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Market interactions between agricultural commodities and the dry bulk shipping market

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ABSTRACT

We investigate and quantify the relationship between agricultural commodities and ocean-going freight rates, using a weekly dataset from 2010 to 2019 and a Vector Error Correction Methodology. The results are firstly supportive of the view that vessel classes are highly interconnected, and secondly confirm that commodity prices can have a strong impact on freight rates across most vessel classes. For commodities in which no impact is registered on freight rates, the possibility of substitution effects exists. Furthermore, the results indicate that the markets in which these products trade can be a significant determinant of future freight rate movements. These findings can be particularly useful for agricultural businesses that are concerned with the transportation cost of their products and the ways that the latter can be mitigated.

1. Introduction

The interrelation between the price of agricultural commodities and the freight rates that farmers will be faced with is a topic that has been of interest both for the academic community and the practitioners for a long time (Hibbard, 1922). However, the increased connectivity that exists in today's world, due to the increase of speed in transportation (Stopford, 2013) and the boosted globalization of trade (Stiglitz, 2002) have lead the agri-businesses to encounter the excess volatility of transportation costs (Kavussanos & Alizadeh-M, 2001).

Thus, both agricultural businesses and individual farmers have to pay a significant proportion of their total expenses for transportation purposes. However, its inherent volatility makes any forecast scenarios highly difficult to implement (Schnepf, 2006; Volpe, Roeger, & Leibtag, 2013). Still, the price of agriculture commodities is not irrelevant to the prices of the vessel freight rates that will transport them. The research of Kilian and Zhou (2018) shows that commodities are not only highly related to the bulk shipborne trade, but can act as a leading indicator for the world economy. In a similar manner, the research of Tsioumas and Papadimitriou (2018) provides evidence that commodities are an intrinsic part of the world economy and thus any changes that would occur in commodities will eventually be reflected to the shipping freight rates of the ocean-going vessels.

In the current research, we employ a risk-oriented approach on theorizing on the connection that exists between commodities and freight rates. More precisely, as suggested by Kristiansen (2004), risk is the product of probability of an undesirable event multiplied by the legal, human, or economic consequences of it. Thus, the price of the goods will have an effect on the freight rates given the higher risk that shipowners will be faced with given the occurrence of an unfavorable event. Based on the latter, the prices of commodities will eventually lead the shipowners to adjust the freight rates that they demand as the risk will adjust accordingly.

While a lead-lag relationship has been documented by previous researches (Angelopoulos, Sahoo, & Visvikis, 2020; Yu, Bessler, & Fuller, 2007; Kavussanos, Visvikis, & Dimitrakopoulos, 2014) between commodities and freight rates of the ocean-going vessels,

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there has not been a precise investigation on agricultural products, per se. Thus, the current research contributes to the literature by looking into the precise nature of the relationship between agricultural commodities, namely cocoa, coffee, rice, soybean, wheat, and ocean freight rates by employing a weekly dataset of 10 years.

The current paper acts as an exercise that further enhances the previous findings of the literature by employing an alternative econometric approach and disaggregated prices for the agricultural commodities. In particular, while previous studies have already documented on the relationship and the leading character that commodity prices have on dry bulk freight rates, both for their spot as their forward prices, (Angelopoulos et al., 2020; Tsioumas & Papadimitriou, 2018), we provide a more detailed research on the nature of the agricultural commodities transportation trade. By using Trip Charter freight rates, specifying the trading routes which are mostly used for the transport of agricultural commodities, employing an alternative econometric tool and analyzing the relationship between each of the examined commodities with all vessel classes used for such routes, the paper enhances our knowledge on the specific characteristics of each trade. As such, the paper, in addition to confirming the relationship between commodities and freight rates using a methodology which has not been previous employed for such purposes, also provides an in-depth assessment of the specificities of the commodity prices-freight rates nexus that can be used by both academics and professionals.

For our research, initially, we employ a Granger causality test so as to confirm that agricultural commodities have a direct relationship with the shipping freight rates of the all the vessel classes. Subsequently, we test for the presence of co-integration between our variables and we also offer a quantification of the system response to an exogenous price shock in agricultural commodities, e.g. due to better or worse weather conditions. Finally, we perform a variance decomposition analysis for our vector error correction model so as to provide a further tool which will help us understand the extent of the penetration of agricultural prices on freight rates and how it could potentially evolve through time.

The current research has implications for both academics and practitioners since it provides an in-depth analysis on one of the major costs that agricultural businesses face, namely, the transportation cost via sea. The latter acts as a steppingstone for the decision-making process of the agricultural company's management given the various options that they may have to hedge their transportation risks.

Following this introduction, the remainder of this paper is organized as follows: Section 2 provides a review of the literature on the issue, Section 3 describes the methodology and data used, Section 4 discusses the empirical results obtained, and Section 5 concludes on the findings.

2. Review of the related literature

Commodities are the cornerstone of the production activity globally since they have been ultimately the key elements that are either consumed or transformed by the secondary economic sector. Nevertheless, commodities are rarely extracted from the area that will be further processed. Thus, world trade has a crucial role in the movement of commodities, especially as globalization in trade has increased in the most recent years (Michail, 2018). Furthermore, recent evidence shows that unexpected shifts in the real world trade activity have an effect on the booms and busts of commodity prices (Kilian & Hicks, 2013; Jacks & Stuermer, 2018; Kilian & Park, 2009; Kilian, 2009).

