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When energy efficiency is secondary: The case of Offshore Support Vessels[☆]

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ABSTRACT

Offshore Support Vessels (OSVs) deal with time-sensitive logistics and sophisticated marine operations for high-value offshore oil and gas installations. We investigate whether this creates preferences that effectively penalize energy efficiency, either through lower hire rates or reduced utilization. We apply hedonic pricing fixed effect models which account for technical vessel specifications, contractual terms and market conditions. Our empirical findings show that energy efficient vessels fare worse both in terms of rates and utilization, reflecting industry preferences for high-powered fast vessels given the requirements for on-time operations, such that environmental considerations and energy efficiency is of secondary importance.

1. Introduction

Maritime transport relies heavily on fossil fuels and, if no action is taken, its CO_2 emissions that account for 2.7% of global greenhouse gases will increase by 17% by 2050 (European Parliament, 2015). Within the maritime industry, approximatively 90% of CO_2 emissions were transport-related (containerships, oil tankers, bulk carriers, ferries, cruise…) in 2012, while non-transport service vessels such as tugs (2.7% of shipping emissions) or offshore vessels (2.9%) represent a limited share (Smith et al., 2015). For both types of vessels, numerous technological and operational measures available (Bouman et al., 2017) could be stimulated by the introduction of an effective CO2 levy payable on marine fuel purchases (Psaraftis, 2012; Sheng et al., 2018).

In reality, the effectiveness of such policy measures with regards to the supply side depends on whether higher fuel prices in fact encourage behaviour that leads to reduced emissions, such as slow steaming or choosing more environmentally sound vessel designs. For deep-sea maritime transportation (e.g. oil tankers and drybulk carriers) the literature is not wholly encouraging in this regard, pointing instead to the existence of substantial organizational and commercial barriers to energy efficiency (Rehmatulla and Smith, 2015). For the more specialized markets (e.g. cruise, ferries) and service vessels (e.g. offshore and tugs), this remains largely an open question.

In this paper we investigate the pricing of energy efficiency in the Offshore Supply Vessels (OSV) market. As of 2012, offshore vessels supporting offshore oil and gas production and port tugs were estimated to emit approximately 60 million tonnes of CO_2 per year, each fleet being responsible for around 3% of global maritime transportation emissions.

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The offshore market is characterized by sophisticated supply chains. Globally, offshore oil production accounted for about 30% of total oil production over the past decade (EIA, 2016), with offshore gas production having increased to a similar percentage (31%) of total global production in 2017 (Clarkson Research, 2018). In terms of offshore rig numbers (both stationary and mobile units), the North Sea (14%), U.S. Gulf of Mexico (13%), Persian Gulf (12%), Far East Asia (12%), South East Asia (11%) and Mexico (7%) are the most important areas for offshore oil and gas activity (Rystad Energy, 2018). Offshore rigs have a wide variety of designs and sizes, ranging from small shallow-water jackups to large semisubmersible drilling rigs or enormous production rigs placed on the seabed (Hyne, 2001).

What they have in common is the need for logistics services, both to serve onboard staff (e.g. fresh water, food waste) and the production or exploration activity of the rig (e.g. fuel oil, spare parts, drilling mud, rental equipment etc.). This complex supply chain – termed upstream logistics – is supported by Plattform Supply Vessels (PSVs) that shuttle containerized and bulk cargo between shoreside supply bases and the offshore installations (Aas et al, 2009). Similarly, in the exploration phase, mobile rigs and their multiple anchors need to be moved, either to commence drilling on a new well on the same field or to a new oilfield when the drilling operation for a field is complete. For the purpose of moving rig anchors and towing rigs, a different specialized OSV – the Anchor Handling Tug Supply (AHTS) vessel – is used.[1]

The diversity of trades and operating duties assigned to OSV means that the optimal design of these vessels is far more complex than for other transport-related vessels (Gaspar et al., 2012), as the context (field development, new technology or new regulation such as limitation from emission control areas) also comes into play. Compared to many cargo ships, offshore support vessels are rather small in size, have low cargo capacity and operate close to their shore base with frequent trips (Erikstad and Levander, 2012). The capability to perform their mission in heavy weather is also very important and vessels must have good sea keeping and maneuvering performance.

PSV main power demand is for propulsion, but also for thrusters in station keeping during off-loading at the platforms, while AHTS need propulsion power to generate high bollard pull, but also auxiliary power for the winches. Herdzik (2013) makes the distinction amongst 10 different operational profiles or modes (Port, Transit 16 kt, transit towing, anchor handling, bollard pull, DP low, DP high, Standby Low and High, Fire Fighting), with Transit at 16 kt being used approximatively 44% of the time, followed by Stand by low (15%) and Anchor Handling (11%). For each mode, the main and auxiliary power delivered are different and may call for different optimal ship design and ship selection criteria.

Therefore, designing the right vessel for the right mission over time requires more than an immediate matching of owners' requirements and vessel capabilities (Andrews, 2012; Gaspar et al., 2015). A possible (but costly) solution tested by Gaspar et al. (2015) is to invest in high-capability vessels, able to perform across a wide range of missions during their lifetime. However, in the specific case of a platform supply vessel, finding a right balance between optimizing the vessel for the first known contract while keeping in mind future market requirements and stakeholders' preferences remains challenging.

Another difficulty is that those preferences may change over the years, as companies are increasingly adding sustainability goals to their business objectives, with an increasing interest in mitigating the social and environmental impact of their supply chain (Blanco and Sheffi, 2017). Being an integral part of oil companies' upstream logistics system, such efforts also extend to the use of offshore support vessels. However, there are usually barriers to improving energy efficiency. Sorrell et al. (2000) classify these barriers into: (a) organizational, (b) behavioral/cognitive and (c) economic factors. George et al. (2016) investigate the barriers to sustainability integration in the performance management systems of an oil and gas company, and find that cognitive barriers play a key role. Similarly, Blumstein et al. (1980) argue that the barriers can be classified as: misplaced incentives, lack of information, regulation, market structure (degree of concentration), availability of financing and custom.

In the transportation literature, the principal-agent problem has been identified as a key challenge to the implementation of energy-efficient solutions (see, for instance, Graus and Worrel, 2008, for company cars; Vernon and Meier, 2012, for trucks; Rehmatulla and Smith, 2015, for ocean shipping). The principal-agent problem here refers to the case where the economic benefits of energy conservation do not accrue to the entity which is trying to conserve (i.e. misplaced incentives). Clearly, the offshore logistics[2] market is also subject to the principal-agent problem since the owners of vessel pay for their construction, while clients pay for the fuel consumed[3] and therefore accrue any savings due to improved energy efficiency. In order to avoid a market failure, charter rates would therefore have to increase to reflect some sharing of the savings (Agnolucci et al, 2014).

