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JUSTIFICATION OF THE OPTIMAL OPTION AND TRANSPORTATION PARAMETERS FOR EXPORT SUPPLIES USING MARINE TRANSPORT

The object of this research is transport provision of supplies using sea transport. The problem of increasing the efficiency of transportation of bulk cargo by bulk carriers or universal destination by optimizing the option and parameters of transport equipment is considered.

For categories of goods that are exported using sea transport, it is possible to use not only different options for transport equipment – own or leased (for vessels – time charter), but also different options from the point of view of the parameters of the vehicles. In this paper, the parameters are understood as the characteristics of sea vessels, on which the main economic indicators depend – deadweight, which reflects the size of the vessel and its carrying capacity for bulk carriers; as well as the age of the courts, which determines the cost of their rent and the level of operational costs.

The result of the research is an optimization model that allows to determine for each market a variant of transport equipment and its parameters. Model not only distributes deliveries according to transport options, but also determines which vessels of what size and age (for time charter) should carry out transportation. These results are focused on the exporter's decision-making process about sales markets in combination with decisions on transport provision before concluding contracts. Varying the size and age of the vessels makes it possible to consider a wider range of options from the point of view of parameters.

The practical use of the model allows the exporter at the stage of preparation (before the conclusion of contracts) depending on the volume of supplies and the market situation, including the freight one, to make decisions about options for transport support, which is taken into account when formulating transport conditions of contracts. Integral consideration of commercial (volumes of deliveries, transport terms of contracts), economic (price levels, freight rates, costs) and technological (size of vessels and their age) factors within the framework of the model allows taking into account the multifaceted nature of the problem of transport provision.

Keywords: *vessel deadweight, sea transportation, transport support, export production, sales logistics.*

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1. Introduction

Transportation is one of the mandatory components of any logistics system, which is present in every chain from the extraction of raw materials to the delivery of products to the final consumer. A significant part of the supply of such goods as grain, coal, ore, metal, fertilizers is carried out using sea transport. As a rule, such deliveries are served by bulk carriers or general purpose vessels, and in the process of transportation such goods are identified as «bulk cargoes».

Control of the exporter – manufacturer or trader – over the transport component of the logistics system determines, first of all, the possibility of effective coordination and more precise coordination of supplies, on the other hand, the possibility of ensuring a reduction in transport costs. That is why many large exporters include in their structures divisions or companies that not only organize, but also carry out transportation, including by sea. Similar examples were presented in [1].

Therefore, some exporting companies associated with the above-mentioned types of production have an alternative to provide sea transportation – a type of transport support. In this case, the type of transport means the form of the vehicle and the parameters of the vehicle [2] – for example, its size, age, other characteristics.

A sufficient number of publications are devoted to the justification of effective options for the transportation of bulk cargo, but, as a rule, the optimization of delivery routes is in the center of consideration [3–7]. Although most of the attention of researchers is focused on the delivery of small-lot cargoes, including the delivery of cargoes in containers [8–10]. Issues of transport logistics and transport support of logistics systems for mass cargo are much less often the object of research, however, examples of such works can serve [1, 11, 12].

Unlike, for example, motor vehicles, the cost of marine cargo vessels is quite high, and the risks of ownership are very significant. Therefore, the acquisition of own vessels to form control over logistics and provide advantages due to the transport factor is not available to many manufacturers or traders. Nevertheless, there are such examples, even of Ukrainian companies of the pre-war period.

A more common form of attracting sea vessels by exporters for independent use in the process of transporting export products is the time-charter vessel lease [13], which ensures the minimization of risks compared to the purchase of vessels. In [14] advantages and disadvantages of using this type of transport equipment are considered.

In [1] it is established that three approaches are used for the organization of transport support of distribution systems:

- first – the attraction of transport on the basis of contractual relations;
- second – long-term lease, leasing;
- third – related to the use of own transport by industrial and commercial enterprises. In the same source [1] it is substantiated that the specifics of sea transport is that the lease of vessels can be carried out on various conditions (bareboat charter, time charter, voyage charter). Thus, various options for transport support are formed, and some of them can serve as an alternative to the purchase of vessels, which is not typical for other types of transport.

