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Investment under uncertainty and irreversibility: Evidence from the shipping markets

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Abstract

This paper investigates whether uncertainty and irreversibility affect new investments for high-value real assets. We examine ocean-going vessels and show that heightened uncertainty reduces both the likelihood of investment triggering and the magnitude of investment spending, conditional on triggering. These effects are more pronounced under an illiquid secondary ship market and a high price discount when reselling the vessel. We also show that uncertainty regarding the global economy and vessel-specific earnings affect the investment decision, but the amplifying effect of investment reversibility operates only through global economic uncertainty. Our work is novel as it models periods of investment inactivity and examines investors' behaviour across vessel segments.

KEYWORDS

dynamic Heckman probit, intermittent investment, irreversibility, ocean-going vessels, uncertainty, vessel investments

1 | INTRODUCTION

Observed investment decisions often stray from the traditional continuous paradigm as provided by standard investment appraisal protocols such as the Net Present Value (NPV) and Tobin's q. Periods of investment inactivity generate intermittent investment behaviour, especially when using disaggregated data on investment decisions. The investment literature attributes this phenomenon to two separate economic rationales.

The first strand of the literature advocates that the presence of irreversibility and fixed adjustment costs result in an intermittent investment activity that includes an inaction zone (Abel & Eberly, 1994, 1999), where the size of the inaction zone increases with uncertainty and irreversibility. In this case, the NPV (Tobin's q) of an investment project must surpass zero (unity) by a multiple known as the irreversibility premium to become profitable. Similar conclusions have been drawn by a second and more recent strand of the literature that views investment opportunities as real options. Investments that are not of the now-or-never type, can be viewed as 'call' options where the agent has the right, but not the obligation, to pursue the investment opportunity now or in the future. In the presence of higher uncertainty, the value of the "option to wait" increases, and so does the opportunity cost of investment which gives rise to the negative effect of uncertainty on investment (McDonald & Siegel, 1986; Pindyck, 1988; Dixit & Pindyck, 1994; Caballero & Pindyck, 1996; Abel et al., 1996). Valuing the optionality embedded in investment decisions is an important investment assessment tool, especially for capital-intensive industries, where there is high uncertainty and irreversibility of investments along with excess and time-varying volatility of earnings. The Real Options Analysis (ROA) accommodates these features, which are ignored by popular investment appraisal techniques, such as the Net Present Value (NPV) and the Internal Rate of Return (IRR).[1]

In this paper, we investigate whether uncertainty and irreversibility affect new investments in ocean-going vessels. This is motivated by the fact that vessels are real

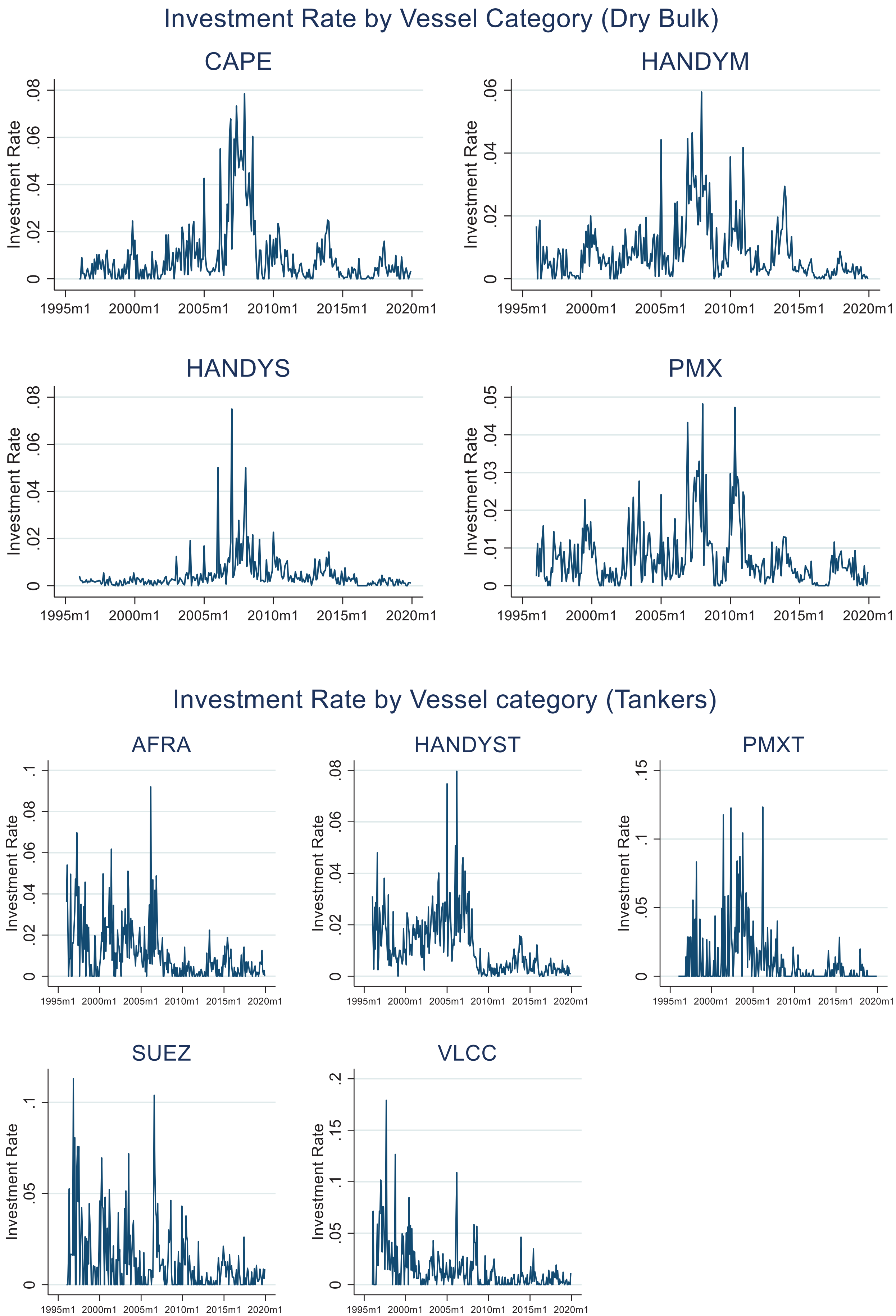

FIGURE 1 Legend on next page.

