants were told to adopt the role of subordinates. We questioned them about document or report falsifications and the impact of the work environment, supervisors, and co-workers on ethical decision-making. In scenario 2, participants were instructed to assume a supervisory or managerial position. We questioned the participants about their decisions on addressing production losses, managing bribery incidents during material procurement, and overseeing subordinates. The section contained a total of 9 questions.

4.2.3. Section 4: Case scenarios

This section presents real-life scenarios that can occur in a food manufacturing setup, followed by questions about behavioural perceptions. We adopted some of the pointers given by Jafarkarimi *et al*. [17] when developing case scenarios. These include introducing a fictitious person who is likely to exist; it should be clear from the outset that there are difficulties; a clear decision under pressure should be presented, and it should be short and easily understandable. The section contains a total of 8 cases and 24 questions.

Case 1 entailed a moral evaluation regarding a supplier confronted with the decision to either incur a loss or gain by altering the weight of the product provided. Case 2 presented a machine operator, Trinity, who faced severe working conditions, resulting in a compromise of process integrity to achieve established targets. Participants were required to evaluate the conduct of the machine operator. In Case 3, participants were instructed to critique a quality controller who, upon a supervisor's request, misrepresented product quality findings and thereafter deliberately misrepresented the results. Case 4 depicts an employee in a detrimental work environment, compelling the respondents to assess the behavioural responses to situational circumstances. Case 5 referenced a salesperson who coerces people to engage in fraudulent activities. We requested participants to assess the ethicality of these acts. Case 6 evaluates whether respondents would violate regulatory rules at the company's request. Case 7 asked if the fraudster's behaviours might persuade others to commit fraud. In Case 8, respondents were questioned whether they would participate in fraudulent activity again if the opportunity arose, despite being previously identified and penalised for it.

5. Results and discussion

5.1. Rationalisation of food fraud variables or factors

The information gathered on malicious intentions (Π) and ethical fading-bounded ethicality (Ω) from the survey is shown in Table 1. The respondents' scores were expressed as percentage frequencies (F_p) for each item or question (Table 1). We ascertain that Yes, or Good, will be represented by q, and No, or Bad, by p, where q and p were coded as 1 and 0, respectively. Table 1 also shows the behavioural traits or items: π for malicious intents and ω for ethical fading-bounded ethicality. This can be used to explain latent variables Π and Ω, as mentioned in Section 2.4. Table 1 shows that malicious intent (Π) contains 8 factors (Π_n) and a total of 26 items (π). Ethical fading-bounded ethicality (Ω) had 5 factors (Ω_n) and 16 items (ω). We noted that items q21-q23 were general, potentially relevant to both malicious intent and ethical fading-bounded ethicality categories (Table 1). As such, the items were considered separately when analysing these categories. Table 1 shows the ideal food fraud set, f_T, and the complementary set for non-fraudsters, f_T^{-1}. There is no criterion for the validation of items; the observer may assess their significance using literature, alternative methods or techniques like factor analysis. This article employs literature to substantiate the significance of items used in this investigation.

The items related to malicious intent seek to establish if food fraud occurs due to the inherent fraud behaviour of individuals. For example, q25 checks if enough money and favourable working conditions are enough to reduce an individual's food fraud intention. Gussow and Mariët [14] and Spink *et al*. [18] showed that a potential fraudster will always be inclined towards the persistence of fraud activity. Spink and Moyer [1] indicate that people in fraud encourage others to do the same by forming networks that are reliable, flexible, and capable of reform or reconnecting after the links have been disrupted. This was investigated using q26 and s7c. Rees *et al*. [19], Nyaga *et al*. [20], and Manning [21] explained that greed, self-serving and bribery are the main causes of fraud through malicious intent. These were all captured in items q311, q314, q321, q323, s1a, s5a-c, s6c, s7d, s8a and s8b. Items regarding ethical fading and bounded ethicality were obtained from Kim *et al*. [8], Tenbrunsel and Messick [9], Rees *et al*.[19], van Ruth and de Pagter-de Witte [22], Tenbrunsel and Smith-Crowe [23], and Boyle *et al*. [24]. These involve intimidation from superiors (q312, s4a, s4b, s6a, s6b), malevolent work environment and abnormal work pressure (s2a, s2b, s3a-c), in-group favouritism, illusion of control and motivational blindness (q313, q324).