Commodities can be distinguished in four different categories: (i) energy commodities, which include hydrocarbon fuels, natural gas, and coal, and are transported in bulk amounts, either with tankers or LNGs or bulk carriers, (ii) base metallic commodities, like iron, copper, and aluminium, are transported with bulk carriers, (iii) precious metallic commodities, that include gold, silver, and platinum, which are transported with containerships, and (iv) agricultural commodities which are transported in bulk, mostly by dry bulk vessels, and to a lesser extent by containerships. Agricultural commodities can be categorized in two groups, grains and soft commodities (Ahn, 2018). In the current paper we elaborate on grain commodities because they account for the biggest part of the agricultural trade, but also because they have a close interrelationship with the world economy (Tsioumas & Papadimitriou, 2018).

Agricultural commodities are mainly transferred by Handymax, Supramax, and Panamax vessels and are chartered in the spot market (Kavussanos & Alizadeh-M, 2001). The reason for the latter is the seasonality of the agricultural production and the difficulty of piling the commodities for long periods due to their perishability. On the contrary, metal commodities like iron ore, do not exhibit any seasonality and thus transportation can be managed more efficiently in the long run. Thus, capesize vessels are mainly used for the transportation of iron ore and the charterparties used and mainly time charters (Kavussanos & Alizadeh-M, 2001). For the interested reader, Appendix A gives an outline of the trade routes of the commodities that we are examining in the current paper.

When it comes to supply and demand of commodities, their fungibility and perfect substitution make them highly tradeable and interlinked with the world markets (Tsouknidis, 2016). Creti, Joëts, and Mignon (2013) provide more detailed evidence on the link between commodities and the stock markets. In their research, which covers the period between 2001 and 2010, they use a two-step maximum likelihood method to estimate the conditional correlation between S&P 500 and the Commodity Research Bureau prices' returns and the spot price of 25 different commodities which are traded in the markets. They show that oil, coffee and cocoa have higher correlation during boom period with the S&P 500 index while during the bust era they exhibit lower correlation. Nevertheless, commodities are not only affecting financial markets but, moreover, they have an effect on the prices of their means of transportation. There is number of researches that are documenting this relation but still the results have not answered all the academic questions that such a relationship arises.

One stream of research is focusing primarily on the river-going vessels and their relation to agricultural commodities. Haigh and Bryant (2001) show that both barge and ocean freight volatility influence grain prices. Likewise, Isbell, McKenzie, and Wade Brorsen (2019) explore the connection between barge forward contracting rates and the grains transported through the Mississippi. Wetzstein et al. (2020) have also looked into the same route of transportation but contrary to Isbell et al. (2019), they employ a spatial vector autoregressive model and structure a forecasting model for the rates of barges that outperforms the previous models.

When it comes to the ocean-going vessels, Kavussanos, Visvikis, and Dimitrakopoulos (2010) have revealed the link that exists between commodities derivative markets and the shipping freight forward agreements of Panamax vessels. More precisely, in their research which ranges from 2005 until 2008, they show that grain futures (corn, wheat and soybeans) are important factors for the financial behaviour of the shipping FFAs, since they precede both in terms of returns and in volatilities. In an extension of their research Kavussanos et al. (2014), show additional evidence on the relation between derivatives of commodities and freight rates.

When it comes to the returns, while Panamaxes and Supramaxes have unidirectional spillovers with commodities. As far as volatility is concerned, uni-directional volatility spillovers are apparent in all vessel classes, while commodity derivatives seem to be affecting freight derivatives rather than the opposite. Likewise, the previous study by Yu et al. (2007), provides evidence on the relationship between corn markets and the freight rates in the US Gulf region.

On a different stream of literature, Hélyette and William (2012), provide a technique that farmers and cooperatives in the grains business can use to hedge their risk exposure by using spot price models. More recently Angelopoulos et al. (2020) have explored extensively the relation between freight rates and commodities. When it comes to the agricultural commodities though their results are inconclusive. On the contrary to prior research they provide evidence that agricultural commodities are leading the relationship. More precisely, Soybeans, rice and sugar are led by the freight rates of Supramaxes while wheat is leading the freight rates by 0.7 months.

Research up to now has proved that commodity prices affect freight rates of ocean-going vessels, since shipping is the most cost-effective way for their transportation. Their leading informational role has been documented by Yu et al. (2007); Kavussanos et al. (2010) and Angelopoulos et al. (2020) both for spot and future prices. Our paper contributes to this strand of the literature by offering the use of an econometric methodology that had not been used in studies of a similar topic and, in addition, serves as an in-depth exercise that can be used both from market practitioners and academics that wish to study fully the particular trades and relationship in general. Our results show that while as a whole, the prices of agricultural commodities strongly affect freight rates, with some commodities registering bigger effects than others.

In particular, using weekly data from 2010 to 2019 and a Vector Error Correction Methodology, we confirm that, firstly, bulk carrier rates have a strong connection between them as changes in one can strongly affect the other. Second, we find that some vessel classes are more affected than others. For example, Handymax vessel rates are more directly affected by agricultural prices than Panamax or Supramax ships, while the system responses suggest that the latter two vessels are more permanently affected by coffee price changes. Some commodities even appear to have inverse effects depending on the class: for example, an increase in cocoa prices has a small positive reaction on Panamax, a larger effect on Supramax, and a negative effect on Handymax, suggesting the importance of a substitution effect between different categories of commodities. Similarly, wheat appears to have a positive impact on Supramax and Handymax rates, but a negative one on the other two.