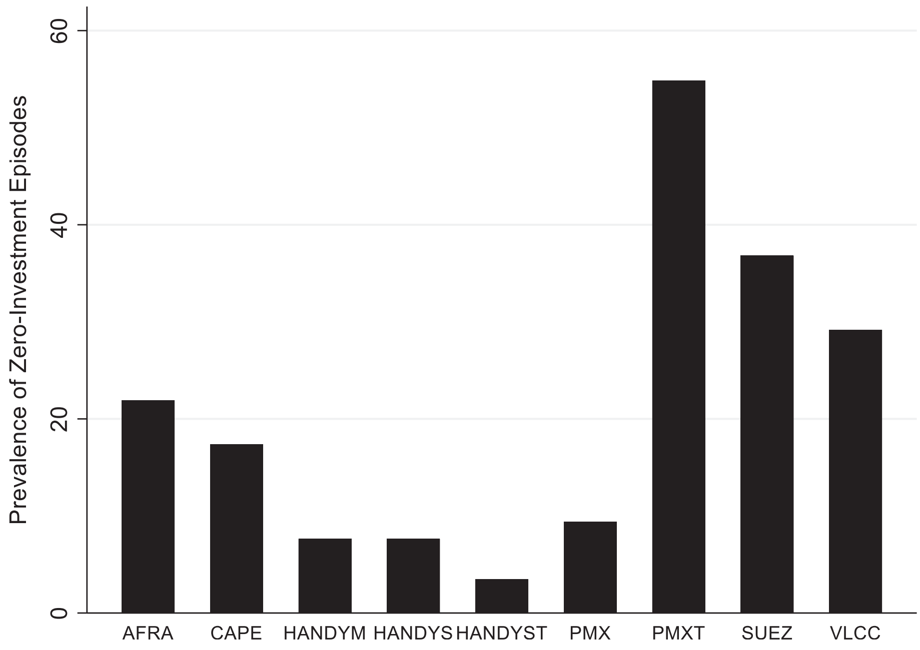

FIGURE 2 Percentage of monthly zero-investment episodes by vessel segment over the period 1996:01 to 2019:12. Source of data: Clarksons SIN

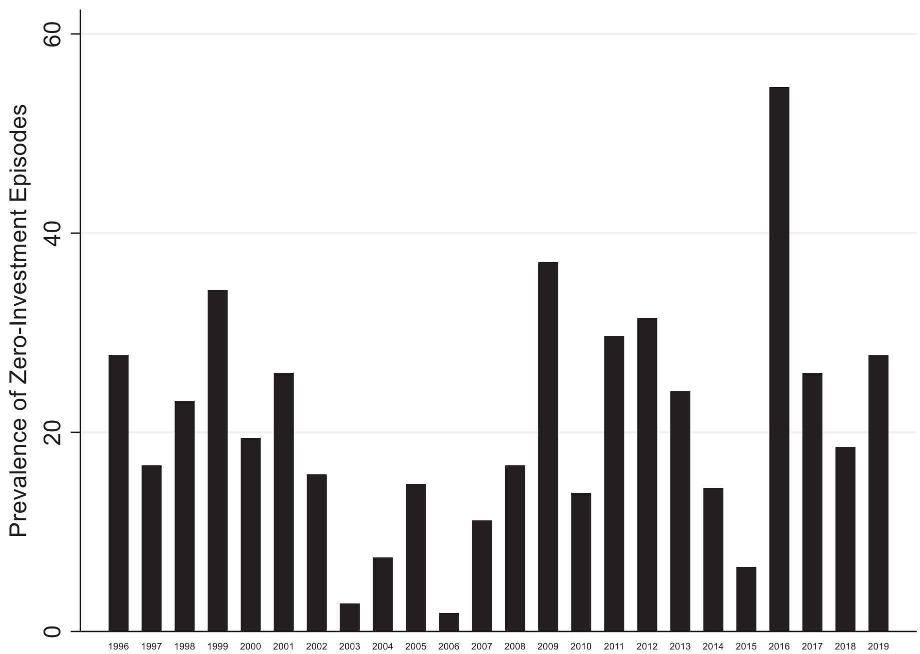

FIGURE 3 Percentage of monthly zero-investment episodes per year and across vessel segments over the period 1996:01 to 2019:12. Source of data: Clarksons SIN

capital-intensive assets and exhibit episodes of investment inactivity (zero-investment episodes) very often. Figure 1 shows the ratio of new investments on vessels over the existing fleet over time and across the vessel segments examined in this paper. As observed, the ratio (investment rate) exhibits pronounced volatility and several zero-investment episodes over time. This intermittent investment behaviour is illustrated further in Figures 2 and 3 which plot the percentage of monthly zero-investment episodes across vessel segments and years, respectively. This intermittent investment behaviour introduces (i) sample selection bias and (ii) extends

FIGURE 1 The evolution of the investment rate ratio, defined as new vessel investments over existing fleet, for dry-bulk and tanker vessel segments over the period 1996:01 to 2019:12. Source of data: Clarksons SIN [Colour figure can be viewed at wileyonlinelibrary.com] the research question of this paper as to what triggers new investment activity on vessels and the magnitude of new investments, once triggered.

In this paper, we contribute by (i) accommodating explicitly the intermittent investment behaviour of the shipping market participants and (ii) pursuing a vessel segment analysis using aggregate data of investors' behaviour across the main vessel segments. Effectively, we model the aggregate choices of shipowners to invest or defer new investments by quantifying the probability of investing in a specific vessel segment and subsequently the magnitude of the qualified investment. Critically, we employ a Heckman (1979) correction to accommodate the sample selection bias induced by the frequent periods of investment inactivity (zero-investment episodes). In addition, we distinguish between global uncertainty, captured by the Global Economic Policy Uncertainty (GEPU) index, and vessel-specific uncertainty, captured by the GARCH-generated conditional volatility of vessel earnings.

Recent contributions document the effects of uncertainty on general economic activity. For instance, Henzel and Rengel (2017) show that increased uncertainty of a commodity price index results in a significant reduction of real economic activity, while Triantafyllou et al. (2022) provide empirical evidence that the U.S. economic activity and its components are reduced due to uncertainty shocks in agricultural, metals and energy commodity markets. Gutiérrez (2021) rely on real options analysis to show that an increase in interest rates triggers investment when the state variable is far from the optimal threshold and tends to favour investment in hi-tech sectors.

Despite the numerous previous contributions in the fields of uncertainty, irreversibility, and real options at the firm level and across different types of capital (assets), the literature is scant for high-value real assets, such as ocean-going commercial vessels. Notably, Kyriakou et al. (2018) introduce a framework for the valuation of vessels and the optimal time to invest. The authors show that the value of the "option-to-wait" increases as the time to build declines pointing to the existence of a high opportunity cost embedded in the investment decision. In a related study, Campello et al. (2021) investigate the effect of uncertainty on ship investment using a near-universal dataset on shipping firms' new orders and document that under increased uncertainty firms hold back the acquisition and disposal of vessels.

Our results extend prior literature in the field by showing that higher uncertainty reduces the likelihood of investment triggering, but also leads to a lower extent of investment once it is triggered. The negative impact of uncertainty in new investment is smaller when the liquidity of the second-hand shipping market and the reversibility of the investment are higher. Effectively, being able to sell the vessel in a short period and with a low-price discount reduces the hampering effects of heightened uncertainty on new investment. By introducing global and industry-specific measures of uncertainty we show that both uncertainty sources are relevant for the investment decision, but reversibility operates only through the global uncertainty channel. These results have important implications for the valuation of real assets under conditions of uncertainty and the decision-making of investors.