5.2. Comparison of the f model and the Jaccard index

The f model was given in Eq. (6) as $f = (n\Lambda_0)/\epsilon_N = f_T \ominus f_A$. The equation can be considered to be similar to the Jaccard index (J). Fletcher and Islam [25] showed that the Jaccard index measures similarities for binarised data, i.e., the data used in this study. The Jaccard index for a sample set A and B ($J(A, B)$) is calculated by dividing the intersection by the size of the union [25, 26],

$$J(A, B) = \frac{|A \cap B|}{|A \cup B|} = \frac{|A \cup B|}{|A| + |B| - |A \cap B|}. \tag{17}$$

Table 1. Summary of the response frequencies (F_p, %) and response sets (f_T and f_T^{-1}).

			F_p (%)			
Factor	Variables	Item	YES	NO	f_T	f_T^{-1}
Π	Knowledge of food fraud	q21	79.6	20.4	1	0
		q22	88.9	11.1	1	0
	Destructive effects of food fraud	q23	96.3	3.70	1	0
	Self-justification	q24	38.9	61.1	0	1
	Effects of good working conditions on fraud	q25	42.6	57.4	0	1
	Encouragement to fraud	q26	83.3	16.7	1	0
		s7a	75.9	24.1	0	1
		s7c	79.6	20.4	1	0
		s7f	44.4	55.6	1	0
	Self-serving/ greediness	q311	20.4	79.6	1	0
		q321	37.0	63.0	1	0
		q323	24.1	75.9	1	0
		s1a	11.1	88.9	1	0
		s1b	40.7	59.3	0	1
		s5a	57.4	42.6	0	1
		s5b	38.9	61.1	0	1
		s5c	14.8	85.2	1	0
		s6c	27.8	72.2	1	0
		s7d	53.7	46.3	1	0
		s7e	25.0	74.1	1	0
	Reactions to bribing	q314	9.30	90.7	1	0
		q322	29.6	70.4	1	0
		s7b	50.0	50.0	1	0
	Changes or reoccurrence of fraud activities	s8a	66.7	33.3	1	0
		s8b	9.30	90.7	1	0
		s8c	88.9	11.1	1	0
Ω	Intimidation from superiors	q312	57.4	42.6	1	0
	Work pressure	s2a	40.7	59.3	0	1
		s2b	55.6	44.4	1	0
	Going with flow	q313	7.40	92.6	1	0
		s3a	22.2	77.8	1	0
		s3b	57.4	42.6	0	1
		s3c	9.30	90.7	1	0
	Toxic work environments/ill treatment	q315	29.6	70.4	1	0
		s4a	75.9	24.1	0	1
		s4b	38.9	61.1	1	0
		s6a	50.0	50.0	1	0
		s6b	27.8	72.2	1	0
	Favouritism	q324	33.3	66.7	1	0

J represents the fraud intention, f, while A and B denote the response sets f_T and f_A. Thus, $|A \cap B| = |f_T \cap f_A| = n\Lambda_0$, the similarity instances between the two sets, and $|A \cup B| = \epsilon_N$, the number of total items in the questionnaire. Earlier in Section 2.2, we indicated that the total number of items $\epsilon_N = |f_T| = |f_A|$, and hence, $|A \cup B| = |f_T \cup f_A| = |f_T| = |f_A| = \epsilon_N$. Thus, the union $|f_A \cup f_T|$ has an idempotent property (e.g., $A \cup A = A$) since the items in f_T and f_A are identical [27, 28].

We observed that the metric characteristic of f satisfies the conditions for distance measurement d (similarity/dissimilarity) mentioned by Basic [28]. Firstly, we consider f a distance/similarity measure between two points, f_T and f_A. We have already mentioned that (in Section 2.2) f_T and f_A are dichotomous, defined by only two responses or choices, i.e., $f_T(p_T, q_T)$ and $f_A(p, q)$, representing the presence or absence of fraud intention. This illustrates that the metric f (or distance/similarity function) should follow these properties according to Fletcher and Islam [25] and Yu *et al.* [29]:

1. The similarity between $f_T = (q_T, p_T)$ and $f_A = (q, p)$ should always be non-negativity $d(f_T, f_A) \geq 0$. This is true since the numerator ($n\Lambda_0 = |f_T \cap f_A|$) and the denominator ($\epsilon_N = |f_T \cup f_A|$) are always positive for calculating the metric f.

Table 2. Statistical distribution of f, f_Ω, and f_Π.