3. Methodology and data

The general Vector Error Correction specification, following Johansen and Juselius (1990) is defined as:

$$\Delta M_{j,t} = \alpha_{1,0} + \sum_{i=1}^{p} \beta_{1,i,j} \Delta M_{j,t-i} + \sum_{k=1}^{K-1} \sum_{i=1}^{p} \gamma_{k,i,j} \Delta \boldsymbol{W}_{t-i} + \delta_j \left(M_{t-1} - \theta_{1,j} \boldsymbol{W}_{t-1} - \theta_{0,j} \right) + \varepsilon_{j,t} \tag{1}$$

where the total number of variables is K, $M_{j,t}$ is the natural logarithm of variable j, and $\boldsymbol{W}_t$ is a $(K-1 \times N)$ matrix that contains all variables included in the estimation, other than variable *j*. Δ is the first difference operator, while. $\beta_{i,i,j}$ and $\gamma_{k,i,j}$ refer to the own and other variable coefficient values in the estimations, with *j* again signifying that the coefficient refers to the equation identified with variable *j*, while *k* refers to the specific variable within matrix $\boldsymbol{W}_t$. $\varepsilon_{j,t}$ refer to the error processes in each equation. The long-run relationship between the two variables is found within the brackets of Eq. (1) with δ_j determining the speed of adjustment to the long-run equilibrium.[1]

Matrix $\boldsymbol{W}_t$ consists of K = 8 variables, and more specifically, the weekly Trip Charters[2] for three vessel classifications (Supramax, Panamax, Handymax), and the weekly average of the major dry bulk agricultural commodities transported via the sea (Cocoa, Coffee, Rice, Soybean, Wheat). All the shipping related data were obtained from Clarksons Shipping Intelligence Network while data for commodity prices were obtained from the Federal Reserve of St. Louis Database. The data ranges from October 29, 2010 to August 02, 2019, with a total of 427 observations. A similar set of variables, however using Time Charter rates was used for robustness purposes.[3] A table with variable details can be found in Appendix B, while, as also mentioned before, Appendix A offers details on the main routes of the Trip charter routes employed.

Table 1 presents the descriptive statistics of the variables employed in the estimation. As expected, the freight rates are related to the size of the vessels, since the Handymaxes are having the lowest mean and median prices of freight rates during the period. We should also mention the particularly high standard deviation that is exhibited by the freight rates especially when compared to those of the agricultural commodities.

To empirically examine whether a long-run relationship exists between the set of variables employed in the estimation, we need to first test for the existence of a cointegrating relationship. In other words, there needs to be an empirical justification for the use of the term in the brackets. However, before we are able to perform the Johansen test for cointegration we first need to establish that both variables are I(1), i.e. they follow a unit root process (for more details see Hendry & Juselius, 2000, 2001). Table 2 presents the results from such an estimation.

In particular, in Table 2, we test for the presence of a unit root using both the Augmented Dickey–Fuller test (Dickey & Fuller, 1979; Mackinnon, 1996) and the Philips and Perron (1988) tests at the levels and the first differences. The main difference between the two tests is that the first uses a parametric approach based on the residuals while the second is nonparametric. The results suggest that there is evidence of a unit root in all the tested variables given that neither test rejects the unit root hypothesis. The fact that the series are I(1) is confirmed in the lower panel of Table 2 as the null of a unit root is rejected in the first differences of the variables. As such, given that both variables follow a unit root process, we can proceed with testing for a cointegrating relationship.

Using the Johansen (1991) method, we test for the presence of a cointegrating relationship in a vector autoregressive setup. The rank of the error-correction matrix δ is found to be one in both the maximum eigenvalue and the trace tests, hence confirming the existence of one co-integrating relationship (Table 3). Following the Granger representation theorem (Engle & Granger, 1987),

[1] The long run, as per Johansen and Juselius (1990), refers to the equilibrium relationship between the variables, i.e. one that would be reached in the absence of any external shocks. Similarly, short run refers to the fluctuations which take place and allow for deviations from the equilibrium value. As such, the terms “long run” and “short run” do not refer to any predetermined time period – it is simply how econometricians refer to these relationships, derived from theoretical models which define the long run as a period with no shocks.

[2] After reviewers' suggestion, we are using for our primary analysis trip-charter rates as they have many common characteristics with spot charter rates, given that they are both not affected by factors such as the timeframe of the hire, and are both reflective of current economic conditions. While we acknowledge that spot prices would have been more relevant for the current research, the lack of information regarding different spot freight rates for various trade routes acts as a limitation for our research.

[3] Since the scope of the current research was to fully examine the effect that commodity prices have on shipping, we have also examined the relation that the latter have on the earnings of bulk carriers. The results are available upon request.

Table 1
Descriptive statistics.