The rest of this paper is organized as follows: Section 2 reviews the literature on the issue; Section 3 describes the dataset; Section 4 outlines the methodology followed; Section 5 discusses the empirical results obtained, and Section 6 concludes the paper.

2 | LITERATURE REVIEW

Abel and Eberly (1994, 1999) have shown that firms often exhibit intermittent investment activity that includes an inaction zone. The authors attribute the existence of the inaction zone to investments' irreversibility and fixed adjustment costs, resulting in altering the standard NPV rule in the following ways. First, the NPV rule must be modified because an investment project needs to have an NPV both positive and greater than the cost of irreversibility to qualify as profitable. Second, irreversibility exacerbates the negative impact of uncertainty on investment by extending the inaction zone.

Similar conclusions have been drawn by another strand of the literature advocating that investment opportunities can be assessed in terms of the Real Options Theory. Investments that are not of the now-or-never type, can be viewed as a "call" option where the agent has the right, but not the obligation, to undertake the investment project. Under increased uncertainty, the value of the "option-to-wait" also increases resulting in hampering investment activity (McDonald & Siegel, 1986; Pindyck, 1988; Dixit & Pindyck, 1994; Abel et al., 1996; Caballero & Pindyck, 1996). Similarly, higher uncertainty raises the investment trigger threshold, thereby discouraging or postponing investments and extending the investment inaction zone.

Other efforts on the same issue show that investment expenditures are sunk if (i) they are firm or industry-specific (McDonald & Siegel, 1986; Pindyck, 1988; Dixit & Pindyck, 1994; Barnett & Sakellaris, 1998; Chirinko & Schaller, 2002), (ii) there is an illiquid second-hand market, and (iii) investors are restricted from relocating their funds due to government regulations or institutional arrangements (Dixit &

Pindyck, 1994). The underlying mechanism follows the rationale that if an asset is firm or industry-specific then it is difficult to find a buyer and if the second-hand market is illiquid then the asset may result in a heavy price discount that widens with the thinness of the market. Thus, irreversibility may be captured by the price differences between the buying and resale prices (Abel & Eberly, 1999; Chirinko & Schaller, 2002). This difference, which is known as irreversibility premium, increases with the user-specificity of capital (McDonald & Siegel, 1986; Pindyck, 1988; Dixit & Pindyck, 1994).

In the same vein, the Industrial Organization literature also argues that irreversibility can be reflected by the "sunkenness" of capital, which may be measured by the part of capital characterized as irrecoverable (see, Worthington, 1995). Therefore, the level of activity in the resale market can capture to a large extent the fungibility of the capital employed in each sector (Kessides, 1990). Thus, the ratio of used capital expenditures over total capital expenditures may be used as a measure of the reversibility of capital which can be proxied by the intensity of the second-hand market. Specifically, a large ratio would suggest a highly active second-hand market (Kessides, 1990; Worthington, 1995).

2.1 | Shipping investments

In bulk shipping markets an ocean-going vessel carries a homogeneous cargo on a specific route (non-scheduled). Vessels are typically employed by individual shippers, who own the entire cargo and pay the freight rate to the ship owner. The commodities transported through dry-bulk shipping are primarily raw materials and food-related products, such as iron ore, coal, grain, and other minor dry-bulk commodities. Accordingly, wet-bulk shipping (tankers) transport mainly crude oil and oil products, such as gasoline and heating oil (UNCTAD, 2021).

Vessels are classified across vessel sizes as follows: (a) dry-bulk carriers: Capesize 100,000+ dead-weight tonnage (dwt), Panamax 60,000–100,000 dwt, Handymax 40,000–60,000 dwt, Handysize 10,000–40,000 dwt; (b) oil tankers: VLCC 200,000–400,000 dwt, Suezmax 120,000–200,000 dwt, Aframax 80,000–120,000 dwt, Panamax Tankers 60,000–80,000 dwt and Handysize Tankers up to 60,000 dwt. The different segments and sub-segments of vessels are typically perceived as different shipping markets (see, Stopford, 2009).

An investment in an ocean-going commercial vessel exhibits several unique features when compared to other types of capital: (1) Vessels are assets of high value, since a typical vessel may often exceed in value $100 mln, depending on its type, size and market conditions; (2) Being assets of high value the transaction costs of entry/exit between the different shipping segments and sub-segments are not negligible; (3) Vessels are homogenous assets, in the sense that they all offer the same standard sea transportation service, what differs is their type, size, age, and commodity transported; (4) The volatility of vessel prices and freight rates is very high and time-varying (Kavussanos, 1996; Tsouknidis, 2016). (5) Freight rates are affected primarily by the supply–demand dynamics of sea transportation (see, Nomikos & Tsouknidis, 2022) and exhibit a persistent skewness premium, i.e. shipping market participants are prone to lower expected returns for the possibility to enjoy high pay-offs in the future (see, Theodossiou et al., 2020).[2] (6) Vessels are characterized by high sector-specificity, as they cannot be re-deployed outside sea transportation (Campello et al., 2021). Naturally, qualifying vessels to invest in is of paramount importance for a shipping firm, as it largely determines its corporate strategy and financial performance (see, Stopford, 2009).

The real options analysis is a prominent method to capture the value of business-decisions flexibility, i.e. expanding the fleet by "contracting" for new vessels and deferring/abandoning a shipping investment.[3] Prior efforts related to our paper include Dikos and Thomakos (2012) who utilized real options analysis and aggregate sectoral data to show that owners of tanker vessels consider the value of the "option to wait" in their investment decisions. In the same spirit, Bendall and Stent (2003, 2005, 2007) follow a ROA framework to quantify the value of the options embedded in liner shipping investments, for instance, fleet expansion/replacement, service network development, and strategic flexibility. One important option to value in the shipping business is whether to reallocate capital across different shipping segments. Sødal et al. (2009) assess the decision to switch between dry-bulk and tanker vessels in the second-hand market developing a ROA valuation model. The authors show that the decision to switch was not profitable on average during the period 1993 to 2005 implying that the second-hand vessel market is efficient. In a similar spirit, Adland et al. (2017) show that the value of the option to switch the cargo of an Aframax tanker vessel from "clean" oil product to "dirty" crude oil has increased over time.