	ϵ_N		Ω		Π	
	$n\Lambda_0$	f	$n\Lambda_0$	f_Ω	$n\Lambda_0$	f_Π
Mean	17.0	0.44	7.0	0.44	12.0	0.47
Mode	13.0	0.33	8.0	0.50	12.0	0.46
Minimum	8.0	0.21	2.0	0.13	6.0	0.23
Maximum	27.0	0.69	13.0	0.81	19.0	0.73
Kolmogov-Smirnov		0.077		0.030		0.001
Skewness		0.465		0.472		0.372
Kurtosis		-0.494		-0.359		-0.145
Standard Dev		0.131		0.164		0.116
ϵ_N	39.0		16.0		26.0	
$R_f = 1/\epsilon_N$	0.0256		0.0625		0.385	
Γ		2^{39}		2^{16}		2^{26}
N (Respondents)	54		54		54	

2. The distance between f_T and f_A must have symmetrical properties; that is, $d(f_T, f_A) = d(f_A, f_T)$ for all points of f_T and f_A. Thus, if we consider Eq. (2) used in obtaining the difference Λ, it is ascertained that $|f_T - f_A| = |f_A - f_T| = \Lambda$.
3. The property of reflexivity/definiteness is defined when $d(f_T, f_A) = 0$, i.e., when the ideal or theoretical fraud intention coincides with the actual fraud intention, $f_T = f_A$. Thus, we expect all cases in both response sets (f_T, f_A), to be equal: $p_T = p$ and $q_T = q$, as illustrated in Section 2.3.

5.3. Statistical distribution of the food fraud intention f

We used Kolmogorov-Smirnov analysis, skewness, and kurtosis to do the normal distribution test for assessing if the f-scale was continuous rather than categorical (Table 2). Normality was examined using the Kolmogorov-Smirnov test because the data exceeded 50.0. The Kolmogorov-Smirnov test rejects the null hypothesis (normal distribution of data) when $p < 0.05$ at a 95.0% confidence interval. Table 2 showed that the data for f was normally distributed $[p(0.077) > 0.05]$, whereas the data for $f_\Pi(p = 0.001)$ and $f_\Pi(p = 0.030)$ were asymmetrically distributed since $p < 0.05$. However, the values for both skewness and kurtosis were within ± 1.0, indicating that the values of f, f_Π, and f_Ω were normally distributed (Table 2). Nevertheless, the values were somewhat skewed to the right and slightly flatter or platykurtic, as the values were not absolute zeros. Given the normal distribution of the f-value, we conduct some parametric tests on the data.

Table 2 shows the descriptive statistics of the value of f, f_Π, f_Ω, and the number of similar instances $(n\Lambda_0)$ for 54 respondents. Table 2 shows that the f value for all items ϵ_N ranges from 0.21 to 0.69; the most common value (mode) was 0.33, and the mean value was 0.44. The results also showed that f_Ω value had the same mean (0.44) as f, the mode was higher (0.50), and the range was wider (0.13-0.81) (Table 2). The mean for f_Π was 0.47, the mode was 0.46, and the range was 0.23-0.73. The mean of f_Π was higher than that of f and f_Ω. The magnitude of the mode and range increased as follows: $f < f_\Pi < f_\Omega$ (Table 2). The standard deviations of f, f_Ω, and f_Π are also shown in the Table 2, and the values were higher for f_Ω, followed by f, and f_Π had the lowest variability. These results suggest that the respondents' fraud intention was slightly non-fraud or neutral when considering the mean values of all categories. However, maximum values showed that higher fraud intentions were a result of ethical fading - bounded ethicality as compared to malicious intent.

The data showed that the distribution of f was undoubtedly affected by the total number of items ϵ_N in each category. Table 2 shows that the complete data contains 39 items, while the data for ethical fading had 16 items and that of malicious intent had 26 items. It seems the lower the ϵ_N, the higher the values of f were obtained. The R_f value, or the rate of change of the f-scale, also explains this phenomenon. The R_f value increased in the order:$f < f_\Pi < f_\Omega$. This means a small change in the value of $n\Lambda_0$ can cause a shift in f_Ω value by a factor of 0.0625 as compared to f_Π and f, which have values of 0.0385 and 0.0256, respectively (Table 2). An increase in the ϵ_N also increased the number of patterns Γ. Table 2 showed that the response set of f was expected to have a larger number of patterns (2^{39}) as compared to that of f_Ω and f_Π.