	Handymax	Panamax	Supramax	Cocoa	Coffee	Rice	Soybeans	Wheat
Mean	8828	11246	10528	2595	152	13	1134	573
Median	8750	11250	10500	2530	138	12	1031	525
Maximum	15500	23125	19250	3718	293	18	1746	911
Minimum	4500	5275	4750	1814	89	9	821	393
Std. Dev.	1961	3245	2582	424	46	2	230	131
Skewness	0.19	0.40	0.22	0.13	1.13	0.17	0.55	0.74
Kurtosis	3.03	3.15	3.03	1.89	3.50	1.74	2.04	2.58
J–B	2.59 (0.27)	11.8 (0.0)	3.51 (0.17)	22.98 (0.0)	95.81 (0.0)	30.23 (0.0)	37.84 (0.0)	42.43 (0.0)
Obs	427	427	427	427	427	427	427	427

Notes: Mean, median, maximum, and minimum values are in dollars. See Appendix B for definitions of variables. Min and max are the minimum and maximum values of the sample data, respectively. Skewness and kurtosis are the estimated centralized third and fourth moments of the data. J–B is the Jarque and Bera (1980) test for normality; the statistic is χ^2 distributed. Numbers in parentheses (.) report p-values.

Table 2
Unit root tests.

Variable	ADF	PP
Levels:		
$\ln Supramax_t$	−2.32	−2.53
$\ln Handymax_t$	−2.31	−2.52
$\ln Panamax_t$	−2.60	−2.59
$\ln Cocoa_t$	−2.39	−2.21
$\ln Coffee_t$	−1.60	−1.44
$\ln Rice_t$	−1.88	−1.84
$\ln Soybean_t$	−1.38	−1.40
$\ln Wheat_t$	−1.84	−1.80
First differences:		
$\ln Supramax_t$	−12.05[a]	−19.87[a]
$\ln Handymax_t$	−11.35[a]	−17.87[a]
$\ln Panamax_t$	−16.20[a]	−16.18[a]
$\ln Cocoa_t$	−17.80[a]	−17.60[a]
$\ln Coffee_t$	−20.73[a]	−20.87[a]
$\ln Rice_t$	−15.69[a]	−18.16[a]
$\ln Soybean_t$	−20.13[a]	−20.12[a]
$\ln Wheat_t$	−20.12[a]	−20.18[a]

Notes: Δ is the first difference operator. Critical values are from Mackinnon (1996).
[a] Indicates rejection of the unit root null and significance at the 1% level.

if two variables are cointegrated, then at least one variable should Granger-cause the other. As such, the use of a VEC model is justified by the data generating processes. The following section presents the results from the estimation of Granger causality, a VECM and the variance decomposition.

4. Market interactions in the dry bulk market

4.1. Pairwise granger causality tests

Before we proceed with the estimation of the VECM, we first test for pairwise Granger causality, i.e. whether a variable is useful in forecasting another. This measure of pseudo-causality, first proposed by Granger (1969), is an indication of whether a variable has a long-term relationship with another. It should be noted that Granger-causality is a measures of direct causality, i.e. a one-to-one relationship, and does not account for potential spillovers.

As already shown in the previous section, since the variables appear to have a cointegrating relationship, then at least some variables will Granger-cause some others (Engle & Granger, 1987).[4] As the name of the test suggests, it is conducted only between two variables, where we employ the lags of X to examine whether the independent variable is suitable for predicting the dependent variable, once the lags of the dependent variable are taken into consideration. Table 4 below provides the results from the Granger causality exercise, which is conducted through an F-test. To ease the reader, the p-values are also provided in the parenthesis below the F-test value. Own tests are naturally omitted.

As the table suggests, commodity prices have a bearing on bulk carrier prices, with Handymax being the category which is mostly impacted by agricultural commodity prices. This is particularly relevant to the agricultural trade, given that the Handy category is the one with the smallest vessel sizes, and as such would be more useful for the transport of crops. Soybeans appear have a bi-directional relationship with Handymax vessels, meaning that not only do soybean prices affect freight rates, but freight rates also affect soybean prices. Soybeans are the commodity most affected by freight rates, and Panamax rates affect it as well. Intra-commodity effects are rare, as only coffee affects the cocoa price.

Overall, the results suggest that a direct relationship between commodity prices and freight rates exists. Still, as already suggested, while Granger causality is important in determining a direct causal relationship between the variables, it is essential to examine whether second round, or indirect effects can potentially impact the relationship. To this end, the following section offers the impulse responses from the system of equations.

4.2. VECM impulse responses

Figs. 1 and 2 present the impulse response functions from the estimation of Eq. (1), for trip charters.[5] Impulse responses measure the change in variable A, following an exogenous shock in variable B, which is allowed to flow through the entire system of equations. For example, a massive scrapping of Supramax vessels would be one which would lead to an increase in Supramax charter rates, but is at the same time independent from the developments in commodity prices. Similarly, an increase in commodity prices related to higher demand for that commodity, or an increase in commodity prices related to shortages in supply due to unfavourable weather conditions, are again examples of exogenous shocks forcing the price to increase but are at the same time irrelevant to the movements of the freight rate market.

The first thing we would like to note is that vessel carrier rates have a strong connection and changes in one can strongly affect the other. In particular, an increase in Supramax carriers freight rates would cause an increase in Panamax vessel rates, as well as in Handymax charter rates. The lowest responses are recorded in

[4] For this reason, we have not opted for testing for Granger causality in a VECM framework. According to the Granger representation theorem, if some variables are cointegrated then they also are Granger-causing each other and vice versa. Hence, the presence of cointegration makes testing for Granger causality redundant in the VECM framework.

[5] Robustness checks using time charters, as well with different sample sizes for trip charters were also conducted but not presented here. These are available upon request.

Table 3
Cointegration results.

