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Comparison Study on Development Path for Small and Medium-sized Enterprises E-commerce Using Complex Fuzzy Sets

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Abstract

E-commerce has grown exponentially in the past decade in global market. In China most E-commerce enterprises are small and medium-sized (SMEs). Compared to their large-sized counterparts, SMEs have to face many obstacles when extending their E-commerce businesses. In view of the complexity and periodicity of criteria in SMEs' development, the paper develop an evaluation method using complex fuzzy sets (CFS) to help them select appropriate development path. Then the paper focuses on a case study in Chongqing, China and compares the results with two other different methods (TOPSIS and COPRAS). The study indicates that the presented work can better handle uncertainty and periodicity in the evaluation process.

Keywords: SMEs, E-commerce, complexity fuzzy sets, TOPSIS, COPRAS, fuzzy methods

1. Introduction

E-commerce has grown exponentially in the past decade in global market. The benefits of E-commerce are apparent not only for large companies but also for small and medium-sized enterprises (SMEs)¹¹. In China, over 99% of newly emerging enterprises are SMEs; and the number of SMEs who employ E-commerce exceeded 48 million³⁵. According to "SMEs Export" (2012), 60% of China's exports are contributed by SME exporters. SMEs have been playing key roles in Chinese economic

development²⁹. However, compared to large-sized enterprises, there exist many obstacles for Chinese SMEs to extend their E-commerce businesses.

Firstly, most researches regarding to SMEs and E-commerce just occur in an international domain²⁰. There has been little findings reported on SME E-commerce in developing countries¹⁰; and majority of the research, particularly those focused on developing countries, is merely qualitative (e.g. Refs. 9, 21, 27, 30).

Secondly, although existing studies of E-

commerce have examined factors such as user acceptance, consumer behaviour, E-commerce software, investment decision making factors in adopting E-commerce, selection of E-commerce sites by the consumer, the impact of innovation and pricing strategies^{1,3,5,12,14,15,16,17,18,6,24,25,26,31,32}, few studies have investigated the magnitude of all these factors on E-commerce development in SMEs. Thus, elucidating the factors required for successful E-commerce development path, particularly in the SME sector, is a worthwhile endeavour for both researchers and SME managers.

To overcome the above-mentioned research gaps, the objective of this study is to evaluate E-commerce development paths among managers/owners of SMEs in China. So this study focuses on different new development paths on SMEs E-commerce. Considering the uncertainties and periodicities in the evaluation, we choose the complex fuzzy set (CFS) as primary tool.

The remainder of the paper is organized as follows. Section 2 presents complex fuzzy sets and relevant operations on them. Section 3 presents a complex fuzzy set based evaluation method for the identified development paths, called the SME-C method. section 4 focuses on a case study in Chongqing, China and compares the results with two other different methods. Finally, Section 5 discusses the conclusions and future works.

2. Complex fuzzy sets

A complex fuzzy set (CFS) is an extension of a conventional fuzzy set (FS) by adopting complex-valued membership degrees to express and process the co-existing uncertainty and periodicity in many applications simultaneously, e.g. signal processing^{23,22}. Roughly speaking, the significant difference between a CFS and an FS is the co-domain on which the membership degree is defined. The membership degree of a CFS is defined in the unit disc $D_C = \{d; \|d\| \leq 1\}$ on the complex plane; while it is the unit interval $[0, 1]$ of the real numbers of an FS. Formally, a CFS \tilde{A} on a discourse U is defined as

$$\tilde{A} = \{(u, \mu_{\tilde{A}}(u)); u \in U, \mu_{\tilde{A}}(u) \in D_C\} \quad (1)$$

where $\mu_{\tilde{A}}(u)$ is conveniently expressed by the Polar coordinate as

$$\mu_{\tilde{A}}(u) = r_u e^{i\phi_u} \quad (2)$$

and therefore r_u and ϕ_u are called the modulus and the phase parts of a complex-valued membership degree respectively. Because of the introduction of complex-valued membership degrees, a CFS is capable of modelling real-world problems which involve both uncertainty and “approximately periodic” phenomena⁴.