While there is a large body of research on the microeconomic analysis of contracted rates in international shipping (see, for instance, Bates, 1969; Tamvakis, 1995; Dick et al., 1998; Tamvakis and Thanopoulou, 2000; Alizadeh and Talley, 2011a, 2011b; Köhn and Thanopoulou, 2011), the empirical literature dealing with the relationship between energy efficiency and hire rates for vessels remains very limited to date.

Agnolucci et al. (2014) investigate the timecharter market for drybulk ships and find that on average only 40% of the financial savings delivered by energy efficiency accrue to the ship owner. Using a bigger sample across time and drybulk vessel sizes, Adland et al. (2017a) argue that the owners' share is lower and, more importantly, that it depends on market conditions. Neither study

[1] As of June 2018, there were approximately 2056 PSVs and 2562 AHTS vessels in the global fleet (Clarkson Research, 2018). Despite a degree of substitution (AHTS vessels can take on supply duties when their own market is poor), the two types of vessels operate in two largely distinct markets.

[2] We include the process of moving rigs around in a wide definition of offshore logistics such that this term incorporates both the use of PSVs and AHTS vessels.

[3] We note here that the vessel's fuel system and the fuel oil cargo tank is connected such that a fuel-efficient vessel can discharge more fuel oil to the rig, all else qual.

incorporates the unobservable effects that buyers, sellers or their match have on contracted prices, as proposed by Adland et al. (2016). Both studies also suffer from the potential methodological flaw identified by Adland et al. (2017b), where a market index is included as an explanatory variable, thus leading to circularity in the regression. Keeping the above weaknesses in mind, there is not yet a clear understanding of the relationship between energy efficiency and the rates for hiring vessels and whether the existing empirical results can be generalized to other vessel types and markets. It is also an open question whether the market rewards energy efficient designs through other channels than a rate premium. For instance, energy-efficient vessels may achieve better utilization by being "first picks" and therefore have less idle time and higher average earnings, particularly when the market is oversupplied (Adland et al., 2017a).

While filling these gaps in the literature provides sufficient incentives for our study, the OSV market is clearly an interesting empirical case for the evaluation of energy efficiency barriers in the framework of Blumstein et al. (1980). Firstly, there is a clear misplacement of incentives, with oil company clients enjoying energy efficiency savings through the chartering market without investing in vessels directly. Secondly, the buyer side is highly concentrated, particularly when the analysis is done at a regional level due to the dominance of many national oil companies in their home markets (Adland et al., 2019). This may lead to a degree of market power and affect the willingness (or need) to pay up for energy efficient technology. Thirdly, as the vessels operate solely within the territorial waters of a country for any given contract, they are subject to heterogeneous national regulations. Fourthly, there are economic factors particular to offshore exploration and production of oil and gas which may lead to the "penalization" of energy efficiency in the OSV market.

Specifically, there is a high positive correlation between marine fuel prices and the crude oil price in addition to a high positive correlation between oil prices and rig activity (Ringlund et al., 2008), which means that high oil prices tend to correspond to high demand for OSVs. Additionally, offshore rigs are extremely capital intensive with corresponding high dayrates, and any interruptions or delays in the drilling or production of oil can have substantial financial penalties. It follows that the security and timeliness of rig moves or supplies is extremely important to the client (buyer) of OSV services. Together, the positive relationship between fuel costs and OSV demand and the very high cost of non-performance could have the perverse effect of rewarding energy inefficiency, with charterers having preferences for high average vessel speeds and large engine installations that are able to maintain sailing speeds during poor weather conditions, the latter being an important performance indicator for OSVs (Aas et al., 2009).

In light of the above, our contributions to the literature are threefold. Firstly, we study for the first time the effect of energy efficiency on dayrates in the OSV market to assess whether the market structure leads to a different outcome than in the deep-sea shipping sectors investigated in the literature. Secondly, we study whether energy efficiency and other design parameters affect vessel utilization in addition to the rates obtained. Thirdly, we resolve the methodological problems in the maritime energy-efficiency literature by explicitly accounting for market conditions and buyer effects using fixed effect regressions. For this purpose, we rely on a unique dataset of nearly 38,000 fixtures covering the 1989–2015 period and estimate hedonic price equations in the framework of Rosen (1974). The remainder of our paper is organized as follows. Section 2 presents our transaction dataset, Section 3 presents our empirical results and Section 4 concludes.

2. Description of the data

We study the effect of energy efficiency on the OSV fleet using a large sample of fixtures completed all over the world between 1989 and 2015. We evaluate the impact of technical vessel specifications as well as contract-specific determinants on the dayrate. In our empirical analysis, we merge detailed information from two different sources of data. The first is an OSV fleet database provided by Clarkson Research (2018), the second consists of individual fixtures provided by ODS Petrodata.[4] Both sources of information are merged using the IMO number which is a unique reference for ships.[5]

The OSV fleet database includes the main characteristics of each vessel such as fuel consumption, year of construction or carrying capacity. A crucial issue in our analysis is the need for reliable information on fuel consumption at design speed to construct an energy efficiency indicator. A difficulty in the study of energy efficiency and pricing in the maritime industry, which is not specific to our empirical investigation, is that the level of fuel consumption at design speed is quite often missing in the fleet database (in more than four of ten cases). In order to avoid discarding a large number of vessels and, thus, transactions from our analysis, we turn to a multiple imputation method to obtain information on fuel consumption at design speed.

Specifically, we rely on the statistical matching procedure proposed by Rubin (1986) which is based on file concatenation with adjusted weights. In the setting described in Rubin (1986), there are two databases A and B. Both A and B share a common set of variables X, but there are specific sets of variables Y and Z which are found only in A and B, respectively. To form a unique dataset comprising both X, Y and Z, Rubin (1986) proposes to concatenate both files and use adjusted weights. Linear regressions explaining Y and Z as a function of X are then used to predict values for observations with either missing values for Y or missing values for Z. An implicit assumption is that Y and Z are conditionally independent given X, but some information on the partial correlation $\rho_{Y,Z|X}$ between Y and Z conditional on X can nonetheless be used (Moriarity and Scheuren, 2003).[6] We proceed in the following way when

[4] See www.clarksons.net and login.ods-petrodata.com for details.