Null	Max eigenvalue test	Critical value (5% level)	Trace test	Critical value (5% level)
Rank = 0	52.62[a]	52.36	160.48[a]	159.52
Rank = 1	29.63	46.23	108.13	125.62
Rank = 2	22.14	40.07	72.96	95.75

Notes: Critical values are taken from Mackinnon, Haug, and Michelis (1999).
[a] Indicates the rejection of the null hypothesis of the hypothesized number of cointegrating equations at least at the 5% level of significance.

Table 4
Pairwise granger causality results.

	Supramax	Handymax	Panamax	Cocoa	Coffee	Rice	Soybean	Wheat
Supramax		3.07[c] (0.00)	1.54[a] (0.10)	0.97 (0.47)	1.13 (0.33)	0.96 (0.48)	0.43 (0.93)	0.89 (0.54)
Handymax	2.15[c] (0.01)		1.09 (0.36)	0.22 (0.99)	0.95 (0.49)	0.54 (0.88)	2.11[b] (0.02)	1.46 (0.13)
Panamax	2.14[c] (0.01)	3.24[c] (0.00)		0.54 (0.88)	1.16 (0.31)	0.94 (0.51)	1.63[a] (0.08)	0.82 (0.62)
Cocoa	0.65 (0.79)	1.78[b] (0.05)	0.70 (0.75)		1.54[a] (0.10)	1.31 (0.21)	1.44 (0.15)	0.94 (0.51)
Coffee	0.81 (0.64)	1.93[b] (0.03)	1.34 (0.19)	1.17 (0.30)		1.19 (0.28)	0.91 (0.54)	1.13 (0.33)
Rice	0.66 (0.79)	1.42 (0.15)	0.60 (0.83)	0.95 (0.49)	0.60 (0.84)		1.33 (0.20)	0.97 (0.47)
Soybean	1.12 (0.34)	2.63[c] (0.00)	0.73 (0.72)	0.97 (0.48)	1.23 (0.25)	1.41 (0.16)		0.98 (0.51)
Wheat	1.01 (0.44)	1.35 (0.19)	0.63 (0.82)	0.136 (0.18)	1.29 (0.21)	0.81 (0.64)	1.51 (0.12)	

Notes: The table offers the results from the pairwise Granger causality test, with automatic lag selection for each pair. For example, cocoa-capsize reports whether a change in the price of cocoa has a direct impact on capsize freight rates, while capsize-cocoa reports whether a change in freight rates has a direct impact on the price of cocoa.
[a] Denotes significance at 10% level.
[b] Denotes significance at 5% level.
[c] Denotes significance at 1% level.