It is natural that the choice of the variant of the organization of transport support in the considered context is influenced, first of all, by the size of deliveries. These issues were investigated in [1], where an optimization model was proposed for substantiating an effective variant of the transport provision of bulk cargo using sea transport depending on the size of annual deliveries.

The issues of transportation support of projects, including the transportation of project cargo by sea, were the object of research in works [2, 15], in particular, a model of optimization of the parameters of vehicles was proposed, ensuring the maximization of the value of the project under budget constraints. The proposed model uses the network graph of the project as a basis and considers the set of works involving transportation and the system effect as the result. Let's note that for the export of production, this approach requires a certain transformation and can be used at the level of an idea, since every export transaction must be effective.

Thus, today, in order to solve the problem of substantiating the effective option of transport support for export production using sea transport for the case of bulk cargo, there are certain scientific results that are related to certain aspects of this problem. Synthesis and further development of the results presented in works [1, 2, 14] may allow to obtain a theoretical basis for decision-making, which more fully covers various aspects of transport support for export deliveries of goods, which are bulk cargo from the point of view of sea transportation.

Based on the above, *the aim of this research* is to develop a mathematical model for optimizing the option and parameters of transport support for export production by sea vessels with bulk carriers or universal purpose.

Based on the aim, the following objectives are set:

1) determination of the main options and parameters of transport support and their influence on the level of transport costs for the export of bulk cargo using sea transport;

2) development of an optimization model for the comprehensive determination of options and parameters of transport support for multiple markets of the exporter.

2. Materials and Methods

According to [11], from the point of view of commercial conditions, the delivery of export products of the considered category with the participation of sea transport can be carried out as follows:

- exporters (producers or traders) do not undertake the organization and risks of sea transportation of products to buyers (importers), the sale of which in this case is carried out on delivery bases such as FCA (Free Carrier), FAS (Free Alongside Vessel Free on board), FOB (Free on Board);
- sellers assume the risks and responsibility for sea transportation, for example, CFR (Cost and Freight), CIF (Cost, Insurance and Freight) delivery bases are used.

The main variants of transport support, using sea bulkers or general-purpose vessels, are the following (taking into account the generalization [1, 2, 14]):

- option 1 – engagement of vessels for servicing deliveries under voyage charter (maximum responsibility of the carrier);
- option 2 – engagement of time-charter vessels leased for delivery services for the period of T^{t-ch} (six months/hour) – the risks of the carrier in this case are assumed by the exporter.

As the main parameters of transport support, let's take the main characteristics of vessels, on which the economic indicators depend – respectively, f^{v-ch}, f^{t-ch}, r^{op} – cost of use, cost of rent, operational costs – dead weight D and age t. The results of research on some of the specified indicators of dead weight and age, in particular, are presented in [15].

For example, taking into account the results of studies [15], the regularity that characterizes the dependence of time charter and voyage charter rates on deadweight can be presented in the form of power-law dependence:

$$f^{t-ch} = a_0(D)^{a_2},\ f^{v-ch} = l_0(D)^{l_2}. \quad (1)$$

Moreover, for various tonnage groups, the coefficients a_2, l_2, which determine the shape of the corresponding curve, can be both greater than and less than 1. The dependence of voyage charter rates on the distance of transportation is quite well described by a linear function, as follows:

$$f^{v-ch} = b_0 + b_1 \cdot L. \quad (2)$$

Taking into account the results of studies [15], all operating expenses of the vessel can be presented as:

$$r^{op} = k_1(D)^{k_2},\ 0 < k_2 < 1. \quad (3)$$

Since the cost of the vessel gradually increases with age, then to account for the aging of the vessel (3) can be specified as:

$$r^{op} = (k_1 + k_3 \cdot t) \cdot (D)^{k_2},\ 0 < k_2 < 1. \quad (4)$$

As for the effect of sea transportation distance L on vessel costs: the growth of L causes a proportional increase

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in operating variable costs, therefore, the dynamics of operating costs can be presented as follows:

$$r^{op} = s_1(L)^{s_2}. \quad (5)$$

Thus, all the main components of costs for transport options are functions of the vessel's parameters and/or the distance of transportation (Table 1).