[5] The IMO number is specific to the hull for its whole lifetime regardless of any change in name, flag or ownership.

[6] When there is simultaneously information on both Y and Z in the same database (even for a subsample), the partial correlation $\rho_{Y,Z|X}$ can be calculated. In the matching procedure, the partial correlation is chosen in order to obtain the desired $\rho_{Y,Z|X}$ after matching. For details, see Alpman (2016).

turning to the data.

We start from the largest database corresponding to the OSV fleet restricted to AHTS and PSV vessels (4897 vessels). Due to technical differences in both types of vessels, we implement separate imputations for AHTS and PSV. For AHTS, there are 2583 vessels: 1281 have information on both speed and consumption, 1026 have information on speed only, and 26 have information on consumption only. The remaining 250 observations with no information on either speed or consumption are discarded. In our setting, Y is fuel consumption, Z is design speed and X includes deadweight (DWT) and year of building. For the 1281 vessels with non-missing information, the partial correlation $\rho_{Y,Z|X}$ between fuel consumption and design speed is 0.148 which is the target obtained after matching. For PSV, among the 2314 vessels, 1036 have information on both consumption and speed, 959 have information on speed only, 28 have information on consumption only and 291 have no information on consumption and speed (these observations were deleted). The partial correlation $\rho_{Y,Z|X}$ between fuel consumption and speed is 0.106.[7]

We end up with a database comprising information on 4356 vessels: 2333 AHTS and 2023 PSVs. For each vessel, we have complete information on fuel consumption, design speed, deadweight tonnes and year of construction. The proportion of imputed values is 45.1% for AHTS and 48.8% for PSV. Table 1 shows the resulting descriptive statistics for the key variables across the fleet, as well as for the imputed and 'non-imputed' sub-groups.[8] We note that the missing information relate to slightly younger tonnage. Typically, this is because reliable vessel information becomes gradually available to the database provider from owners and other market sources over time. The averages in Table 1 reflect the different use of the two vessel types, with PSVs being designed with a higher average carrying capacity at a more economical fuel consumption and AHTS vessels having a larger engine installation (higher fuel consumption) and higher design speed.

Data on the OSV fleet covers a long period of time since some vessels have been built more than 50 years ago. In our sample, the oldest vessels have been constructed in 1963 for AHTS and 1962 for PSV. There have been significant changes in the characteristics of PSVs over that period. Fig. 1 illustrates the long-term changes in DWT, design speed and fuel consumption as a function of the year of construction for AHTS and PSV, respectively. We note the consistent increase in vessel size over the sample period, and an apparent reduction in nominal vessel speeds and fuel consumption over the past decade, certainly for AHTS vessels. This could indicate an improvement in the nominal energy efficiency for modern tonnage, particularly as we have seen an increase in the size of the average engine installation for AHTS vessels over the same period (Adland et al, 2017b). The reduction in fuel consumption for younger tonnage is greater in the AHTS segment.

The fixture database covers the period 1989–2015 and includes 39,045 transactions. We delete 133 observations with missing information on the region where the contract is operated. The remaining 38,912 fixtures are then matched with the OSV fleet data. As vessels demolished more than four years ago no longer exist in the OSV database provided by Clarksons, we are not able to match all observations. Nevertheless, the matching rate still remains very high (97.3%). Overall, our sample selection consists of a total of 37,866 OSV fixtures matched with information on vessels.

OSVs can be hired to perform offshore support services in ether a short-term spot market (defined here as contracts with a duration less than 30 days) and longer contracts in the term market. In either case, the vessel is hired on a fixed daily rate (the dayrate) for the duration of the contract, which may be a firm time period with optional extension, or related to the duration of the marine operation that the vessel will support (e.g. a rig move or the drilling of a certain number of wells). In addition, the oil company or rig operator hiring the vessel (charterer) pays for the fuel and any harbor dues. As pointed out by Aas et al (2009), offshore installations used in drilling operations have more uncertain demand patterns for supplies, typically resulting in a heavier reliance on spot market chartering to cater for demand peaks. Similarly, rig moves are infrequent and of short duration, which creates an active spot market also for AHTS vessels (Adland et al, 2019). The OSV market is constituted by a series of regional markets where dayrates and technical requirements may differ substantially due to legal, fiscal or geographic differences.[9]

In our analysis, we include all spot and term fixtures between 1989 and 2015 for all regions over the world (Northwest Europe and other locations such as North Sea, Brazil or West Africa). Table 2 provides the breakdown of the sample by contract type, region and vessel type (AHTS and PSV). We note that although spot fixtures dominate in terms of number of contracts (80.7%), term contracts (19.3% of fixtures) have longer average duration such that the number of shipdays in the global term market is in fact larger. Importantly, the dominance in terms of spot market transactions is solely driven by the very liquid Northwest Europe spot market, while OSV capacity outside of this region is secured almost exclusively on term contracts. This can in part be explained by the maturity and size of the North Sea offshore market and the corresponding development of an efficient network of offshore brokers facilitating the matching of spot vessels and rig operator demand (ICS, 2011).[10]

Fig. 2 illustrates the change in the number of spot and term charter fixtures over time. Two broad trends are evident here. Firstly, both the AHTS and PSV markets saw a sharp increase in the number of term charters during the oil market boom until 2014, illustrating both the need to secure long-term operational control of tonnage in a fundamentally tight market, as well as the substantially lower daily hire for term charters compared to spot charters during this period. Secondly, following the sharp fall in the oil price and corresponding rig activity levels since end of 2014, the term contract activity has been reduced. In this case, the reasoning

[7] For AHTS, we fix the correlation to 0.066 to obtain $\rho_{Y,Z|X} = 0.148$ after matching. For PSV, the correlation is set to 0.045 to obtain $\rho_{Y,Z|X} = 0.106$ after matching.

[8] We have checked that our results remained unchanged without the concatenation procedure.

[9] These differences are, for instance, related to weather conditions (harsh environment, ice-persistent area) and to the localization of rigs (deep or shallow water, distance to the base port, etc.) (ICS, 2011).

[10] In emerging and smaller offshore markets, the low volume of transactions generally does not warrant such dedicated support services, making it preferable to secure tonnage on long-term contracts.

Table 1
Description of the OSV fleet.
Source: Authors' calculations, Clarksons Research OSV fleet database.