The complex-valued membership degree used in the CFS theory enhances its capability of describing complicated uncertainties and enriches the theory of the conventional FS. However, an issue has raised naturally that a complex-valued membership degree is hard to be understood compared with the conventional real-valued membership degree. To clarify the necessity of a complex-valued membership degree, Ref. 28 presented a new interpretation of it from a complex fuzzy class which is embedded with the complex fuzzy set class operations.

Similar to conventional FS theory, operations are defined for CFSs. However, they are not intuitively understandable compared to those defined for conventional FSs. Refs. 22, 23 defined some set-theoretical operations which are mainly defined on the modulus part of the complex-valued membership degrees rather than the phase part. Ref. 7 presented the concept of rotational invariance and defined a complex fuzzy logic system to address how to combine them closely. In order to deliver operations that better illustrate the phase part of a CFS, Ref. 37 defined the distance and δ -similarity of two CFSs considering both the modulus and the phase parts. However, the modulus and phase are combined loosely. Research indicates that the main challenge is how to give an intuitional and readily understandable definition for the phase part of a CFS.

A Pythagorean fuzzy set (PFS) is a kind of extension of intuitionistic fuzzy set² presented by Ref. 34 which is very similar to a CFS except that the membership degree is defined on the first-quarter of the unit disc of the complex plane. Ref. 33 discussed its applications in multi-criteria decision making. Furthermore, Ref. 8 discussed the relationships between CFSs and Pythagorean fuzzy sets. In below discus-

sion of aggregation and partial order for CFSs, we borrowed some ideas from the Pythagorean fuzzy sets.

Ref. 34 defined the general forms of aggregations for the Pythagorean fuzzy sets; and the weighted quasi-power mean *Agg* is defined as

$$\begin{aligned} & \text{Agg}(\{C(a_i, b_i)\}_{i=1}^n, \{w_i\}_{i=1}^n) \\ &= \left(\left(\sum_{i=1}^n w_i a_i^2 \right)^{1/2}, \left(\sum_{i=1}^n w_i b_i^2 \right)^{1/2} \right) \end{aligned} \quad (3)$$

where $C(a_i, b_i)$ is a Pythagorean membership satisfying $a_i, b_i \in [0, 1]$ such that $a_i^2 + b_i^2 \leq 1, i = 1, \dots, n$; and $\sum_{i=1}^n w_i = 1$. In Eq. (3), we note that

$$\begin{aligned} \sum_{i=1}^n w_i a_i^2 &\leq \sum_{i=1}^n w_i a_i \\ \sum_{i=1}^n w_i b_i^2 &\leq \sum_{i=1}^n w_i b_i. \end{aligned} \quad (4)$$

and the weighted vector sum of all $C(a_i, b_i)$ s is

$$\left(\sum_{i=1}^n w_i a_i, \sum_{i=1}^n w_i b_i \right) = \sum_{i=1}^n w_i C(a_i, b_i) \quad (5)$$

If we can prove the weighted vector sum is in the unit disc $D_{\mathbb{C}}$, then we can use it as the aggregation of all $C(a_i, b_i)$ s. In fact, this can be proved by the Cauchy-Schwarz inequality. Inspired by this definition, we will define the weighted mean *Agg* on CFSs as

$$\begin{aligned} & \text{Agg} \left(\left\{ \tilde{A}(a_i, b_i) \right\}_{i=1}^n, \{w_i\}_{i=1}^n \right) \\ &= \left(\sum_{i=1}^n w_i a_i, \sum_{i=1}^n w_i b_i \right) \end{aligned} \quad (6)$$

where $a_i = r_i(u) \cos(\phi_i(u))$, and $b_i = r_i(u) \sin(\phi_i(u))$. By $a_i^2 + b_i^2 = r_i^2(u) \leq 1$, we can prove that the right-hand of Eq. (6) falls in the unit disc of the complex plane and can be used as membership degree of a CFS.