In another study, Axarloglou et al. (2013) investigate the drivers of the spread between spot (voyage) and time-charter rates under a real options framework. The authors argue that the spread reflects the strategic decision to commit vessels for a short period during a market bull market and vice versa. In a related study, Gkochari (2015) derives the stochastic dynamic equilibrium in the Capesize market and reveals that moving from

TABLE 1 Description of variables

	Description
Dependent variable	• *Investment Rate:* This rate is calculated per vessel type as: the new investments (contracting), i.e. the number of agreed deals for newbuilding contracts over the existing fleet, i.e. the number of the existing vessels in the global fleet.
Variables of interest	• *Global uncertainty:* The Global Economic Policy Uncertainty (GEPU) index is a GDP-weighted average of national EPU indices for 21 countries. Each monthly national EPU index value is proportional to the share of own-country newspaper articles that discuss economic policy uncertainty in that month. • *Vessel-specific uncertainty:* The conditional volatility obtained by a GARCH (1,1) model with *t*-distributed errors. • *Sales-based reversibility:* This measure is defined as number of vessels sold (sales) over existing number of vessels (fleet). • *Price-based reversibility:* This measure is defined as the second-hand 5 yr old price of a vessel over its newbuilding price.
Control variables	• *Libor:* This is the 3-Month London Interbank Offered Rate based on U.S. Dollar, i.e. the average interest rate at which banks borrow sizeable funds from other banks in the London market and is used to capture the ease of finance for shipping investors. • *Spread:* Defined as the difference between the 1 yr TC minus the spot (voyage) freight rate over the spot (voyage freight rate). Both the 1 yr TC and spot rates are expressed in $/day. The constituent routes of these average earnings figures are listed in Annex 4(b) of the Clarksons' (2015) SIN SIW report. • *Ipgr:* The Industrial Production for the G7 economies, which captures to a large extent the demand for sea transportation. • *Infation (CPI):* The Consumer Price Index of US, which captures changes at the level of the prices over time. • *Returns of earnings (Ret):* The first logarithmic differences of spot voyage earnings, which captures the current state of the shipping market.

Note: This table lists and provides a brief description of the variables examined in this paper.

completion delays to no time-to-build reduces the trigger value of newbuilding vessels. In the same vein, Rau and Spinler (2016) provide evidence that in the shipping markets, optimal investments are affected by the number of market participants and the intensity of competition.

In what follows we provide empirical evidence on the impact of uncertainty on new investments in ocean-going vessels considering the effects of (i) liquidity of the second-hand vessel market and (ii) irreversibility of the investment in a vessel. Furthermore, we quantify the probability of investing in a specific vessel segment and subsequently the magnitude of the qualified investment. The econometric framework we adopt corrects for the existence of sample selection bias induced by periods of investment inactivity (zero-investment episodes).

3 | DATA SOURCES AND VARIABLES CONSTRUCTION

We examine a panel dataset of 2592 vessel-month observations, whose cross-section (i) comprises nine different vessel sizes: dry-bulk vessel sizes (Capesize, Panamax, Handymax, Handysize) and tanker vessel sizes (VLCC, Suezmax, Aframax, Panamax Tanker, Handysize Tanker). The time series dimension covers the period from January 1996 to December 2019 (288 monthly observations).[4] All variables along with their full descriptions are presented in Table 1, while Table 2 reports their descriptive statistics.

For each vessel size we obtain the following monthly time series from Clarksons Shipping Intelligence Network (SIN): (1) new contracting which measures new investments, i.e. the number of agreed deals for newbuilding contracts (N); (2) existing fleet, i.e. the number of the existing vessels in the global fleet (F); (3) sales of vessels, i.e. the number of vessels that change hands (S); (4) newbuilding vessel prices, i.e. the average price for a newbuilding vessel in million dollars (p^{+}); (5) second-hand 5-year old vessel prices, the average price of a second-hand 5-years old vessel in million dollars (p^{-}); (6) Average long-run historical earnings for a voyage charter agreement; (7) Average long-run historical earnings for a 1-year time charter agreement. We refer to vessels' earnings as "freight rates", instead of focusing on the "nominal" freight rates earned by the shipowner from the employment of the vessel. This is performed to orthogonalize freight rates to fluctuations in bunker fuel and operating costs that affect nominal freight rates.

TABLE 2 Descriptive statistics of key variables, 1996:01 to 2019:12

	Mean	Median	Min	Max	Standard deviation	Skewness	Kurtosis
Panel A: Key variables across different vessel segments							
New investments (number of vessels)	8.439	4	0	211	13.232	4.519	40.549
Global fleet (number of vessels)	1265	836	39	3987	1134.455	0.910	2.456
Sales (number of vessels)	6.345	4.000	0.000	41.000	6.319	1.469	5.348
Newbuilding price (mln. $)	45.976	40.500	14.500	162.000	24.231	1.536	5.887
Second-hand 5 yr price (mln. $)	38.462	32.000	9.000	165.000	24.019	1.770	7.229
1 year time-charter earnings ($/day)	21,884	17,181	4375	161,600	16,473	3.229	21.005
Spot voyage charter earnings ($/day)	23,350	15,810	1071	204,361	21,750	2.740	14.670
Panel B: Dependent variable: Investment rate ratio for each different vessel segment							
Cape	0.009	0.005	0.000	0.079	0.014	2.676	10.662
Pmx	0.007	0.005	0.000	0.048	0.008	2.105	8.645
Handym	0.008	0.005	0.000	0.059	0.009	2.070	8.327
Handys	0.005	0.003	0.000	0.075	0.007	5.219	39.982
Vlcc	0.015	0.007	0.000	0.179	0.022	3.142	16.989
Suez	0.012	0.006	0.000	0.113	0.018	2.474	10.636
Afra	0.011	0.007	0.000	0.092	0.014	2.171	9.199
Pmxt	0.011	0.000	0.000	0.123	0.021	2.885	12.710
Handyst	0.011	0.008	0.000	0.080	0.012	1.983	9.349
Across vessels	0.010	0.005	0.000	0.179	0.015	3.421	21.099
Panel C: Control variables							
Libor (%)	2.641	1.916	0.226	6.790	2.178	0.433	1.621
Spread	0.115	0.002	−3.150	9.137	0.664	4.139	37.934
Ipgr (index units)	96.837	97.515	82.386	106.325	5.682	−0.483	2.617
Inflation: CPI (index units)	206.420	211.422	154.700	258.444	30.659	−0.093	1.688
Ret: Log returns of vessel earnings	0.002	0.001	−1.574	1.698	0.317	0.148	7.027

Note: 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. For the dry-bulk shipping segment: cape, pmx, handym, handys refer to Capesize, Panamax, Handymax, Handysize vessel sizes in a descending order, respectively. For the tanker shipping segment: vlcc, suez, afra, pmxt, handyst refer to Very Large Crude Carriers (VLCC), Suezmax, Aframax, Panamax tanker, Handysize tanker vessel sizes in a descending order, respectively. All variables are defined in Table 1.

Furthermore, using vessels' earnings allows us to normalize freight rates across vessel types.[5]

Panel A of Table 2 presents the descriptive statistics for the variables discussed above. As observed, the average new investments measured in the number of vessels across all vessel sizes and years examined is 8.439, but the median value is 4 indicating the presence of large values, such as the 211 new vessel investments recorded in January 2007 for the Handysize vessels. Furthermore, based on untabulated results across all vessel types and years examined, there are zero new investments in 542 vessel-month observations (21% of the total 2592; while the standard deviation is equal to 13.23 vessels), which suggests considerable variation in new investments on vessels over time.