Table 1

A theoretical type of dependence of the components of transport costs on the size and age of the vessel and the distance of transportation

Cost element	Analytical type of dependencies	
	From the distance of transportation L	From the parameters of the vessel D, t
Flight charter rate	$f^{v-ch} = b_0 + b_1 \cdot L$	$f^{v-ch} = l_0(D)^{l_2}$
Time charter rate	–	$f^{t-ch} = a_0(D)^{a_2}$
Operating expenses	$r^{op} = s_1(L)^{s_2}$	$r^{op} = (k_1 + k_3 \cdot t) \cdot (D)^{k_2}$

Fig. 1 presents in a generalized form depending on the dependence of individual economic indicators related to the export of production, on the deadweight of the vessel with other parameters being equal – the age of the vessel t, the volume of delivery Q. $C^{CIF}(Q)$ characterizes the export value when selling production in the amount of Q on *CIF* terms, taking into account purchase/production, that is, profit without taking into account the transport factor.

Naturally, in addition to the characteristics of the vessels, the effectiveness of each transport option is influenced by a number of different factors that are related to:

– or with the terms of the contract (volume and portion of deliveries, ports of departure and destination);
– or with the market situation (the level of freight rates, the price of a bunker) (Fig. 2).

Thus, a specific variant of transport provision with specified parameters, which may be effective for some market conditions, will be economically unfeasible for other conditions. The range of deadweight $[D_{min}, D_{max}]$, acceptable for this delivery is determined on the basis of their characteristics of the ports, route of delivery, portioning, which follows from the conditions of the contract (Fig. 2).

Let's note that Fig. 1 characterizes conceptually considered dependencies, however, in each specific case, the type of these dependencies is determined based on current market conditions and contract conditions (geography of transportation).

Thus, the decision to choose a transport option is made depending on what is more important – the benefits of using one's own vehicle or the costs associated with its temporary ownership (rental) and operation.

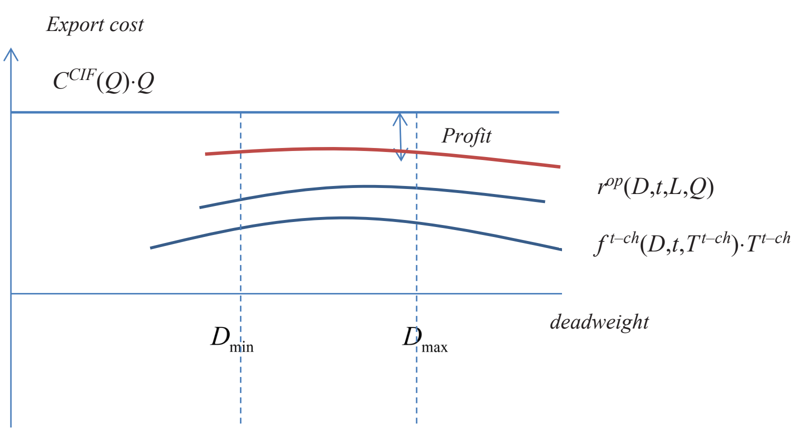

Fig. 1. Generalized type of dependencies of the components of transport costs for the option of renting a vessel in a time charter

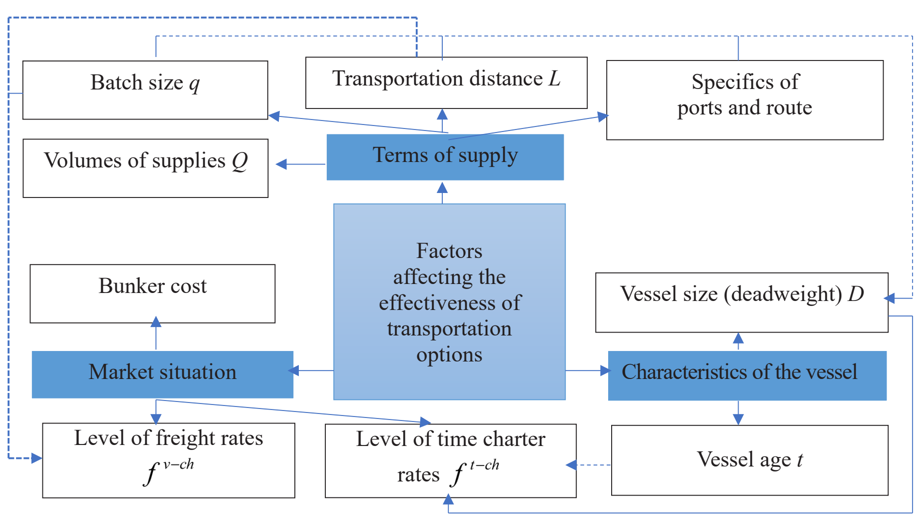

Fig. 2. Factors affecting the effectiveness of the option of transport support for foreign trade supplies using sea transport (for bulk cargo)