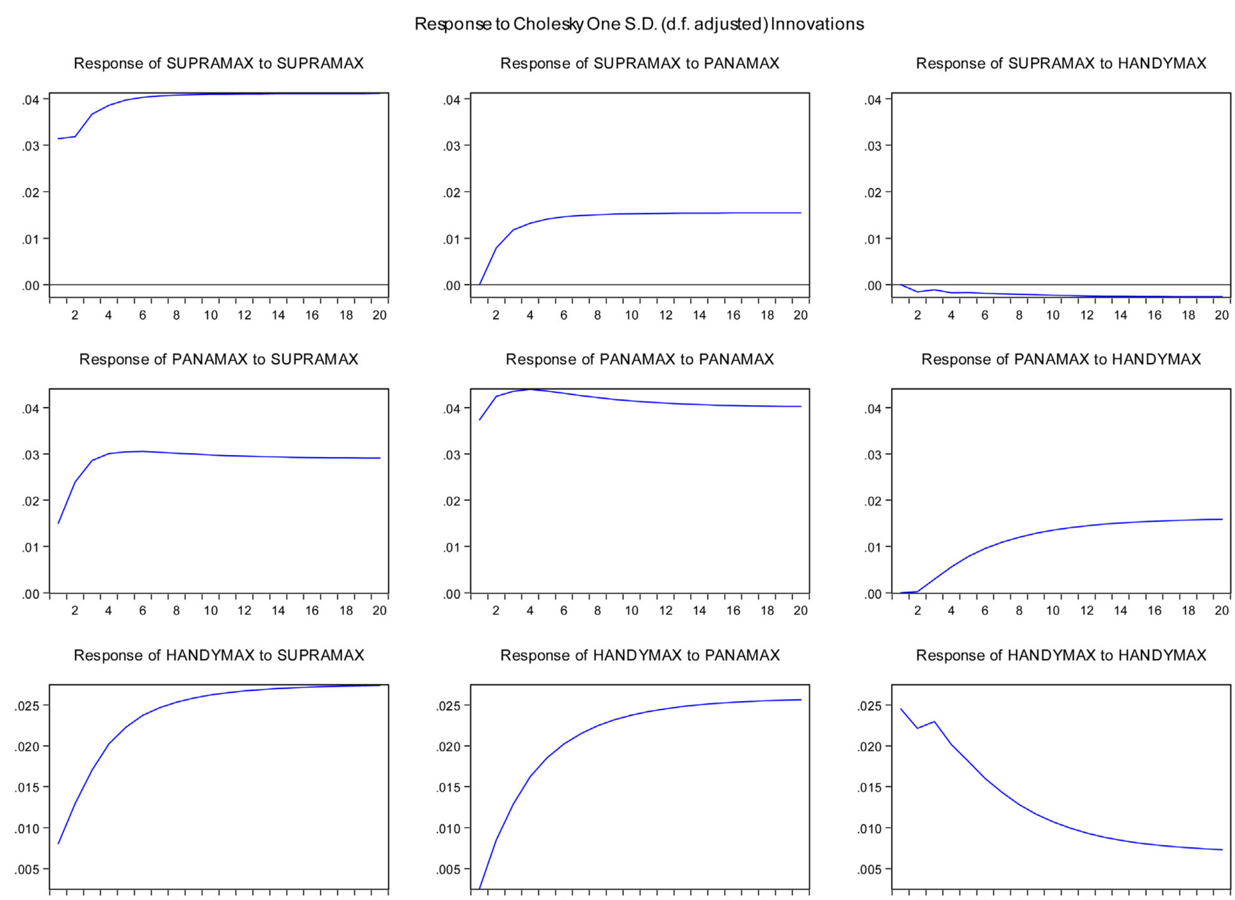

Fig. 1. Responses from weekly Trip Charter rates (intra-classs responses).

the Supramax class, which does follows the changes in Panamax and Handymax vessel rates but at a smaller extent. In particular, a 1 standard deviation shock in Panamax vessel time charter rates causes a 1.2% increase in Supramax rates, but at the same time caused a 2.5% increase in Handymax rates.

Overall, it appears some vessel classes are more interconnected than others. The impact appears to be dependent on the class, with Supramax vessels not affected by Handymax, while the opposite holds. Similarly, the Panamax response to a Supramax shock is larger than the opposite. Overall, the results are in accordance with

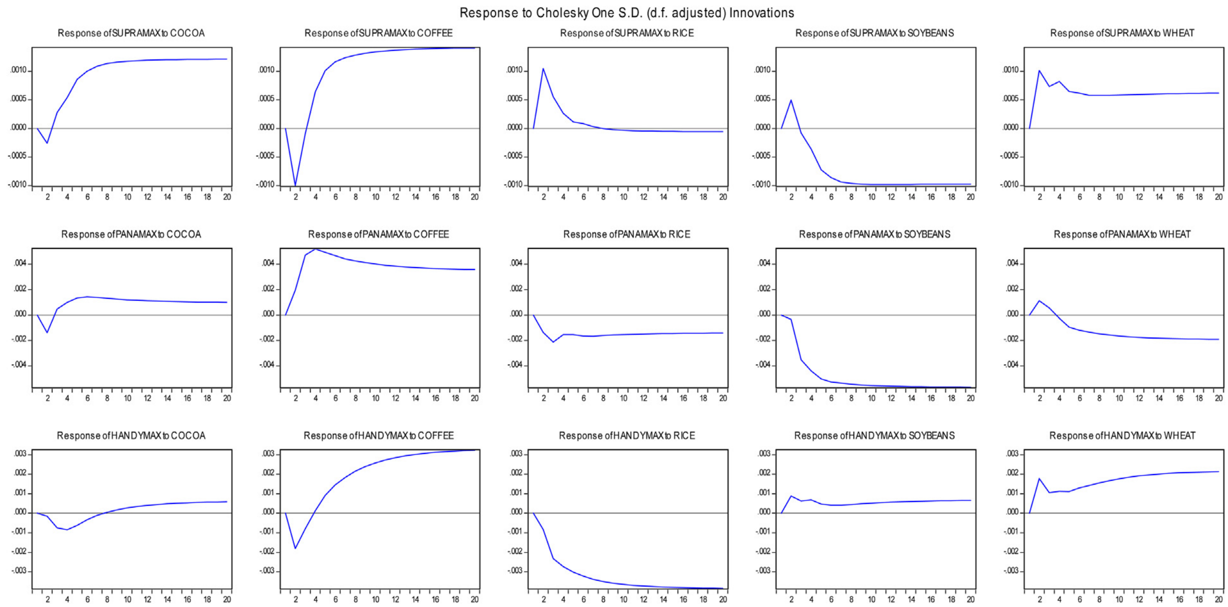

Fig. 2. Responses from weekly Trip Charter rates (commodity shocks).

Tsouknidis (2016) who has shown that Supramax vessels are primarily acting as transmitters of volatility shocks to the rest of the dry-bulk market.

Moving on to the impact of commodity prices on vessel classes (Fig. 2), it appears that the extent of a shock in prices is, naturally, far lower than the intra-class relation. A shock in cocoa prices appears to have almost zero impact on Handymax and Panamax vessel rates, while they have a 1.3% impact on Supramax vessel rates. Interestingly, cocoa prices appear to have an initial negative response on Handymax and Panamax vessels. This suggests that larger vessels, such as Supramax, are more usually employed for the transfer of cocoa, rather than Panamax or Handymax. This also offers information about the sea routes, given that is more likely to use a Panamax vessel for transport of cocoa to North America, and a Handymax vessel to transport in general. Thus, the impact from an increase in cocoa prices would also mean higher transport costs for shippers in those two categories.

Coffee shocks appear to have the largest impact on Supramax vessels, at 1.4%, while the increase in Panamax and Handymax vessels is much lower, at 0.4% and 0.3% respectively. The results are again in accordance with Tsouknidis (2016), suggesting that Supramax vessels are more volatile than the other two vessel types. Similar to the cocoa case, the responses are also indicative of the sea routes used to transport the commodity.