We used one-way ANOVA and Fisher's Least Significant Difference (LSD) as a post-hoc test to see if there were any significant differences between the means of f, f_Π, and f_Ω. The null hypothesis assumed that the means of the variables were all equal, i.e., $H_0 : \mu_1 = \mu_2 = \mu_3$, where μ_1, μ_2, and μ_3 represented the mean for f, f_Π, and f_Ω, respectively. The p-value from the ANOVA analysis was greater than 0.05 ($p = 0.373$), indicating a higher probability that the mean values for f, f_Π, and f_Ω were significantly the same (we failed to reject H_0). The post-hoc test using Fisher's LSD showed that there were no differences between groups ($p > 0.05$) at a

95.0% confidence interval. The results from the ANOVA suggest that there was no significant difference in the extent of food fraud intention, whether the drivers for fraud were coming from malicious intent (Π), ethical fading-bounded ethicality (Ω), or both. This observation could also have been effected by our assumption that all items or questions were of equal weight (Section 2).

6. Conclusion

The mathematical framework for assessing participants' food fraud intention was based on their malicious intent (Π) or their ethical fading-bounded ethicality (Ω). Food fraud intention (f) can be conceptualised as the distance between two sets: f_T, denoting the theoretical fraud intention, and f_A, indicating the actual responses from the participants. The model employed a similarity metric (similar to the Jaccard index) to transform categorical (binary or dichotomous) data (from a typical survey) into a continuous variable. The distribution of Π and Ω (from a survey data, N = 54) suggests that both malicious intention and ethical fading-bounded ethicality exert an equivalent influence on the value of f. Future research work can develop the probability distributions of f to establish the likelihood that an individual will commit fraud with malicious intent, considering scenarios of ethical fading and bounded ethicality (and vice versa). Additional surveys are required that encompass a larger and more diverse sample that incorporates standardised questions.

Data availability

The data is openly accessible in the Mendeley data repository at https://data.mendeley.com/datasets/cx6bcdmp6d/1.

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APPENDIX

Appendix A. Survey questions/item and response frequencies

The questions or items (ϵ) used for validating the mathematical model f are shown in Table A. The Table A also indicated the frequencies for respondents (N=54).

Table A: Summary of the response frequencies (F_p, %) and response sets (f_T and f_T').

	F_p (%)		
Code	Question / Item	YES	NO
q21	Have you ever heard the term food fraud?	79.6	20.4
q22	Do you understand food fraud as an intentional falsification and/or misrepresentation of food, ingredients, information, and documents for economic gain?	88.9	11.1
q23	Do you think food fraud has destructive effects on the operations of a worker and/or company?	96.3	3.70
q24	Who do you think promotes food fraud?	38.9	61.1
q25	Do you think if people are given enough money and good working conditions, food fraud can end?	42.6	57.4
q26	Do you think people who are involved in food fraud they will encourage others to do the same?	83.3	16.7
q311	Will you change the product or process results or other related documents because it will look better for your carrier or role?	20.4	79.6
q312	Will you change the process procedure or results because your superior told you to?	57.4	42.6
q313	Will you change process procedure or results because your fellow workers are doing it too?	7.40	92.6
q314	Will you change the proper way of doing things if someone offered you money or some other gift?	9.30	90.7
q315	Will you change the proper way of doing things because of low payment or ill-treatment by the employer, superiors, or other employees?	29.6	70.4
q321	Will you rather lose 20 tonnes of product over the compromised quality issue even if it is not a health risk?	37.0	63.0
q322	Will you accept a token of appreciation from a raw materials supplier, whose intentions is to stay in business with your company?	29.6	70.4
q323	Will you over-rule a reasonable work-related concern from your subordinates to protect your position as the manager?	24.1	75.9