After defining aggregation on CFS, another issue we need to solve is how to order (rank) the aggregated result. In literatures, we can easily find several different methods based on various initiatives. Yager and Abbasov³⁴ ordered the aggregated result using

a binary function F from a Pythagorean membership degree to a value in $[0, 1]$:

$$F(r, \theta) = \frac{1}{2} + r \left(\frac{1}{2} - \frac{2\theta}{\pi} \right) \quad (7)$$

where $C(a, b)$ is a Pythagorean membership grade, $r^2 = a^2 + b^2$ and $\theta = \arctan(\frac{b}{a})$. Because the definition given is in the first quarter of the unit disc, we choose the following definition given in Ref. 19 to extend it to the whole unit disc: for any two CFSs \tilde{A} and \tilde{B} ,

$$\tilde{A} \leq \tilde{B} \iff r_{\tilde{A}} \cos(\phi_{\tilde{A}}) \leq r_{\tilde{B}} \cos(\phi_{\tilde{B}}). \quad (8)$$

3. The SME-C method

Using the discussion of aggregation and partial order for CFSs in Section 2, this section proposes an evaluation method for SME development path which is named the SME-C method. Firstly, we describe the basic formalisation of the application; then outline the main steps of the SME-C method; and finally discuss details of each step.

3.1. Formalisation of the application

Given a set of n candidate development paths (referred as alternatives $a_i, i = 1, \dots, n$), a set of m criteria ($c_j, j = 1, \dots, m$) and their corresponding weights ($w_j, j = 1, \dots, m$), and an initial assessment matrix $X = (x_{ij})_{n \times m}$, the ultimate target of the application is to select the best candidate path(s) based on available information. This formalisation is a typical multi-criteria decision making configuration without any other specifications. In this paper, we require x_{ij} to be a complex-valued membership degree of an underlying CFS $\tilde{F}_j, j = 1, \dots, m$.

3.2. Outline of the SME-C method

The steps of the SME-C method are briefly listed below:

- Step 1 Normalise initial assessment matrix X to normalized assessment matrix \bar{X} ;
- Step 2 Generate weighted assessment matrix \hat{X} from \bar{X} ;

Step 3 Calculate aggregated assessment S_i for each alternative;

Step 4 Rank S_i s based on partial order given in Eq. (8).

3.3. Normalisation of initial assessment matrix

That normalising initial assessment matrix is commonly attribute to two practical purposes: 1) to make the comparisons between different criteria on a unified measurement scale; and 2) to make the following calculation or operation confined to specific properties. In the SME-C method, this step is optional when setting x_{ij} to be a complex-valued membership degree. When the requirement is not satisfied, we need to normalise the initial assessment matrix X to meet the aforementioned two purposes. Hence, we give two possible normalised methods, named type-I and type-II.

Definition 1. Let $\Delta_{I,j} = \sum_{i=1}^n \|\tilde{x}_{ij}\|$, then the type-I normalisation of \tilde{x}_{ij} , $i = 1, \dots, n$, gives

$$\tilde{\tilde{x}}_{ij} = \frac{\tilde{x}_{ij}}{\Delta_I} \quad (9)$$

Definition 2. Let $\Delta_{II,j} = \|\sum_{i=1}^n \tilde{x}_{ij}\|$, then the type-II normalisation of \tilde{x}_{ij} , $i = 1, \dots, n$, gives

$$\tilde{\tilde{x}}_{ij} = \frac{\tilde{x}_{ij}}{\Delta_{II}} \quad (10)$$

Following Definition 1 and Definition 2, we can show that under both normalisations, the vector sum $\sum_{i=1}^n \tilde{\tilde{x}}_{ij}$ of normalised assessments $\tilde{\tilde{x}}_{ij}$, $i = 1, \dots, n$, is in the unit disc D_C .

3.4. Generation of weighted assessment matrix

This step aims at measuring the influence of each criterion c_j by importing its corresponding weight w_j into the normalised assessment matrix. For any $\tilde{\tilde{x}}_{ij}$, the weighted assessment is defined as $\hat{\tilde{x}}_{ij} = w_j \tilde{\tilde{x}}_{ij}$, $i = 1, \dots, n$, $j = 1, \dots, m$. Obviously, $\hat{\tilde{x}}_{ij} \in D_C$ and $\sum_{i=1}^n \hat{\tilde{x}}_{ij} \in D_C$.

3.5. Calculation and ranking of aggregated assessment

By Eq. (6) and the fact that $\sum_{i=1}^n \hat{\tilde{x}}_{ij} \in D_C$, we define the aggregated assessment $S_i = \sum_{i=1}^n \hat{\tilde{x}}_{ij}$. Once S_i is obtained, we can rank them by the partial order given in Eq. (8). This is a straightforward step.