3.1 | Dependent variables

We define the new investment rate as the ratio between the number of agreed deals for newbuilding contracts and the number of existing vessels in the global fleet:

$$I_{i,t} = \frac{N_{i,t}}{F_{i,t}} \tag{1}$$

Figure 1 plots the time series of the investment rate by type of vessel. As observed, new investments have been null on several occasions and across vessel types. However, they are generally higher across vessel types during the golden era of the shipping markets, i.e. the period 2003 to early 2008; followed by a sudden drop after the default of Lehman Brothers in the Fall of 2008. The observation of multiple zeroes in new investment leads us to calculate the zero-investment episodes by vessel type, which we show in Figure 2. As observed, zero-investment episodes exhibit a positive relationship with vessel size for dry-bulk vessels, i.e. larger dry-bulk vessels exhibit more frequently zero-investment episodes. However, this relationship is not monotonously positive for tanker vessels. Figure 3 confirms the low zero-investment episodes over the 2003 to 2008 period of strong shipping markets; while the opposite is true after 2008 and the realization of the global financial crisis.

Panel B of Table 2 reports the descriptive statistics for the dependent variable, i.e. the new investment rate for different vessel segments. As observed, the average investment rate is comparable across vessel sizes for the dry-bulk vessels apart from the smaller ones, i.e. the Handysize vessels; while it is noticeably larger for the largest tanker vessels (VLCC) compared to the rest of the tanker vessel sizes.

3.2 | Measuring uncertainty and reversibility

Measuring uncertainty is not a straightforward task since there is no consensus in the literature about the appropriate source of uncertainty affecting investment decisions. Prior studies on the issue have used stock price return volatility (e.g. Leahy & Whited, 1996 and Bloom et al., 2007) or survey-based measures of perceived uncertainty (e.g. Patillo, 1998; Driver et al., 2006). A typical way out of this debate is constructing an unconditional measure of uncertainty, such as the sample standard deviation of a variable capturing the state of the market of interest or by estimating a conditional volatility measure through a GARCH model (Drakos, 2011; Drakos & Konstantinou, 2013).

We introduce in our model specification both global and sector-specific measures of uncertainty. Specifically, we rely on the global version of the popular Economic Policy Uncertainty (EPU) index, i.e. the GEPU index, as constructed by Davis (2016), which builds upon the US EPU index developed by Baker et al. (2016). Heightened levels of EPU result in a reduction in global industrial production, (see, Baker et al., 2016) and eventually reduce investment rates (see, Gulen & Ion, 2016). The Global Economic Policy Uncertainty (GEPU) index is constructed as a GDP-weighted average of the individual EPU indices across 21 countries. The individual country EPU indices capture the relative frequency of newspaper articles that contain words for the economy (E), policy (P), and uncertainty (U). Thus, each month, the EPU country index reflects the proportional share of the country's newspaper articles that refer to economic policy uncertainty.[6]

In turn, to obtain a vessel segment-specific measure of uncertainty, we employ a standard GARCH (1,1) model (Bollerslev, 1986; Engle, 1982) with t-distributed errors which fit reasonably well vessels' earnings (e.g. Drobetz et al., 2012). We obtain a conditional volatility estimate by calculating the fitted values from the volatility equation. Hence, the uncertainty measure obtained reflects the information available at the time of decision-making for an investment.

Regarding the reversibility of investments in ocean-going commercial vessels, we rely on two different variables. First, we use a liquidity ratio defined as sales of vessels over the existing fleet (*sales-based reversibility*), $\left(\frac{S}{F}\right)$ which indicates how easy it is to sell the vessel without dropping its price substantially or waiting for too long to find a buyer. Second, we use the ratio of the second-hand 5-year vessel price over the newbuilding price (*price-based reversibility*), $\left(\frac{p^-}{p^+}\right)$ which captures the appetite of the market to acquire a vessel by comparing the prevailing price for a second-hand vessel to the newbuilding one. Typically, the second-hand price of a vessel is smaller than its newbuilding price since it has a shorter economic life remaining. However, it is conceivable that the prevailing freight rates in the shipping markets can be so high as to drive the second-hand price of a 5-year old vessel higher rather than its newbuilding price. This is because a newbuilding vessel is subject to a significant time lag of construction of around 18–36 months (Kalouptsidi, 2014).[7] In untabulated results we observe that the mean values of the sales-based reversibility measure are relatively low while the standard deviations are relatively high across the vessel segments examined. Accordingly, the mean values for the price-based reversibility measure indicate that the second-hand price of a 5-year-old vessel has been around 70% to 85% of the price of the corresponding newbuilding, depending on the vessel segment; while the standard deviations are modest.

Based on these sample properties of investment decisions as well as those that potentially affect them, one may draw two main conclusions: (i) investment inaction leading to an intermittent behaviour of investment is frequent, and (ii) reselling vessels at will without a significant price discount seems rather limited implying high levels of irreversibility. This is in line with evidence reported in Caballero et al. (1995), Barnett and Sakellaris, (1998), Doms and Dunne, (1998), Gelos and Isgut (2001), Nilsen and Schiantarelli (2003) and Sakellaris (2004). Our econometric modelling approach accommodates these features.

3.3 | Control variables

Using the variables discussed earlier, we calculate two vessel segment-specific control variables: (1) The spread of freight rates (*Spread*), defined as the difference of 1 year Time charter rate minus the spot freight rate, over the spot rate, which captures the expectations in freight markets, i.e. a positive value of the spread reflects that the market expects stronger freight rates. (2) we calculate the first logarithmic difference of spot voyage earnings (*Ret*), which captures the current state of the shipping market.

Next, we obtain data for three macroeconomic control variables: (1) The 3-Month London Interbank Offered Rate (*LIBOR*), based on the U.S. Dollar, i.e. the average interest rate at which banks borrow sizeable funds from other banks in the London market and is used to capture credit conditions; (2) The Consumer Price Index (*CPI*) of US, which captures changes at the level of the prices over time; (3) The Industrial Production for the G7 economies (*Ipgr)*, which captures at a large extent the demand for sea transportation. The variables *Libor* and *CPI* are from the website of the Federal Reserve Bank of St. Louis, while *Igpr* is from the website of OECD Data.

Panel C of Table 2 reports the descriptive statistics for the control variables included in the estimations discussed later in the paper. The mean value of the 3-month LIBOR interest rate is equal to 2.64% with a standard deviation of 2.18%. The spread of freight rates, i.e. the difference of the 1-year TC freight rate minus the spot freight rate, over the spot freight rate, has a positive average value of 0.115; exhibiting a considerable standard deviation equal to 0.664.

4 | ECONOMETRIC METHODOLOGY

The unit of analysis is the vessel segment (i). In the context of the modern investment theory one can break down the investment decision into two sequential processes, as follows:

$$INV_{i,t} = \begin{cases} 1 \text{ if positive investment is triggered} \\ \\ 0 \text{ if no investment is triggered} \end{cases} \tag{2}$$

Where, when $INV_{i,t}=0$ there is no investment triggering, while 1 denotes that positive investment in a vessel type is observed, i.e. investment has cleared the zero thresholds.