With regards to the other agricultural commodities, rice is negatively correlated with Panamax and Handymax, perhaps suggesting that higher rice prices would suggest a shift towards other types of products, given that substitution is high among agricultural crops. On the other hand, an increase in the price of soybeans causes a drop in freight rates. Finally, wheat prices appear to have a positive impact on Supramax (0.6%) and Handymax (0.2%) freight rates, but have a negative effect on Panamax vessels.

The results can be summarized in the following way: (a) an exogenous shock to one vessel class will have an impact on the other classes, the magnitude of which depends on how related the classes are; (b) certain types of vessels are more used for certain routes or types of agricultural commodities, as the responses suggests; (c) commodity prices have a strong impact on most vessel classes, with the exception of rice and soybeans, where most likely a strong substitution effect between those products exists.

Overall, the results support the view that commodity prices and freight rates are interconnected, showcasing that the markets in which these products trade can be a significant determinant of future freight rate movements. The following section provides an overview of how the variance of each variable is affected by the other variables in the system.

4.3. Variance decomposition

Variance decomposition enables the researchers to understand how much of the variability in a variable is due to its own variance, and how much the remaining variables can affect that variance. For example, if variable 1 can explain more of the variance of variable 2 than any other variables, then we can say that it has a "stronger" relationship with it over time.

Fig. 3 indicates the results from this exercise. As the figure suggests, the interrelations between agricultural products themselves and the carriers among them. In particular, agricultural products only have a maximum impact of 1.86% on Panamax variance, while the respective numbers for Supramax, and Handymax are 0.18%, and 0.70%. This showcases the fact that freight rate volatility is inherent to their nature, and thus suggests the need to find a way to effectively hedge against it. On the other hand, while the volatility of agricultural commodities is large, there at least some amount of it that can be attributed to the freight rate volatility. As Fig. 3 shows, freight rates affect commodity variance by 1.96% (cocoa), 2.13% (coffee), 2.54% (rice), 6.31% (soybeans) and 0.46% (wheat).

In general, it appears that there is not much of a variance pass-through from agricultural products to freight rates, while the opposite relationship is more significant. Still, as the decomposition suggests, there is significant pass-through between commodities, strengthening the results of the previous section, given that the relationship between the variables is strong enough for a change in one to promote a change in the other making it persistent due to the own lags effect.

For example, coffee's own lags are important for ten periods ahead, suggesting that this would allow a variance shock, e.g. an increase in Supramax rates, to remain in the price long after it has been initially passed on through to the prices. Naturally, this increase, once incorporated in the commodity, would only have a meaningful impact (i.e. an increase in variance), if the shock was

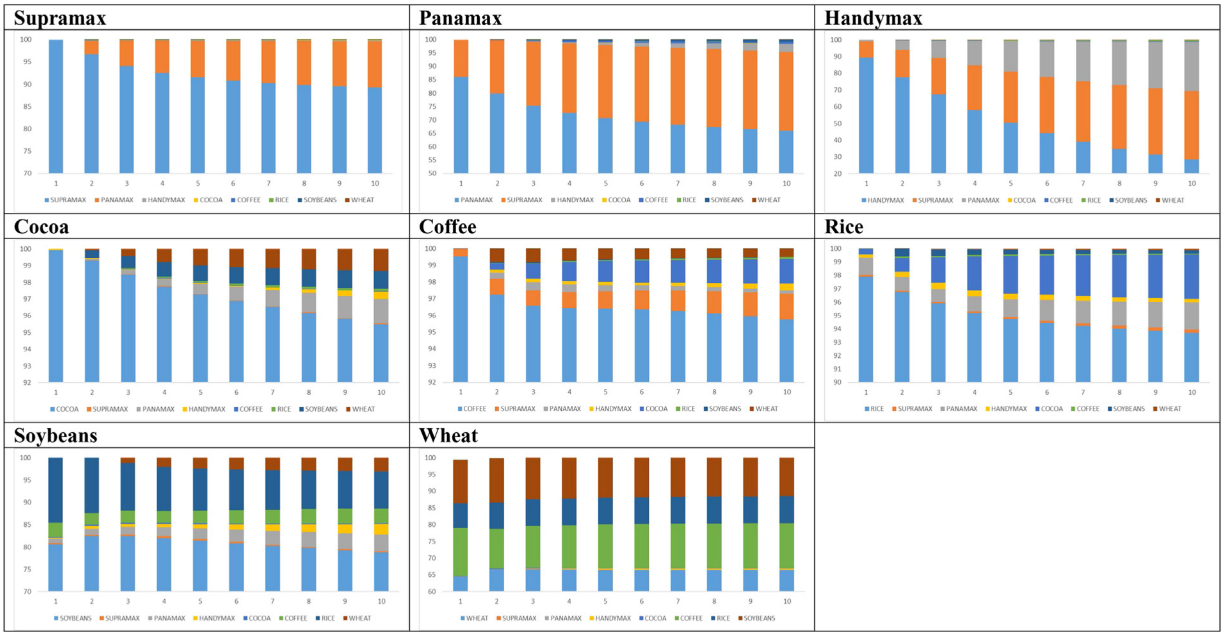

Fig. 3. Variance decomposition.

sufficiently large. Put simply, the magnitude of the variance shock would have to be large enough to produce any effects on the commodities.