Vessels	AHTS			PSV		
	All	Not imputed	Imputed	All	Not imputed	Imputed
Fuel consumption (tonnes/day)	14.5	15.7	13.1	9.3	9.9	8.7
Design speed (knots)	13.7	13.8	13.5	12.9	13.0	12.9
Deadweight (tonnes)	1730	1756	1698	2525	2647	2397
Year of construction	1997	1994	2000	1998	1997	1999
Number of observations	2333	1281	1052	2023	1036	987

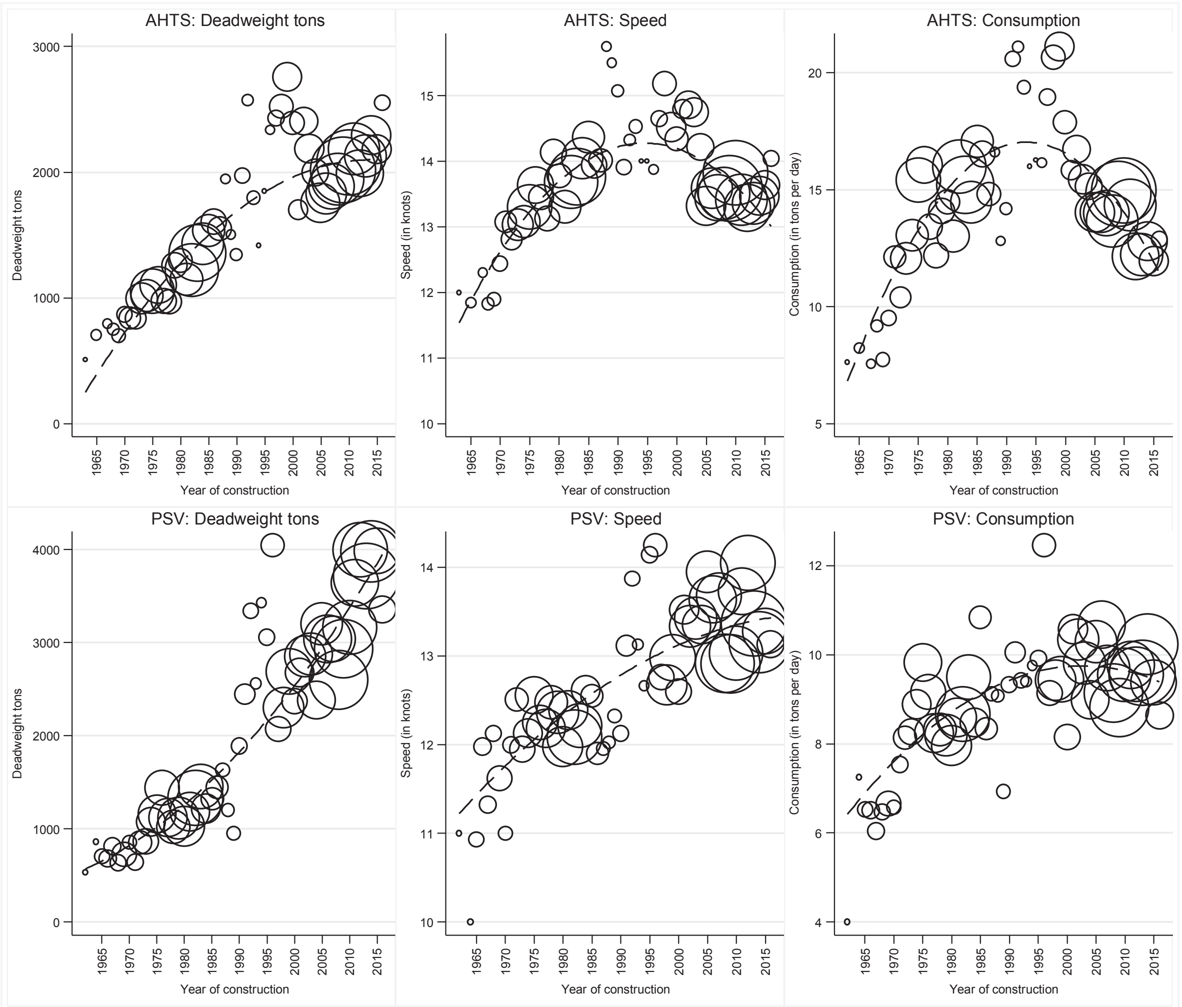

Fig. 1. Characteristics of the OSV fleet, by year of construction.
Source: Authors' calculations, Clarksons Research OSV fleet database. Note: the size of each circle is proportional to the corresponding number of vessels in the fleet.

works in reverse with the sudden reduction in demand leading to an oversupply of inexpensive quality vessels forced to operate on the spot market. In this situation, charterers neither have any need to secure long-term control of ships, nor is there a cost advantage of doing so. However, we note that while the reduction in term charter activity for PSVs has been somewhat compensated by an increase in spot market activity, this was not the case for the AHTS market. This reflects the fact that a large share of demand for PSVs is related to logistics services for offshore oil and gas production, which continued largely unabated even after the oil price fall, rather than exploration activities for which AHTS vessels play a key role.

Fig. 3 shows the development in OSV dayrates in our sample period. Of note is the higher volatility for AHTS vessels, with

Table 2
Number and average duration of PSV fixtures 1988–2015.
Source: Authors' calculations, Clarksons Research OSV fleet database and ODS Petrodata fixture database.

Fixtures	Spot		Term	
	Number	Duration (days)	Number	Duration (days)
Panel A. AHTS vessels				
Northwest Europe	17,710	3.6	683	294.1
Other locations	212	26.2	2917	536.0
All regions	17,922	3.9	3600	490.1
Panel B. PSV vessels				
Northwest Europe	12,394	4.2	683	389.8
Other locations	185	20.3	1988	639.2
All regions	12,579	4.4	3765	521.5
Panel C. All vessels				
Northwest Europe	30,104	3.9	683	363.2
Other locations	397	23.4	4905	577.8
All regions	30,501	4.1	7365	506.1