3. Results and Discussion

For a separate contract, dependencies based on the ideas expressed above can be found. But, as a rule, the exporter deals with many importers and the corresponding sales markets. This allows, for example, using one leased vessel on several transportation routes related to several markets. In this case, the problem of optimization of transport equipment must be solved comprehensively, for which it is proposed to use a mathematical model based on the ideas expressed in [1, 2, 11], as the development of these results taking into account the characteristics of the vessel.

Let's introduce the following notation:

– k – variant of transport provision, $k=\overline{0,2}$: $k=0$ – sea transportation carried out by the buyer, $k=1$ – voyage charter, $k=2$ – time charter;

– Q_{ik} – the volume of deliveries to the i-th market, $i=\overline{1,n}$ using the k-th variant of transport equipment; Q_i^* – restrictions on the possibilities of selling products on the i-th market; Q^* – limitation on the possibilities of production of products for sale on the considered markets; $R_i^{com}\left(\sum\limits_{k=0,1,2} Q_{ik}\right)$, $R_i^{prod}\left(\sum\limits_{k=0,1,2} Q_{ik}\right)$ – respectively, commercial and production costs associated with the delivery of products to the i-th market using various options for transportation;

– $C_{ik}(Q_{ik})$ is the selling price of goods on the i-*th* market using the k-th variant of the organization of transport support (without limiting the generality, let's consider that when $k=0$ the basis of FOB delivery is used, when $k=1,2$ – CIF);

– $f_i^{v-ch}(D)$ – voyage charter rate for the delivery of goods to the i-th market, dollars/t, $P_i(D)$ – the carrying capacity of the considered category of vessels in the direction of the i-th market for the considered period of time);

– $R_i^n\left(\sum\limits_{k=0,1,2} Q_{ik}\right)$ – cost of delivery to the port of departure for delivery to the i-th market, USD/t; $f^{t-ch}(D,t)$ – time charter rate, dollar/day; T^{t-ch} – time charter period, in the situation of annual planning, it is accepted as one year;

– $r_i^{op}(Q_{i2})$ – operating costs of the charterer for the vessel in the case of a time charter (in this case, the charterer pays the variable costs – bunker, port fees, passage of channels);

– $f_i^{v-ch}\cdot Q_i^r$ – the amount of freight for the transportation of cargo on a voyage charter in the opposite direction (towards the market) – in fact, additional income due to the commercial use of the vessel for the period of the time charter, in the time free from the main traffic. Let's assume that:

$$Q_i^r=\gamma\cdot\lambda_{i2}\cdot P_i(D,t),$$

where γ is the coefficient that takes into account the probability of reverse loading of the vessel on the considered direction; λ_{i2} is the share of the time of operation of the vessel (vessels) in the direction of the i-th sales market when renting in a time charter (the second option of transport provision); N is the maximum allowable number of vessels leased in time charter – a limit set by the company's management.

As a criterion of optimality, let's accept profit, which, in contrast to the simple minimization of transport costs, allows taking into account the additional income of the exporter as a «temporary shipowner» in the case of a time charter lease:

$$\begin{aligned}\mathrm{Pr}=\sum_{i=1}^{n}\Bigg[&\sum_{k=0,1,2}\big(C_{ik}(Q_{ik})\cdot Q_{ik}-R_{ik}(Q_{ik},D,t)\big)-R_i^n\left(\sum_{k=0,1,2}Q_{ik}\right)-\\&-R_i^{prod}\left(\sum_{k=0,1,2}Q_{ik}\right)-R_i^{com}\left(\sum_{k=0,1,2}Q_{ik}\right)+\mathrm{Pr}_i^{ad}(D,t,\lambda_{i2})\Bigg]-\\&-R^{t-ch}\left(\sum_{i=1}^{n}\lambda_{i2}\right)\to\max_{Q_{ik},D,t,\lambda_{i2}},\end{aligned}\tag{6}$$