4. Case study

4.1. Background

Chongqing is the fourth municipality of China. It is historically a heavy and military industry base because of its remoteness in geography. With the acceleration of China's National Western Development Strategy, more and more new economy forms have been developed in the past two decades. Small and medium-sized E-commerce enterprises have rapidly emerged in last 10 years. However, due to the inland location and limited volumes of products and services, these enterprises face numerous constraints on e-commerce development. In this study, we choose one typical enterprise as illustrative example to solve its development path selection issue. There are three potential paths for the enterprise to choose from. Path 1 is Whole course E-commerce model based on cloud computing. Path 2 is Location based service (LBS) model based on E-commerce integrator (E-integrator). Path 3 is third party market mode based on information technology. To make sure which path is the best for the enterprise, a third-partied consultancy has identified seven criteria to measure which are Core Strategy Management (c_1), Learning and Capability Development (c_2), Information and Communication Technology (ICT, c_3), Convenience and Security of Data Information (c_4), Cost (c_5), Product and Service (c_6), and Enterprise Stakeholders (c_7).

Regarding to each individual criterion, the consultancy defined its optimisation direction and weights for each alternative path which are listed in Table 1. In these seven criterion, two are negative. For cost (c_5) criterion, it is obvious that the less the cost, the better for the enterprise. For Enterprise stakeholders (c_7), we argue for the small enterprise,

the less the stakeholder, the easier for them to make new measures.

In these seven criterion, we argue that criteria c_2 , c_5 and c_7 are periodic. When the enterprise face a new circumstance, people need spend more time to learn it. With the increase in learning time, people are more and more skilled and therefore improve significantly work efficiency and increase adaptability. Finally everyone will get used to it. When facing new circumstance again, the same process repeats. So we argue learning and capability development (c_2) is a periodic criterion. According to the degree of learning difficulty, the paper define c_2 a $(0, \pi/2)$ periodic criterion. In enterprise development, cost (c_5) and stakeholder relationship (c_7) are affected by many factors and often depict periodic features. Hence the paper defines them as periodic criteria and assigns a $(0, \pi)$ period.

With respected to the seven criteria, evaluations on the three paths are given (see Table 2) based on underlying CFSs of those criteria.

Table 2. Initial assessment matrix (“+” = positive, “-” = negative).

Criteria	Direction	r_1	ϕ_1	r_2	ϕ_2	r_3	ϕ_3
c_1	+	2	0	3	0	1	0
c_2	+	1	0π	3	$\pi/3$	2	$\pi/6$
c_3	+	1	0	2	0	3	0
c_4	+	3	0	2	0	1	0
c_5	-	3	$\pi/2$	2	$3\pi/4$	1	π
c_6	+	3	0	2	0	1	0
c_7	-	1	$\pi/2$	3	$\pi/3$	2	$\pi/6$

In order to rank the potential paths, we apply the SME-C method. The ranking is conducted as follows:

Step 1: Normalise assessment matrix X

Let $X = (x_{ij})_{7 \times 3}$ be the initial assessment matrix given in Table 3.

Table 3. Initial assessment matrix in terms of Cardinal coordinate

criteria	Cardinal coordinate		
	a_1	a_2	a_3
c_1	$2 + 0i$	$3.000 + 0.000i$	$1.000 + 0.000i$
c_2	$1 + 0i$	$1.527 + 2.582i$	$1.731 + 1.002i$
c_3	$1 + 0i$	$2.000 + 0.000i$	$3.000 + 0.000i$
c_4	$3 + 0i$	$2.000 + 0.000i$	$1.000 + 0.000i$
c_5	$0 + 3i$	$-1.414 + 1.414i$	$-1.000 + 0.000i$
c_6	$3 + 0i$	$2.000 + 0.000i$	$1.000 + 0.000i$
c_7	$0 + 1i$	$1.527 + 2.582i$	$1.731 + 1.002i$

As discussed above, we use the type-I normalisation for illustration purpose. For $j = 1$,

$$\Delta_{I,1} = 2 + 3 + 1 = 6.$$

Hence, the type-I normalisation result is $0.400 + 0.000i$ (a_1), $0.333 + 0.000i$ (a_2), $0.267 + 0.000i$ (a_3). Similarly, we can calculate the normalised assessments for other criteria.