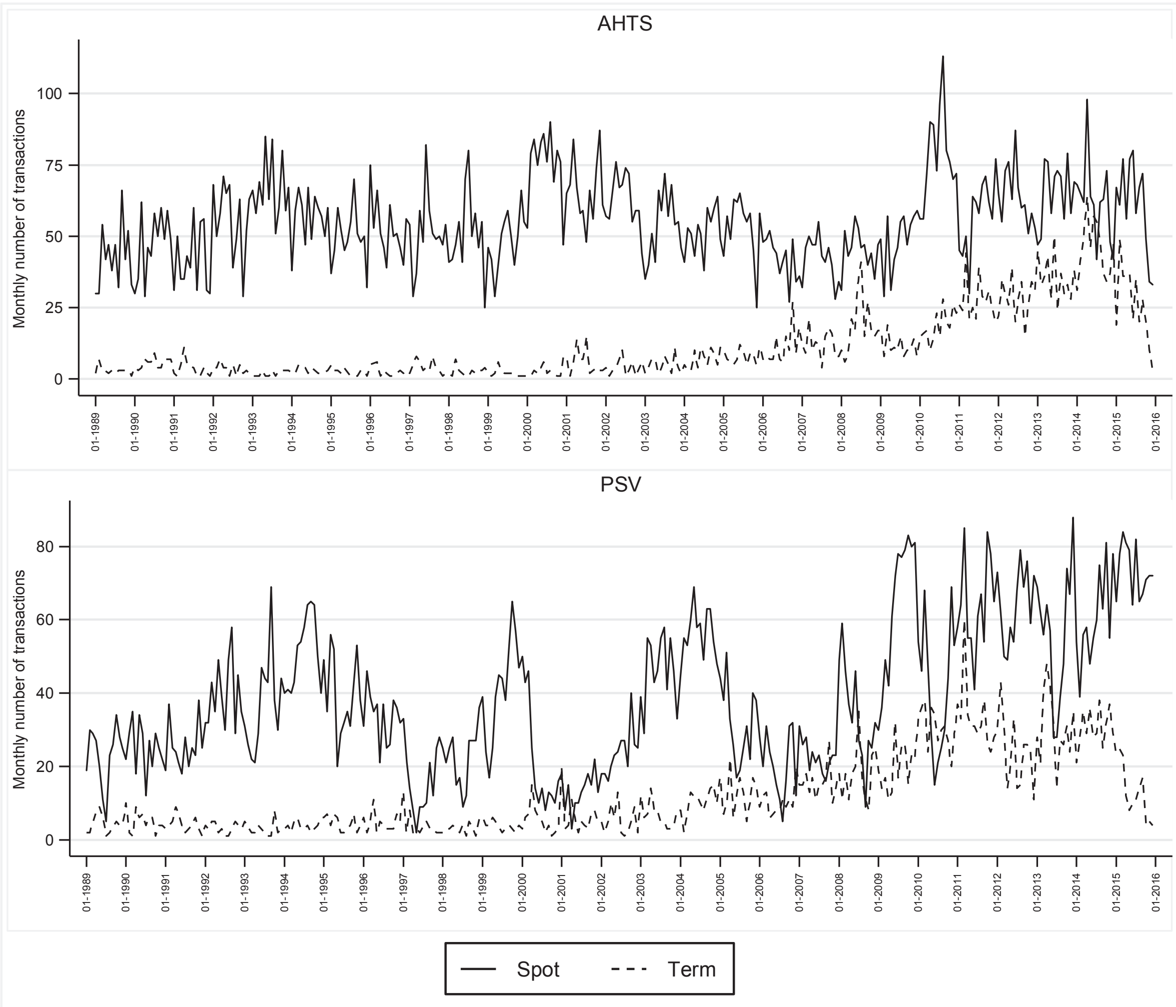

Fig. 2. Monthly number of OSV fixtures 1988–2015.
Source: Authors' calculations, Clarksons Research OSV fleet database and ODS Petrodata fixture database.