where $R_{ik}(Q_{ik},D,t)$ is the costs of sea transportation when delivering products to the i-th market using the k-th option of transport equipment:

$$R_{i0}(Q_{i0},D,t)=0,\tag{7}$$

$$R_{i1}(Q_{i1},D,t)=f_i^{v-ch}(D)\cdot Q_{i1},\tag{8}$$

$$R_{i2}(Q_{i2},D,t)=\lambda_{i2}\cdot f^{t-ch}(D,t)\cdot T^{t-ch}+r_i^{op}(Q_{i2},D,t),\tag{9}$$

where $\mathrm{Pr}_i^{ad}(D,t)=f_i^{v-ch}(D)\cdot Q_i^r-r_i^{op\_ad}(Q_i^r,D,t)$ is additional profit due to the commercial use of the time chartered vessel (vessels), namely, due to the provision of transportation services in the opposite direction from the market; $R_i^{op\_ad}(Q_i^r)$ is additional costs associated with cargo transportation in the opposite direction – additional bunker, port costs.

$R^{t-ch}\left(\sum\limits_{i=1}^{n}\lambda_{i2}\right)$ is adjustment of costs related to time charter – in (9) the share of the vessel's working time in a certain market is used, but in fact the vessel may not work for some time, and the payment of the time charter is made for the entire period under consideration:

$$R^{t-ch}\left(\sum_{i=1}^{n}\lambda_{i2}\right)=f^{t-ch}(D,t)\cdot\left(\left\lceil\sum_{i=1}^{n}\lambda_{2,i}\right\rceil-\sum_{i=1}^{n}\lambda_{2i}\right)\cdot T^{t-ch},\tag{10}$$

where $\left\lceil\sum\limits_{i=1}^{n}\lambda_{2,i}\right\rceil$ is rounding to a larger whole. Let's note that, $\left\lceil\sum\limits_{i=1}^{n}\lambda_{2,i}\right\rceil\geq 1$ that is, several vessels can be taken into the time charter within the maximum possible number N.

Control parameters – model variables – are: Q_{ik} is the volume of deliveries to the i-th market, for which the k-th option of transport equipment is used with parameters D, t, characterizing the deadweight of the vessel and its age (for the time charter option). Thus, the model not only distributes deliveries according to transport options, but also determines which vessels of what size and age (for time charter) should carry out transportation. Limitations of the model take into account the requirements:

– according to demand – delivery possibilities – for every market:

$$\sum_{k=0,1,2}Q_{ik}\leq Q_i^*,\ i=\overline{1,n};\tag{11}$$

– according to the exporter's general capabilities:

$$\sum_{i=1}^{n}\sum_{k=0,1,2}Q_{ik}=Q^*;\tag{12}$$

– by the number of vessels leased in time charter:

$$\left[\sum_{i=1}^{n}\lambda_{i2}\right]\leq N; \tag{13}$$

– by deadweight of vessels:

$$D_{\min}\leq D\leq D_{\max}; \tag{14}$$

– according to the carrying capacity of vessels taken on time charter:

$$Q_{i2}=P_i(D,t)\cdot\lambda_{i2}, i=\overline{1,n}. \tag{15}$$

Since profit maximization does not provide the necessary profit level, the model should be supplemented with restrictions on the profit level for each market:

$$\mathrm{Pr}_i=\left[\sum_{k=0,1,2}\left(C_{ik}(Q_{ik})\cdot Q_{ik}-R_{ik}(Q_{ik},D,t)\right)-R_i^n\left(\sum_{k=0,1,2}Q_{ik}\right)-\right.$$
$$\left.-R_i^{prod}\left(\sum_{k=0,1,2}Q_{ik}\right)-R_i^{com}\left(\sum_{k=0,1,2}Q_{ik}\right)+\mathrm{Pr}_i^{ad}(D,t,\lambda_{i2})\right]-$$
$$-R^{t-ch}\left(\sum_{i=1}^{n}\lambda_{i2}\right)\geq\mathrm{Pr}_i^{\min}(i=\overline{1,n}). \tag{16}$$

And also the model includes the conditions of non-negativity of the variables:

$$Q_{ik}\geq 0, i=\overline{1,n};\ k=0,1,2; \tag{17}$$

$$0\leq t\leq t^{\max}. \tag{18}$$

Let's note that λ_{i2} are auxiliary parameters and are used in the model to simplify the recording of the target function and some constraints.