Then in the second stage according to a set of state variables X, the extent of positive investment is decided:

$$INV^{+}_{i,t} = f(X'\gamma) \tag{3}$$

The appropriate econometric method for modelling such a process is given by the Heckman selection model consisting of two equations. The first equation is the so-called selection (probit) model that models the dichotomous decision to trigger or not a positive investment. Modelling this decision is important to the extent that the errors of the investment triggering equation are correlated with the errors from the extent of the investment equation. In such instances, the Heckman estimator provides unbiased and consistent estimates of the parameters. Specifically, the outcome equation of the Heckman method is extended to include the inverse Mill's ratio from the first-stage probit estimation.

According to the modern investment theory the choice between inaction and action is driven by the level of uncertainty (U_t) and the compounding effect on uncertainty due to the degree of irreversibility. Our analysis will consider two possible sources of uncertainty; global ($U_{G,t}$) and vessel-specific ($U_{i,t}$).

As discussed earlier, following the literature, we have deployed two metrics for the degree of reversibility of investment ($REV_{i,t}$); the first captures the liquidity of the second-hand market, defined as the ratio of sales to the total fleet $\left(\frac{S_{i,t}}{F_{i,t}}\right)$, and the second captures the price differential between second-hand and new capital, defined as the ratio of the selling price to the new buying price $\left(\frac{p^{-}_{i,t}}{p^{+}_{i,t}}\right)$. The reversibility's compounding effect will be captured by its interaction effect with uncertainty ($U_t \cdot REV_{i,t}$).

Thus, the general setup we use consists of the *selection equation*, that models the probability of positive investment triggering, which is as follows:

$$\text{Prob}(INV_{i,t}=1) = \beta_0 + \beta_1 U_t + \beta_2 (U_t REV_{i,t}) + \varepsilon_{i,t} \tag{4}$$

We have two priors regarding the signs of the involved parameters:

A. Higher uncertainty tends to reduce (increase) the probability of investment triggering (inaction), that is we expect that $\beta_1 < 0$, and
B. For a given level of uncertainty, the probability of investment triggering is higher (lower) as reversibility (irreversibility) increases, and therefore we expect that $\beta_2 > 0$.

Then, once the zero-investment threshold has been cleared, and the positive investment is triggered, one must model the so-called *outcome equation* as follows:

$$\left(INV_{i,t}^{+} \mid INV_{i,t}=1\right)=\delta_0+\delta_1 U_t+\delta_2(U_t REV_{i,t}) + \varphi INV_{i,t-1}^{+}+\sum \gamma_j X_j+(\rho\sigma_\varepsilon)\lambda_{i,t} + u_{i,t} \tag{5}$$

We assume that $(\varepsilon_{i,t}, u_{i,t})$ follows a bivariate normal distribution with:

$$\begin{pmatrix}\varepsilon_{i,t}\\ u_{i,t}\end{pmatrix}\sim N\left[\begin{pmatrix}0\\0\end{pmatrix},\begin{pmatrix}\sigma_\varepsilon^2 & \rho\sigma_\varepsilon\\ \rho\sigma_\varepsilon & \sigma_u^2\end{pmatrix}\right] \tag{6}$$

where ρ is the correlation between $(\varepsilon_{i,t}, u_{i,t})$ while $\lambda_{i,t}$ is the inverse Mill's ratio denoting the non-selection hazard. The significance of the estimated $\left(\widehat{\lambda}_{i,t}\right)$ would imply the rejection of the null hypothesis that ρ is zero and that thus selectivity bias is present.

The specification has allowed for the possibility that investment exhibits some persistence by including in the model an autoregressive component, which would be empirically supported if $\varphi \neq 0$. However, this persistence may be triggered by 'genuine state dependence' or 'spurious state dependence'; the latter refers to the case where unobserved heterogeneity of market participants is correlated with their propensity to invest. Pure state dependence would imply that the likelihood of triggering investment at a time t differs according to whether there was investment activity or inactivity in terms in $t-1$. To deal with this issue we will resort to the Wooldridge method that employs the initial period's investment status $(INV_{i,0})$ as a proxy for initial conditions, which if not controlled for, might lead to biased results. Uncertainty and irreversibility may also be potential drivers of the extent of investment, even when the zero threshold has been cleared. So, again we expect $\delta_1 < 0$ *and* $\delta_2 > 0$. Our econometric setup is given by a dynamic Heckman model with initial conditions:

$$\begin{cases} \text{Prob}(INV_{i,t}=1)=\beta_0+\beta_1 U_t+\beta_2(U_t REV_{i,t})+\xi INV_{i,0} + \varepsilon_{i,t} \\ \left(INV_{i,t}^{+} \mid INV_{i,t}=1\right)=\delta_0+\delta_1 U_t+\delta_2(U_t REV_{i,t}) + \varphi INV_{i,t-1}^{+}+\sum \gamma_j X_j+(\rho\sigma_\varepsilon)\lambda_{i,t} + u_{i,t} \end{cases} \tag{7}$$

Our estimation consists of six models that are variants of each other assessing, (i) which source(s) of uncertainty, if any, is relevant for investment decisions, (ii) which dimension(s) of reversibility, if any, is relevant for investment decisions, and (iii) via which source of uncertainty, if any, reversibility exerts its compounding effect.[8] Below we provide these sets of models. M1: uncertainty is proxied by global uncertainty and reversibility is only sales-based; M2: uncertainty is proxied by global uncertainty and reversibility is only price-based; M3: uncertainty is proxied by global uncertainty and reversibility is based on both reversibility dimensions (sales & price based); M4: both sources of uncertainty are allowed (global and vessel-specific) and reversibility interacts with global uncertainty only; M5: both sources of uncertainty are allowed (global and vessel-specific) and reversibility interacts with vessel-specific uncertainty only; M6: both sources of uncertainty are allowed (global and vessel-specific) and reversibility interacts both with global and vessel-specific uncertainty.

As a robustness test to consider any vessel and/or time (month) fixed effects that might drive our results we introduce such effects across all model specifications estimated (M1 to M6). Apart from the case of introducing vessel fixed effects in specification M1, these effects are jointly not statistically significant from zero and as a result, the estimations are almost identical. The non-significance of vessel fixed effects is expected to an extent, as most of the model specifications introduce vessel-specific uncertainty. Furthermore, the non-significance of the month fixed effects is also expected to an extent, since the investment rate on new ships should not exhibit strong seasonal patterns as opposed to freight rates (see Kavussanos & Alizadeh, 2001). This is because there are significant time lags of construction for a newbuilding vessel (18–36 months), which renders month effects largely immaterial for a shipping investor.[9]

5 | EMPIRICAL RESULTS

Table 3 reports the first set of estimation results from the dynamic Heckman model with initial conditions where global uncertainty is considered and reversibility is presented in three alternative variants; (a) M1: sales-based, (b) M2: price-based, and (c) M3: both sales-based and price-based metrics. We focus the discussion below on the M3 specification, as it exhibits the lowest value for the Bayesian Information Criterion (Schwarz, 1978).