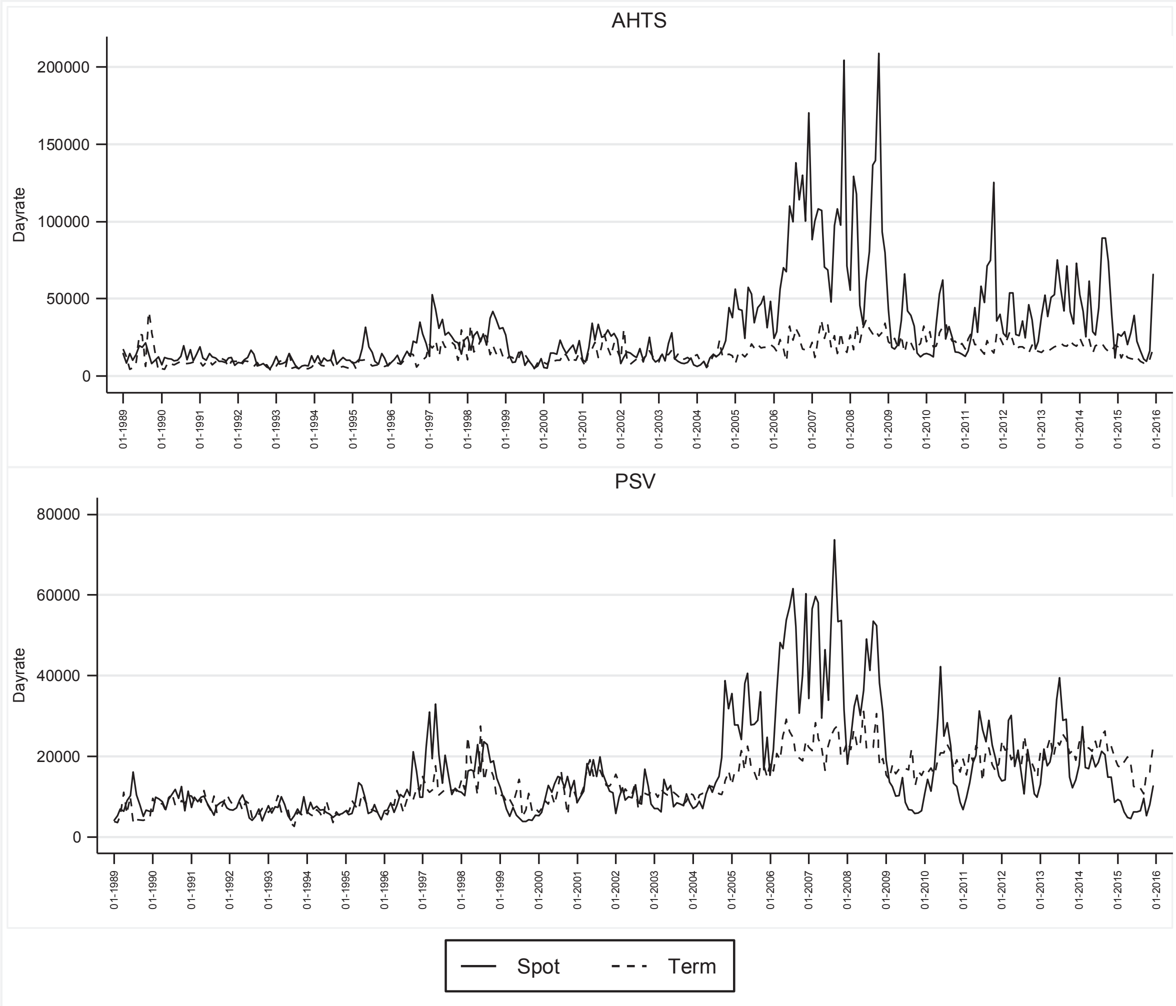

Fig. 3. Dayrates (in $/day) for OSV fixtures 1988–2015.
Source: Authors' calculations, Clarksons Research OSV fleet database and ODS Petrodata fixture database.

dayrates reaching as high as GBP 200,000/day in a strong spot market. This reflects the greater volatility in AHTS demand, with a single rig move taking out several vessels at the same time and many rig moves potentially occurring at the same time due to weather dependency. While PSV operation is also weather dependent, particularly the discharging operation offshore, the underlying supply flows between the offshore rigs and onshore bases are necessarily less volatile. We also see that the dayrates for term contracts are less volatile than dayrates for spot contracts, which is a general finding in the maritime economic literature (see Kavussanos, 1996).

We use two different measurements of energy efficiency: standard *Fuel consumption* (tonnes/day) and the *Deviation in fuel expenditure* ($/day) which is the deviation in daily fuel costs for a vessel relative to the fleet average at prevailing fuel prices. In both cases, a larger value denotes lower energy efficiency (either higher fuel consumption or higher fuel costs). As is common in the literature (Agnolucci et al., 2014; Adland et al., 2017a,b), all values refer to design conditions for the vessels and are not necessarily equal to the true fuel consumption in the seaway at observed operating speeds. However, while some owners may collect such detailed information, it is neither available across the fleet, nor for the duration of the sample. Table 3 presents the descriptive statistics for our dataset.

We see that average dayrates and fuel consumption are higher in the AHTS segment than for PSVs, both in the spot and term market, reflecting the generally larger engine installations on these vessels. We can also notice the general tendency that the vessels operating in the spot market are larger (as measured by *Brake horsepower* for AHTS vessels and *Deck area* for PSVs) than the average vessel operating on term contracts. Similarly, the more technologically sophisticated vessels tend to be reserved for the spot market, with a greater proportion of vessels having high grade dynamic positioning system (DP2), helideck, ROV support, ice class classification and European build. For the AHTS market, spot vessels are also younger than their counterparts in the term market, though

Table 3
Description of OSV fixtures 1989–2015.
Source: Authors' calculations, Clarksons Research OSV fleet database and ODS Petrodata fixture database.

Variables	AHTS		PSV	
	Spot	Term	Spot	Term
Dependent variable				
Dayrate ($/day)	30,063	18,758	14,399	17,790
Explanatory variables				
Fuel consumption (tonnes/day)	22.4	16.0	11.2	10.3
Brake horsepower	15,902	10,041		
Deck area (m^2)			3265	3090
Age (years)	7.8	8.6	10.6	9.5
Diesel electric engine	0.067	0.019	0.093	0.141
Dynamic positioning class 1	0.176	0.324	0.201	0.271
Dynamic positioning class 2	0.529	0.377	0.490	0.535
Remotely operated vehicle support	0.063	0.017	0.101	0.045
Ice class	0.458	0.149	0.100	0.071
Built in Northwest Europe	0.684	0.279	0.755	0.426
Built elsewhere	0.316	0.721	0.245	0.574
Activity: cargo run	0.225	0.000	0.753	0.001
Activity: rig move	0.561	0.001		
Activity: supply			0.214	0.033
Activity: other	0.214	0.999	0.032	0.967
Number of observations	17,922	3600	12,579	3765