q324	Will you secretly show favouritism to some of your subordinates because they listen to or respect you?	33.3	66.7
Case 1	*Blessing has been a supplier of sugar at a certain company for more than 5 years now. After the changes in the economic environment, Blessing suggested an increase of price by a margin of 2%. The company denied Blessing's proposal. Afraid to lose the contract, Blessing continues to supply the sugar but deliberately reduces the weight of sugar to make a profit. Blessing knew that the company she supplies to, do not always test the weight of all the bags. And in a case when a bag with low weight is observed she could just pretend it was a mistake and replace it with that of required weight.*		
s1a	What do you think about Blessing's business strategy?	11.1	88.9
s1b	If you were Blessing, will you choose to lose the contract and maybe go broke?	40.7	59.3
Case 2	*Trinity is an experienced batch prepare personnel and machine operator. Currently, because of a shortage of staff Trinity is doing more than 12 working hours per day and no off days. This work schedule is making him exhausted and crippled by fatigue. Using the unquestionable expertise, he has; Trinity could skip some steps which he thinks are not critical during the production process. Like recording the time, he started pasteurizing the product. Trinity is still managing to produce the required volume of product and no unusual batch failures have been reported yet.*		
s2a	Can you blame Trinity for skipping some steps he thought are not necessary during production processing?	40.7	59.3
s2b	Would you react the way Trinity did if you are given too much pressure at work?	55.6	44.4
Case 3	*Tanaka is a quality controller at a processing company. Many times, Tanaka has reported products with defects to superiors, but usually, the products are sent to the market nonetheless, without any proper feedback or communication. This frustrates Tanaka, and now depending on the mood, Tanaka might report product defects or sometimes just indicate all products are OK since they will be sent to market anyway.*		
s3a	How can you judge the action taken by Tanaka?	22.2	77.8
s3b	If Tanaka gets caught by her supervisor. Is it alright or justified for the supervisor to put Tanaka on a disciplinary charge?	57.4	42.6
s3c	Would you feel OK if a supervisor or work mates change your results without a solid explanation?	9.30	90.7
Case 4	*Ali was among the employees that were supervised by a mean or ungenerous boss. Many people were complaining about the treatment they were also given, and a silly mistake could end up as a hearing with the HR department. Ali found out that the best way to prevent this was to make sure all he does was so perfect. Even if it takes, for example, writing things that are reasonable but not so true in reports or control forms.*		
s4a	Is Ali wrong, for forging documents to prevent arguing with his supervisor?	75.9	24.1
s4b	If you were Ali, will you do the same to prevent confrontation with your boss?	38.9	61.1
Case 5	*Besides being a salesman, Avis is very friendly. He helps and motivates everyone to like their job. Avis is a prominent figure at the company, and he might get another promotion. Almost everyone knows him and likes him. But Avis usually does this so that he may gain favours from people and superiors.*		
s5a	If you find Avis doing something which is not good for the company, will you report him provided that he once helped you?	57.4	42.6
s5b	Will you doubt Avis if he asks you to help him with something?	38.9	61.1

s5c	Is it a good intention, to appear nice to someone because you need something in return?	14.8	85.2
Case 6	*Billie is a new employee, carrying out the same activities she used to do about 7 years ago, at another company. Billie noticed that they were several things that are done at the new company which is not quite right with the common standards and regulations. On approaching her superiors Billie was told that the company will be making some changes, to comply with known regulations soon. She was told that for now, they must work the way they always do to make profit. Billie agreed to this and continue to work as was told.*		
s6a	Is it good to comply with company protocols even if they are not in line with standards or regulation set by country, organizations, or society? Provided they is risk to lose your job?	37.0	63.0
s6b	If you were Billie, would you choose to work the way you are told even if you know it's not, right?	50.0	50.0
s6c	Would you blame Billie for accepting the job even if she knew how the company was working or operating?	27.8	72.2
Case 7	*Bay is a young junior manager who buys raw materials and reports to Dale. Bay and Dale have developed some relationships, and Dale ends up being a mentor and advisor to Bay. Dale has a way of making suppliers pay him so that they will continue supplying their products. Dale told Bay about this and in no time, he was also doing the same thing as Dale does.*		
s7a	Is it wrong for Bay to follow in Dale's footsteps?	75.9	24.1
s7b	If you were Bay, would you risk losing your job or relationship with Dale, by exposing him or denying doing what he does?	50.0	50.0
s7c	Do you think Dale influence Bay to make suppliers to pay?	79.6	20.4
s7d	Given an opportunity do you think Bay was going to make suppliers pay even without Dale's help or influence?	53.7	46.3
s7e	If someone you admire or look-up-to, asked you to do something, that you know it's not quite right, but benefit you greatly. Would you, do it?	25.0	74.1
s7f	Do you think people who are into food fraud will influence others to do the same?	44.4	55.6
Case 8	*Timothy, after being exposed for food fraud, lost his job and was almost convicted. He was employed again at a small-scale food company. The company still had loose policies, and this makes it a conducive environment for anyone to do fraud.*		
s8a	Do you think Timothy will take a chance and engage in fraud again, given the fact that he had a bad experience before?	66.7	33.3
s8b	Would you commit fraud knowing the punishment it may bring over gaining wealth or a good position?	9.30	90.7
s8c	Do you think people who have fraud before will continue doing so, if given the chance?	88.9	11.1