$$\begin{pmatrix} 0.333 + 0.000i & 0.500 + 0.000i & 0.167 + 0.000i \\ 0.167 + 0.000i & 0.254 + 0.430i & 0.289 + 0.167i \\ 0.167 + 0.000i & 0.333 + 0.000i & 0.500 + 0.000i \\ 0.500 + 0.000i & 0.333 + 0.000i & 0.167 + 0.000i \\ 0.000 + 0.500i & -0.236 + 0.236i & -0.167 + 0.000i \\ 0.500 + 0.000i & 0.333 + 0.000i & 0.167 + 0.000i \\ 0.000 + 0.167i & 0.255 + 0.430i & 0.289 + 0.167i \end{pmatrix}$$

Step 2: Generate weighted assessment matrix \hat{X}

Noted that $\hat{x}_{ij} = \tilde{x}_{ij} \cdot w_{ij}$, we get \hat{X} as below

$$\begin{pmatrix} 0.033 + 0.000i & 0.050 + 0.000i & 0.017 + 0.000i \\ 0.017 + 0.000i & 0.025 + 0.043i & 0.029 + 0.017i \\ 0.017 + 0.000i & 0.033 + 0.000i & 0.050 + 0.000i \\ 0.100 + 0.000i & 0.067 + 0.000i & 0.033 + 0.000i \\ 0.000 + 0.100i & -0.047 + 0.047i & -0.033 + 0.000i \\ 0.100 + 0.000i & 0.067 + 0.000i & 0.033 + 0.000i \\ 0.000 + 0.017i & 0.025 + 0.043i & 0.029 + 0.017i \end{pmatrix}$$

Step 3: Calculate aggregated assessment S_i

For each alternative, the aggregated assessment S_i is calculated based on Eq. (6). Here, we can simply add the weighted assessments for each alternative; therefore, they are shown in Table 4.

Table 1. Criteria for E-commerce development and predefined weights.

Criterion	Description	weight	Direction
c_1	core strategy development	0.1	positive
c_2	learning and capability development	0.1	positive
c_3	ICT	0.1	positive
c_4	convenience and security for data information	0.2	positive
c_5	cost	0.2	negative
c_6	product and service	0.2	positive
c_7	enterprise stakeholders	0.1	negative

Table 4. Aggregated assessment for each alternative path.

S_1	S_2	S_3
0.267+0.117i	0.220+0.133i	0.158+0.033i

Step 4: Rank alternative paths

Based on the aggregated assessments and Eq. (8), path a_1 is the best path and then followed by a_2 and a_3 .

4.2. Discussions and comparisons

In this section, we will compare the presented SME-C method with other two popular multi-criteria decision methods, i.e. the COPRAS and the TOPSIS. We choose these two methods because they have similar processing steps and they need to identify positive and negative decision direction which we can use the phase part of a complex-valued membership degree to imitate.

The COPRAS method is a widely-used multi-criteria decision making technique, which contains three main steps ³⁶: (1) normalises initial assessments regarding to each individual evaluation criterion; (2) calculates two optimisation indexes for each alternative based on criteria’ optimisation directions (decision directions); and (3) ranks alternatives based on an overall index calculated from optimisation indexes. These steps are briefly described below.

Suppose X is the initial assessment matrix

$$X = \begin{pmatrix} x_{11} & \cdots & x_{1m} \\ \vdots & \ddots & \vdots \\ x_{n1} & \cdots & x_{nm} \end{pmatrix} \quad (11)$$

then the normalised assessment \bar{x}_{ij} is given as

$$\bar{x}_{ij} = \frac{x_{ij}}{\sum_{k=1}^n x_{kj}}, \quad (12)$$

and the weighted assessment \hat{x}_{ij} is

$$\hat{x}_{ij} = \bar{x}_{ij} \cdot w_j, \quad (13)$$

for $i = 1, \dots, n, j = 1, \dots, m$.