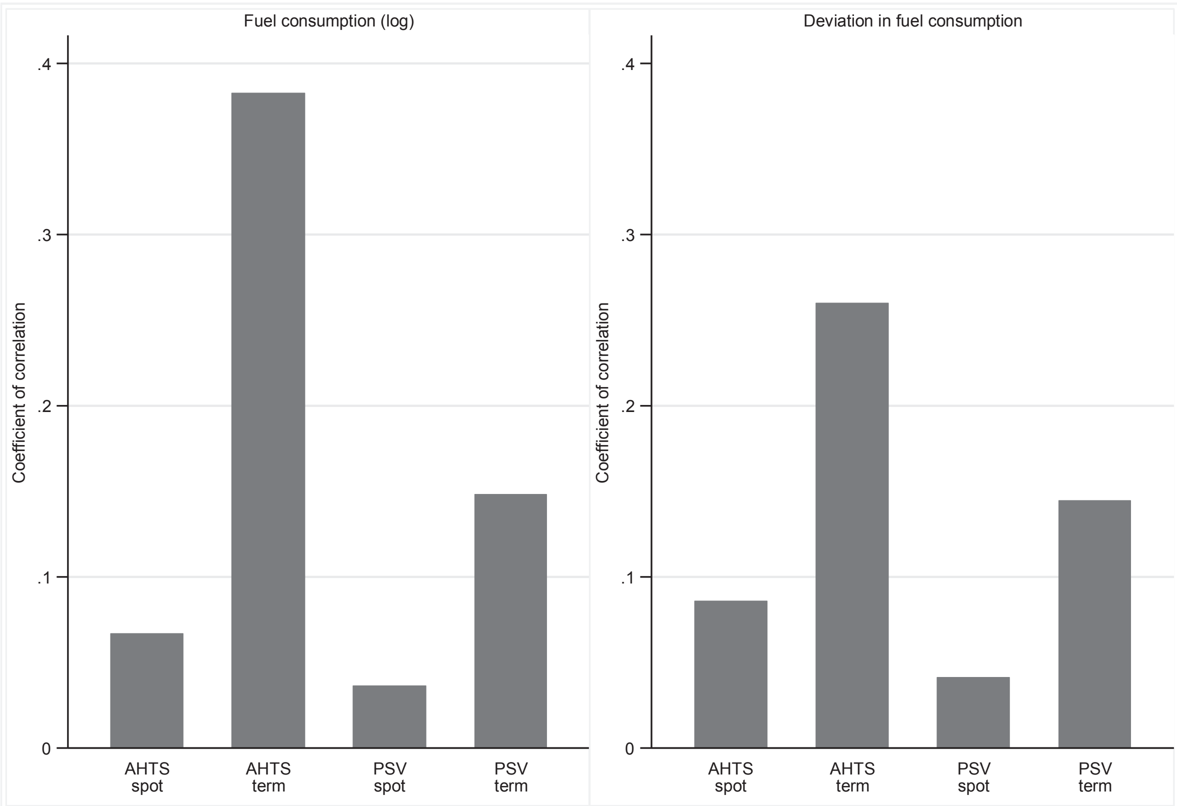

Fig. 4. Correlation between fuel efficiency measures and dayrates 1989–2015.
Source: Clarksons Research OSV fleet database and ODS Petrodata fixture database.

this does not hold for PSVs. As alluded to earlier, clients source AHTS vessels for rig moves from the spot market only.[11]

Finally, as an early check of the relationship between dayrates and fuel efficiency, Fig. 4 shows the estimated correlation between our two energy efficiency measures and dayrates for the AHTS/PSV segments and spot/term contracts, respectively. We see that for both markets and both contract types there exists an apparent positive relationship, with simple correlations ranging between less than 0.1 for all the spot markets to nearly 0.4 for the AHTS term market. However, in order to verify these relationships, we need to properly control for the observable and unobservable heterogeneity in the transactions.

3. The effect of energy efficiency on dayrates

We turn to regression models to assess the sign and magnitude of the correlation between dayrate and energy efficiency. For the presentation, we denote by D_{ft} the dayrate observed for a fixture f beginning at date t. In our setting, t is the starting day of the contract. The fixture f concerns a vessel v and a client c so that f as subscript is in fact $f(vc)$. Let E_{vt} be the energy efficiency of the vessel concerned by the contract f and X_{ft} the other characteristics either associated to the vessel or specific to the fixture (like the type of activity).[12] Following the hedonic equation model à la Rosen (1974), we estimate linear regressions such that:

$$\ln D_{ft} = \delta \ln E_{vt} + X_{ft}\beta + \mu_t + \pi_c + \varepsilon_{ft} \tag{1}$$

with δ the elasticity of energy efficiency on the dayrate, β a set of coefficients to estimate, μ_t a time fixed effect, π_c a client fixed effect and ε_{ft} a residual perturbation. We assume that $E(\varepsilon_{ft}) = 0$ and $V(\varepsilon_{ft}) = \sigma^2$. As there are two large series of fixed effects in our sample (there are about 500 clients and more than 6000 days), our model defines a two-way fixed effect model which can be estimated using a within transformation at the daily level and inclusion of client dummies (Abowd et al., 1999; Andrews et al., 2006). We do not consider the impact of shipowners due to the fragmented nature of the supply side. Capturing the market conditions using time fixed effects resolves the endogeneity problem introduced by the use of a market index as an explanatory variable (see Agnolucci et al, 2014; Adland et al., 2017b).

Following earlier research on the OSV market (Adland et al., 2017b), we expect that dayrates are positively related to vessel size, as measured by *Brake horsepower* for AHTS and *Deck area* for the PSV segment. Similarly, a common finding in the literature is that the relationship between age and freight rates is non-linear, with a premium for very modern vessels and a progressively increasing discount as vessels becomes older (Dick et al., 1998, Alizadeh and Talley, 2011a, 2011b; Adland et al., 2016). Finally, we expect that the more sophisticated *dynamic positioning class 2* obtains a premium, as do sophisticated technical solutions such as *Ice Class* classification and *Remotely Operated Vehicle support*. Vessels *Built in Northwest Europe* are also of a higher perceived quality and should attract a premium in dayrates. We also expect that AHTS vessels obtain higher rates when they are hired for a *rig move*, compared to being used for a *cargo run*, which is not their core activity.

Table 4A shows our estimates for the AHTS market[13]. For the spot market (specification 1A and 1B), nearly all coefficients are highly significant and have the expected sign irrespective of the energy efficiency measure we adopt. Principally, more advanced vessels (i.e. those with ice class notation, ROV support, and more advanced dynamic positioning systems) earn a premium dayrates, as do vessels with larger brake horsepower. Vessel age has the same non-linear impact on dayrates as found in the rest of the literature, with very modern vessels having a slight premium and older tonnage having to accept progressively larger discounts. Most importantly for our study of the relationship between energy efficiency and dayrates, the coefficients for both measures of energy efficiency is highly significant and positive, suggesting that energy-*inefficient* vessels are rewarded through higher dayrates. This confirms our *a priori* expectation that the immediacy of marine operations such as rig moves (and the high alternative cost of non-performance) means that energy efficiency is secondary to the capacity and operational performance of the vessel.

In the AHTS term market (specifications 2A and 2B), the significance of both the more sophisticated vessel attributes and energy efficiency disappears. The former could be explained by the observation that special features such as ice class or ROV support are required only for a limited number of contracts, and that clients are better off taking such vessels from the spot market when the need arises rather than paying for such features on a long-term charter.[14] Overall, AHTS vessels on term contracts can therefore be of a simpler design, just meeting the minimum standards set out in the clients' tenders. Indeed, the pricing mechanism appears to be very simple, with only vessel age, dynamic positioning system and size of the engine installation influencing dayrates, in addition to the charterer effect and market balance. While energy efficiency is no longer penalized, it is still not rewarded. This sets the AHTS market apart from the deep-sea timecharter markets investigated in the literature (Agnolucci et al., 2014; Adland et al., 2017a).

Table 4B shows our estimates for the PSV segment. For the spot market, the results are with the expected and significant positive relationship between dayrates and deck area, a non-linear impact of vessel age, and a premium attributed to advanced dynamic positioning, ROV support, Ice class and Northwest European build. Once again, the number of significant variables are reduced for the term market. However, we now have a situation where energy efficiency is a significant determinant only in the term market. Arguably, this is aligned with the observation that the supply duties normally undertaken by PSVs are less time sensitive than the rig

[11] We do not distinguish between regions in Table 3. Many of our findings are a result of the North Sea spot market dominating in our sample. Given the harsh operating environment in this area of the world, the vessels are necessarily larger, stronger and more sophisticated, with simpler, smaller vessels being relegated to the benign waters of Southeast Asia and the Middle East (ICS, 2011).