Starting with the diagnostics, the significance of the independence test and the Inverse Mills Ratio verify the choice of the Heckman selection model, indicating that the decision to invest (triggering) and the size of the investment are interrelated. The selection equation indicates that the event of investment triggering is negatively affected by increases in the global uncertainty. However, this effect is dampened as reversibility increases, i.e. the negative effect of global uncertainty on an investment decision is mitigated if the investment exhibits high

TABLE 3 Dynamic Heckman selection with initial conditions for investment under global uncertainty and reversibility - estimates of Equation (7)

	M1: Sales-based reversibility	M2: Price-based reversibility	M3: Both reversibilities
Panel A: Selection model (probit)			
Uncertainty	−0.005***	−0.015***	−0.016***
	(0.0003)	(0.001)	(0.001)
Sales-based reversibility* uncertainty	0.245***	-	0.230***
	(0.051)		(0.053)
Price-based reversibility* uncertainty	-	0.016***	0.016***
		(0.001)	(0.001)
Initial conditions	0.337***	0.361***	0.371***
	(0.076)	(0.094)	(0.072)
Panel B: Outcome equation (OLS)			
Uncertainty	−0.00008***	−0.0002***	−0.0002***
	(0.000006)	(0.00001)	(0.00001)
Sales-based reversibility* uncertainty	0.004***	-	0.0044***
	(0.0008)		(0.0008)
Price-based reversibility* uncertainty	-	0.0002***	0.0002***
		(0.00001)	(0.00001)
Lagged investment rate	0.121***	0.126***	0.112***
	(0.023)	(0.039)	(0.028)
Libor	0.036***	0.052***	0.050***
	(0.009)	(0.012)	(0.010)
Spread	−0.031	−0.127	−0.115
	(0.117)	(0.100)	(0.095)
Ipgr	−0.004	−0.008	−0.015
	(0.024)	(0.025)	(0.024)
Infl	−0.024	−0.077	−0.069
	(0.058)	(0.063)	(0.063)
Ret	−0.0006	0.00003	−0.0004
	(0.0005)	(0.0003)	(0.0004)
Panel C: Diagnostics and hypotheses tests			
Observations (vessel-months)	2484	2484	2484
Selected	1972	1972	1972
Non-selected	512	512	512
Inverse Mills ratio	0.015***	0.015***	0.014***
AIC	−9949.63	−9966.33	−10084.07
BIC	−9862.37	−9879.07	−9985.16
Wald test of independence	229.34***	77.86***	162.35***
Wald test overall significance	327.46***	465.11***	485.77***
Test for zero uncertainty and interaction effects	377.88***	408.70***	493.77***

Note: This table presents the results of the estimated two-stage probit regressions described in the methodology section of the paper. Standard errors are reported in the parentheses below the estimated coefficients. Statistical significance of the estimated coefficients is denoted with *, ** and *** for 10%, 5% and 1% significance levels, respectively. Columns M1 to M3 refer to the inclusion of the sales-based reversibility measure, the price-based reversibility measure and both. The BIC information criterion assesses the explanatory power of each estimated model with smaller values indicating higher explanatory power of the regressors. Introducing vessel or month fixed effects yields qualitatively the same (almost identical) results, apart from specification M1 which exhibits very small deviations. Therefore, such effects are jointly insignificant across all specifications apart from M1. All variables are defined in Table 1.

TABLE 4 Dynamic Heckman selection with initial conditions for investment under multiple uncertainties and reversibilities - estimates of Equation (7)

	M4: Global & vessel-specific uncertainties & reversibilities* global	M5: Global & vessel-specific uncertainties & reversibilities*vessel specific	M6: Global & vessel-specific uncertainties & reversibilities*both uncertainties
Panel A: Selection model (probit)			
Uncertainty global	−0.015*** (0.001)	−0.002*** (0.0003)	−0.014*** (0.002)
Uncertainty vessel specific	−0.328*** (0.123)	−4.634*** (0.412)	−0.926*** (0.791)
Sales-based reversibility* global uncertainty	0.232*** (0.053)	-	0.109 (0.105)
Price-based reversibility* global uncertainty	0.016*** (0.001)	-	0.015*** (0.003)
Sales-based reversibility* vessel uncertainty	-	65.537*** (17.689)	39.131 (34.191)
Price-based reversibility* vessel uncertainty	-	5.247*** (0.594)	0.505*** (1.139)
Initial conditions	0.359*** (0.079)	0.327*** (0.068)	0.356*** (0.083)
Panel B: Outcome equation (OLS)			
Uncertainty global	−0.0002*** (0.00001)	−0.00004*** (0.000001)	−0.0001*** (0.00002)
Uncertainty vessel specific	−0.001 (0.001)	−0.060*** (0.005)	−0.011 (0.009)
Sales-based reversibility* global uncertainty	0.0043*** (0.0008)	-	0.002* (0.001)
Price-based reversibility* global uncertainty	0.0002*** (0.00001)	-	0.0001*** (0.00003)
Sales-based reversibility* vessel uncertainty	-	1.183*** (0.286)	0.535 (0.484)
Price-based reversibility* vessel uncertainty	-	0.069*** (0.007)	0.010 (0.013)
Lagged investment rate	0.113*** (0.028)	0.106*** (0.030)	0.113*** (0.030)
Libor	0.061*** (0.012)	0.052*** (0.011)	0.059*** (0.012)
Spread	−0.130 (0.095)	−0.095 (0.105)	−0.123 (0.095)
Ipgr	−0.017 (0.025)	−0.011 (0.023)	−0.018 (0.024)
Infl	−0.079 (0.062)	−0.069 (0.053)	−0.079 (0.061)
Ret	−0.0004 (0.0002)	−0.0004 (0.0003)	−0.0004 (0.0002)
Panel C: Diagnostics and hypotheses tests			
Observations (vessel-months)	2484	2484	2484
Selected	1972	1972	1972
nonselected	512	512	512

TABLE 4 (Continued)

	M4: Global & vessel-specific uncertainties & reversibilities*global	M5: Global & vessel-specific uncertainties & reversibilities*vessel specific	M6: Global & vessel-specific uncertainties & reversibilities*both uncertainties
Inverse mills ratio	0.014***	0.014***	0.014***
AIC	−10087.09	−10054.91	−10084.05
BIC	−9976.56	−9944.37	−9950.24
Wald test of independence	136.73***	104.06***	107.72***
Wald test overall significance	486.94***	445.38***	503.87***
Test for zero uncertainty and interaction effects	509.27***	460.83***	535.53***

Note: See note in Table 3.

reversibility. Notably, the sales-based and price-based reversibility measures are both individually (M1 and M2) and simultaneously (M3) significant. Turning to the outcome equation, the size of the investment, once the positive investment is triggered, is also negatively affected by uncertainty. Similarly, this effect is mitigated as reversibility increases. These findings are in line with the predictions of the investment theory i.e. that higher uncertainty induces investment deferral (Leahy & Whited, 1996; Bloom et al., 2007). Furthermore, the reported results support the lower propensity of investment inactivity for vessels with higher reversibility.