Experimental studies confirmed the reliability of the obtained results and their correspondence to real decision-making processes, that is, the optimization results reacted accordingly to changes in the input data. In particular, in Fig. 3 shows the dependence of the number of leased vessels for transport support under the control of the exporter on the level of the lease rate – the results logically reflect a decrease in the number of vessels with an increase in the cost of their lease.

Let's note that in this study it is accepted that vessels of the same (optimal) size are used. A natural development and complication of the model may be the consideration of different court sizes for different markets, which will be the subject of further research.

The practical significance of the obtained results is that the use of the proposed model allows the exporter to make decisions about options for transport support before concluding contracts, depending on the volume of supplies and market conditions, including freight, which is taken into account when formulating transport conditions of contracts. Integral consideration of commercial (volumes of deliveries, transport terms of contracts), economic (price levels, freight rates, costs) and technological (size of vessels and their age) factors within the framework of the model allows taking into account the multifaceted nature of the problem of transport provision. All this is aimed at increasing the efficiency of foreign trade.

The limitation of the use of these results is the volume of deliveries, which must be justified in each specific case. But, as a rule, the main exporters of grain, ore, and metal have such volumes of supplies that consideration of alternative transport options is expedient.

It is natural that the military situation and the current situation make it practically impossible to export metal, ore, fertilized by the sea. The only product that is currently exported using sea transport is grain (within the «grain corridor»), therefore, until the end of martial law, only for this category of export goods can the proposed developments be applied.

4. Conclusions

It is shown that for some categories of goods that are exported using sea transport, various options for transport support are possible. These options are associated with the use of, for example, time chartered vessels. Vehicle parameters are also subject to variation. In this paper, the parameters are understood as the characteristics of sea vessels, on which the main economic indicators depend – deadweight, which reflects the size of the vessel and its carrying capacity for bulk carriers; as well as the age of the courts, which determines the cost of their lease, the level of operational costs.

To solve the problem of complex determination of options and parameters of transport equipment for multiple deliveries to multiple markets, an optimization model is proposed that allows determining the option of transport equipment and its parameters for each market.

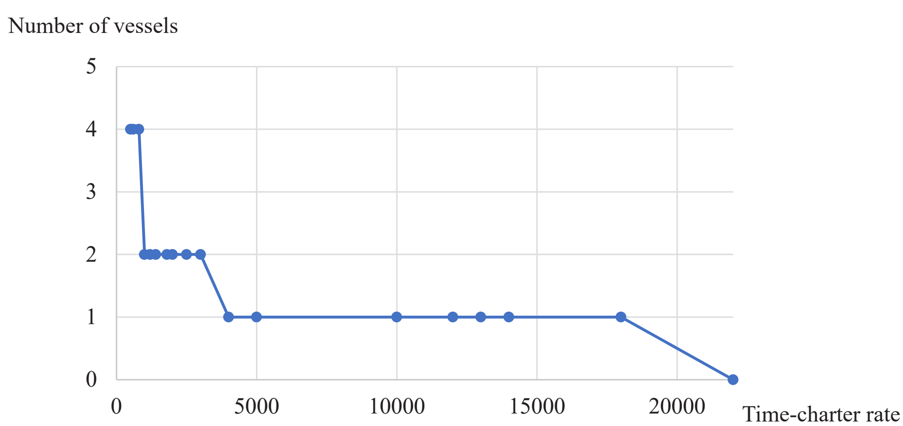

Fig. 3. The number of vessels leased in time charter depending on the level of the lease rate $f_i^{t-ch}(D,t)$ for an optimal solution

It is noted that the proposed model not only distributes deliveries according to the options of transport equipment, but also determines what size and age vessels (for time charter) should carry out transportation. These results are focused on the exporter's decision-making process about sales markets in combination with decisions on transport provision before concluding contracts. Varying the size and age of the vessels makes it possible to consider a wider range of options from the point of view of parameters.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data availability

The manuscript has no associated data.

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