As emphasised before, the fact that own shocks have a strong variance impact suggests that factors related to the variable would be much more important with regards to variance. These factors, in the case of agricultural products would be the definitions of exogenous shocks, such as an increase in demand for the commodity, bad weather conditions, worse than expected crop outcomes, and so on. Similarly, vessel-specific factors are also more likely to have an impact on its variance, such as movements in demand for seaborne trade, fleet supply, etc (Michail, 2020).

To sum up, the findings of this section further highlight the fact that the impact from the shocks from agricultural commodities to vessels and vice-versa would only impact the variable in the case that the shock is large enough. While the magnitude of the shock poses an interesting question, we leave it open for future research. Finally, the fact that freight rate own shocks have a strong contribution to their variance also helps to underline the importance of hedging against adverse movements of freight rates, given their inherent volatile nature.

5. Conclusions

This paper examines the extent at which changes in the underlying commodity prices that vessels transport have an impact on the corresponding freight rates, and the way this is reflected in the respective vessel classes. To the best of our knowledge, this is the first research that disaggregates the relationship between agricultural commodities and dry freight rates. The distinctive characteristics of agricultural commodities (namely, perishability and seasonality) create a unique setting for the latter relationship which has not been researched up to now per se. We show that not all agricultural commodities are acting the same when it comes to their transportation costs.

In particular, using weekly data from 2010 to 2019 and a Vector Error Correction Methodology, we confirm that, firstly, bulk carrier rates have a strong connection and an exogenous shock, such as higher or lower demand for a vessel class, can strongly affects other classes. Commodity prices are also found to have a strong impact on most vessel classes, with the exception of rice and soybeans, where most likely a strong substitution effect between those products exists.

Changes in commodity prices also appear to show some evidence of a substitution effect between vessel classes, as higher prices usually suggest a shifting preference towards larger vessels in order to benefit from the reduction in per tonne cost. Overall, the results support the view that commodity prices and freight rates are interconnected, showcasing that the markets in which these products trade can be a significant determinant of future freight rate movements. Further research, however, can delve into such topics with more detail. In particular, more work may be useful with regards to the financial tools that agricultural businesses can use so as to hedge against the volatility that the shipping freight rates can potentially exhibit both on their own, as well as, due to the link with agricultural commodities. Furthermore, the addition of more agricultural commodities can be incorporated in the future research agenda so to enhance our knowledge on the behaviour of minor bulk commodities.

Conflicts of interest statement

The authors whose names are listed immediately below certify that they have NO affiliation with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

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Appendix A. Trade routes for grain agricultural commodities

Commodity	Main exporting countries	Main importing countries	Vessel types	Main exporting ports	Main importing ports	Source
Cocoa	Cote d'Ivoire, Ghana	Netherlands, USA	Handymax, Supramax, Panamax	Abidjan (Cote d'Ivoire), San-Pedro (Cote d'Ivoire), Takoradi (Ghana)	Amsterdam (Netherlands), Philadelphia (USA)	International Cocoa Organization
Coffee	Brazil, Vietnam	EU, USA	Handymax, Supramax, Panamax	Santos (Brazil), Ho Chi Minh (Vietnam)	Hamburg (EU), Bremen (EU), New Orleans (USA)	International Coffee Organization
Rice	Thailand, Vietnam	East Asia, Africa	Handymax, Supramax, Panamax	Bangkok (Thailand), Ho Chi Minh (Vietnam)	Port of Busan (South Korea), Lagos (Nigeria)	US Department of Agriculture, International Grains Council
Soybeans	Brazil, USA	China	Handymax, Supramax, Panamax	New Orleans (USA), Corpus Christi (USA), Santos, Sao Paulo (Brazil)	Nantong (China)	US Department of Agriculture, International Grains Council
Wheat	USA, Australia	Egypt, Indonesia, Japan	Handymax, Supramax, Panamax	Portland (USA), Seattle (USA), Kwinana (Australia)	Alexandria (Egypt)	US Department of Agriculture, International Grains Council

Appendix B. Variables definition and sources

Variable	Description	Source	Units of Measurement
Handymax	Trip charter rates for Handymax bulk carriers (Long Run Historical Series)	Clarksons Shipping Intelligence Network	U.S. Dollars per day
Panamax	Trip charter rates for Panamax bulk carriers (Long Run Historical Series)	Clarksons Shipping Intelligence Network	U.S. Dollars per day
Supramax	Trip charter rates for Supramax bulk carriers (Long Run Historical Series)	Clarksons Shipping Intelligence Network	U.S. Dollars per day
Cocoa	Global price of Cocoa	Federal Reserve Bank of St. Louis, Economic Division	U.S. Dollars per Metric Ton, Monthly, Not Seasonally Adjusted
Coffee	Global price of Coffee, Robusta	Federal Reserve Bank of St. Louis, Economic Division	U.S. Cents per Pound, Monthly, Not Seasonally Adjusted
Rice	Global price of Rice, Thailand	Federal Reserve Bank of St. Louis, Economic Division	U.S. Dollars per Metric Ton, Monthly, Not Seasonally Adjusted
Soybeans	Global price of Soybeans	Federal Reserve Bank of St. Louis, Economic Division	U.S. Dollars per Metric Ton, Monthly, Not Seasonally Adjusted
Wheat	Global price of Wheat	Federal Reserve Bank of St. Louis, Economic Division	U.S. Dollars per Metric Ton, Monthly, Not Seasonally Adjusted

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