Table 4 presents the estimation results when introducing both sources of uncertainty. As discussed earlier, this exercise is motivated by the possibility that vessel-specific uncertainty regarding vessels' earnings might be of importance for the decision of an investor to enter the shipping market, over and above the impact of global uncertainty. Furthermore, the inclusion of two uncertainty sources, also allows us to investigate whether the dampening effects of reversibility hold and in which form. To tackle this issue, we present three variants of the model as follows (a) M4: reversibility operates through global uncertainty only, (b) M5: reversibility operates through vessel-specific uncertainty only, and (c) M6: reversibility operates through both uncertainty sources.

Again, we focus on the specification with the lowest value of BIC, that is M4. Hence, both uncertainty sources are relevant for the investment decision, but reversibility operates only through global uncertainty. Both reversibility dimensions exert an indirect impact on investment triggering by lowering global uncertainty's effect. In turn, and in line with our previous findings, we find that investment triggering is negatively affected, not only by global uncertainty but also by vessel-specific uncertainty.[10]

All in all, the main findings of this paper are that (i) higher uncertainty reduces the likelihood of investment triggering but also leads to a lower extent of investment, once it is triggered; (ii) the impact of uncertainty is lower (higher) when reversibility is higher (lower); (iii) both dimensions of reversibility affect investment decisions; (iv) the size of the investment is negatively affected both by global and vessel-specific uncertainties, while global uncertainty's effect is reduced as reversibility is higher.

The results of this paper are novel and show that higher uncertainty lowers both investment triggering and the size of the investment once it is triggered. Both sales-based and price-based measures of reversibility mitigate the negative effect of uncertainty on investment. However, the moderating role of reversibility operates only through global uncertainty and not through vessel segment-specific uncertainty. This result confirms the global nature of the shipping industry as shown also into different contexts of the shipping finance literature by, among many others, Kavussanos and Tsouknidis (2014, 2016) and Drobetz et al. (2013).

Overall, our results are in line with Campello et al. (2021) who show that increased uncertainty leads shipping firms into holding back on decisions with higher irreversibility, such as the acquisition and disposal of vessels, as opposed to more reversible decisions, such as buying/selling vessels in the second-hand vessel market. The authors also show that these effects are stronger when the vessel market is illiquid since firms have an incentive to delay their decisions.

Taken together, the results of this paper have important implications for the investments in new vessels and the valuation of real assets under conditions of uncertainty and the decision-making of investors. For instance, assessing default risk in a bank loan agreement involves the accurate valuation of a vessel and the computation of the loan-to-value ratio. Failing to consider the effects of high uncertainty and/or low reversibility of such an investment might lead to the computation of a biased

LTV ratio; on this see, Bian et al. (2018) for an application in the housing market.

6 | CONCLUSION

This paper contributes to the literature by modelling the aggregate choices of shipowners to invest or defer an investment across shipping segments. Specifically, we provide empirical evidence on the effect of uncertainty on triggering investment, and once triggered on the size of the investment. We document that, for real assets of high value, such as ocean-going vessels, higher uncertainty reduces the likelihood of investment triggering, but also leads to a lower extent of investment once it is triggered. The negative impact of uncertainty is lower when reversibility is higher, using two different measures of reversibility. The results avoid the sample selection bias as we estimate a dynamic Heckman model. Finally, we distinguish between a global uncertainty measure (GEPU) and a vessel-specific uncertainty measure (conditional volatility of vessel earnings) and show that both uncertainty sources are relevant for the investment decision process, but reversibility operates only through global uncertainty.

DISCLAIMER

The views and opinions expressed in this paper are those of the authors and do not reflect the views of their respective institutions.

DECLARATION OF COMPETING INTEREST

None.

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DATA AVAILABILITY STATEMENT

Data availability statement: Data subject to third party restrictions: The data that support the findings of this study are available from Clarksons Shipping Intelligence Network (SIN). Restrictions apply to the availability of these data, which were used under the institutional license of the Athens University of Economics and Business for this study. Data are available through Clarksons SIN (2020).

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ENDNOTES

[1] Using the Discounted Cash Flow (DCF) method for assessing an investment depends on crucial assumptions related to future cash-flows and discount rates. In fact, there seems to be extended misuse of the DCF methods. For instance, Lai and Trigeorgis (1995) show that a less rational management team often rely on a DCF method to justify already undertaken investments (see also, Bendall & Manger, 1991).

[2] This may be attributed to the substantial "options" often embedded in business decisions within commercial shipping. Trigeorgis and Lambertides (2014) provide relevant evidence, as they show that investors may rationally accept a lower required return for an exposure to a positively skewed risk–return profile.

[3] For a comprehensive review of the use of ROA models in the shipping markets, see Alexandridis et al. (2018).

[4] Not all variables are available in all years. The GEPU index starts on January 1997 up to December 2019, which results into 276 monthly observations. Thus, the total number of observations reported later in the results section of the paper is equal to 2484 vessel-month observations.

[5] According to Clarksons (2015), "Sources & Methods for the Shipping Intelligence Weekly", daily net freight rates or earnings for each route are computed as the net of total revenue minus: (i) bunker costs, computed as the average bunker price across several representative regional bunker ports, (ii) port fees, adjusted for different currency exchange quotations and total commissions due to the port operator. The result is divided by the number of voyage days, to provide the earnings per day for each vessel type. The assumptions and standard ship types used in the voyage earnings calculations are reported Clarksons (2015) and reviewed on a regular basis by Clarkson Research and H. Clarkson brokers. More details of the calculations freight rates and their constituent parameters and assumptions are set out in Annexes 1–4 of the Clarksons (2015) "Sources & Methods for the Shipping Intelligence Weekly". Average earnings for each ship type are averages of the voyages earnings for selected routes, which are listed in Annex 4(b) of the Clarksons (2015) "Sources & Methods for the Shipping Intelligence Weekly."

[6] We use the PPP-adjusted GDP version of the GEPU index. For more information regarding the construction of this index, see Davis (2016).

[7] As pointed out by an anonymous referee the ratio of second-hand vessel price to newbuilding price is subject to shipyard capacity. However, in untabulated results, we show that the ratio of orderbook over existing fleet has increased considerably only during the years 2006 to 2008 because of the unprecedented high freight rates prevailing at the time. Thus, we expect that our results are not driven by shipyard capacity.

[8] The investment-uncertainty literature typically considers market power (competition effects), see for example Guiso and Parigi (1999) among many others. However, we examine aggregate

vessel level (sectoral) data and therefore neglect individual firms' market power.

[9] The results with vessel and time (month) fixed effects are available from the authors upon request.

[10] As an important robustness test, we replace the GEPU index with the VIX index as our global uncertainty measure. The results are qualitatively the same. The VIX index is a widely used measure of the stock market's expectation of volatility based on S&P 500 index options.

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