After getting the weighted assessment matrix \hat{X} , the COPRAS needs to calculate optimisation indexes determined by the preferable optimisation direction of each criterion. A c_j is associated with one of two preferable optimisation directions, i.e., positive (the bigger the better, a.k.a. “optimisation direction is maximisation”) or negative (the smaller the better, a.k.a. “optimisation direction is minimisation”). Without loss of generality, let C^+ be the set of criteria with positive optimisation direction and C^- be the set of criteria with negative optimisation direction, then for each alternative $a_i \in A$ two optimisation indexes corresponding to C^+ and C^- respectively can be calculated as

$$S_i^+ = \sum_{c_j \in C^+} \hat{x}_{ij}, \quad S_i^- = \sum_{c_j \in C^-} \hat{x}_{ij}, \quad i = 1, 2, \dots, n \quad (14)$$

Using these two optimisation indexes, an overall ranking index Q_i is therefore calculated for each alternative a_i :

$$Q_i = S_i^+ + \frac{\sum_{k=1}^n S_k^-}{S_i^- \sum_{k=1}^n \frac{1}{S_k^-}}, \quad i = 1, 2, \dots, n \quad (15)$$

Finally, Q_i , ($i = 1, 2, \dots, n$) is used to rank alternatives. A higher Q_i means a better assessment on a_i .

By using the COPRAS method, we get a similar ranking with the following reference indexes (Table 5).

Table 5. Ranking result by COPRAS method.

	S^-	S^+	Q	rank
a_1	0.117	0.267	0.347	1
a_2	0.117	0.267	0.347	1
a_3	0.067	0.167	0.307	3

The TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) may be the most-used multi-criteria decision making method, which has many different extensions. TOPSIS has two main difference compared with the COPRAS method. The first one is the normalisation method used. TOPSIS adopts the vector-based normalisation, i.e.

$$\bar{x}_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^n x_{ij}^2}}$$

This normalisation is exactly the Type-II normalisation in the presented SME-C method. The second difference is how to get the ranking index. By TOPSIS, the index is calculated as

$$Q_i = \frac{d_{iw}}{d_{iw} + d_{ib}}$$

where

$$d_{iw} = \sqrt{\sum_{j=1}^n (\hat{x}_{ij} - \hat{x}_{wj})^2}, \quad d_{ib} = \sqrt{\sum_{j=1}^n (\hat{x}_{ij} - \hat{x}_{bj})^2}$$

$$\hat{x}_{wj} = \left\{ \max_{c_j \in C_-} \hat{x}_{ij}, \min_{c_j \in C_+} \hat{x}_{ij} \right\}, \quad \hat{x}_{bj} = \left\{ \min_{c_j \in C_-} \hat{x}_{ij}, \max_{c_j \in C_+} \hat{x}_{ij} \right\}.$$

By using the TOPSIS method, we get a similar ranking with the following reference indexes (Table 6).

Table 6. Ranking result by TOPSIS method.

	Q_i	rank
a_1	0.549	1
a_2	0.526	2
a_3	0.432	3

Our previous experiments indicate, the TOPSIS and the COPRAS methods can produce similar ranking in most situations. In this example, we get the same ranking using three different methods.

5. Conclusion

5.1. Summary

The purpose of this paper was to contribute towards an analytical understanding of E-commerce development path in SMEs. We summarised three development paths for SMEs, identified seven different criteria and evaluated them with CFS. Finally we compared the results with other two popular methods (COPRAS and TOPSIS).

5.2. Limitations and Suggestions for further study

It is inevitable that researchers deal with some limitations in their studies and the present study is no exception. These limitations set stage for future research.

Firstly, this study used a limited number of experts from a third-party consultancy. Future research may repeat this method using multiple experts to justify the validity of the study.

Secondly, it should be mentioned that understanding the barriers and drivers of SME-C implementation helps E-commerce to introduce costly effective practices. So, further research will attempt to focus on this issue.

Thirdly, this research has explored only one case study in a small E-commerce enterprise. Hence conclusions may not generally suit various companies and industries. Future works should conduct research related to investigation on E-commerce practices and performances in different sectors.

Finally, identifying weights and decision direction is an important issue in the evaluation of enterprise development strategy. In the presented work, we used a predefined weights and direction from the consultancy. We noted that this may include too much personal or subjective opinions and we could improve it by using pairwise comparison like that used widely in fuzzy AHP research area¹³. This

may require more discussion about how to efficient calculation on CFS. We will work on this in future work.

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Conflict of interest

The authors declare that there is no conflict of interests regarding the publication of this article.

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