[12] The energy efficiency E_{vt} refers to the vessel v since it is a time-invariant vessel characteristic.

[13] Our models are characterized by a very high explanatory power with an R^2 of 0.939 for the spot market and 0.967 for the term market.

[14] This suggests that an AHTS vessel on a term charter is to assist in marine operations of a more stable nature.

Table 4A
Estimates of the log of dayrate AHTS 1989–2015.
Source: Clarksons Research OSV fleet database and ODS Petrodata fixture database.

Variables	AHTS spot		AHTS term	
	(1A)	(1B)	(2A)	(2B)
Fuel consumption (log)	0.019***		−0.001	
	(2.95)		(−0.03)	
Deviation in fuel expenditure (normalized)		0.023***		0.012
		(5.60)		(0.86)
Brake horsepower (log)	0.511***	0.514***	0.904***	0.893***
	(34.99)	(36.06)	(30.30)	(31.00)
Age (/10)	0.093***	0.095***	0.110***	0.108***
	(6.32)	(6.46)	(3.63)	(3.58)
Age^2 (/100)	−0.074***	−0.075***	−0.052***	−0.052***
	(−11.14)	(−11.25)	(−5.29)	(−5.30)
Diesel electric engine	0.015	0.004	−0.063	−0.063
	(1.31)	(0.31)	(−1.26)	(−1.27)
Dynamic positioning class 1	0.052***	0.054***	0.103***	0.103***
	(5.30)	(5.58)	(4.39)	(4.37)
Dynamic positioning class 2	0.040***	0.045***	0.146***	0.145***
	(3.21)	(3.64)	(4.97)	(4.97)
Remotely operated vehicle support	0.047***	0.049***	−0.025	−0.021
	(4.10)	(4.27)	(−0.45)	(−0.37)
Ice Class	0.031***	0.030***	−0.038	−0.040
	(5.33)	(5.23)	(−1.46)	(−1.52)
Built in Northwest Europe	0.035***	0.034***	0.029	0.031
	(5.72)	(5.68)	(1.19)	(1.29)
Activity: cargo run	−0.197***	−0.197***		
	(−18.82)	(−18.82)		
Activity: rig move	0.019**	0.019**	0.242	0.239
	(2.09)	(2.12)	(1.14)	(1.12)
Region: Northwest Europe	−0.162***	−0.169***	−0.048	−0.050
	(−3.26)	(−3.39)	(−1.03)	(−1.09)
Week fixed effects	YES		YES	
Client fixed effects	YES		YES	
Number of observations	17,922	17,922	3600	3600
R^2	0.940	0.940	0.967	0.967

Note: estimates from linear regression models, with robust standard errors in parentheses. Significance levels are 1% (***), 5% (**) and 10% (*).

moves undertaken by large AHTS vessels. Instead, what matters in the term market appears to be the ability to maintain consistent high speeds such that the long-term contracted base fleet serving the cluster of rigs can be reduced. Clients are willing to pay for this implicit economies of scale effect provided by fuel inefficient PSV vessels through higher dayrates.

Up to this point, we have only considered the effects of energy efficiency on dayrates. However, the true annual revenue generated by an Offshore Support vessel is a function of both the dayrates obtained for individual contracts and the number of contracted days per year. The latter measure can be taken as an indication of vessel demand (utilization), provided that the transparency and coverage of public fixture data is sufficiently high. Having established the impact on dayrates for individual contracts we therefore proceed to estimate the impact of vessel characteristics and energy efficiency on demand at the micro level. The dependent variable is the number of contracted days per year and per vessel (Table 5). Due to the limited differences between the two energy efficiency measures, we here only consider fuel consumption as explanatory variable (in addition to the other vessel characteristics).

Higher fuel consumption is positively related to vessel demand in the AHTS spot and PSV term market, with high fuel consumption vessels (low energy efficiency) being contracted for a greater number of days per year. Accordingly, in the AHTS spot market, energy efficiency is penalized both through lower utilization and a discount in spot dayrates. However, as we have evidenced, AHTS spot market vessels deal mainly with the most sophisticated and time-sensitive of all marine operations such as rig moves. This merely reflects preferences for vessels with large engines, and correspondingly high fuel consumption, that can deliver such services with high reliability. There is also ‘economies of scale’ in the OSV chartering market, where dayrates are not proportional to engine power or deck area. Consequently, it will be cheaper for clients to hire fewer large AHTS vessels to facilitate a rig move than a larger number of smaller AHTS vessels, while also catering for a safety buffer in total pulling power available. Similarly, a fleet consisting of faster, larger PSV vessels can supply a cluster of rigs with a smaller fleet (Aas et al, 2009). As a result, advanced vessels with large fuel-inefficient engine installations get the dual benefit of higher rates and higher utilization.

Interestingly, advanced design features such as diesel-electric propulsion, ROV support and ice class do not result in a vessel having higher utilization. Indeed, the only significant technical vessel variables in Table 5 are ROV support and DP2 in the AHTS market, both negative. This indicates that ROV support capabilities obtain a premium when required, yet most contracts do not require the feature, in which case preference may be given to simpler and cheaper vessels. We note here that our work does not clarify whether the added revenue is sufficient to warrant the substantial added investment cost of such advanced tonnage. From a

Table 4B
Estimates of the log of dayrate PSV 1989–2015.
Source: Clarksons Research OSV fleet database and ODS Petrodata fixture database.

Variables	PSV spot		PSV term	
	(1A)	(1B)	(2A)	(2B)
Fuel consumption (log)	0.007***		0.061**	
	(0.68)		(2.47)	
Deviation in fuel expenditure (normalized)		0.010		0.079***
		(0.81)		(2.68)
Deck area (log)	0.358***	0.359***	0.545***	0.542***
	(28.15)	(28.94)	(14.32)	(14.23)
Age (/10)	0.022*	0.022*	0.015	0.013
	(1.86)	(1.85)	(0.45)	(0.40)
Age^2 (/100)	−0.027***	−0.027***	−0.032***	−0.031***
	(−6.70)	(−6.69)	(−3.61)	(−3.53)
Diesel electric engine	0.020*	0.020*	0.042	0.041
	(1.78)	(1.79)	(1.64)	(1.62)
Dynamic positioning class 1	0.020**	0.020**	0.095***	0.100***
	(2.12)	(2.12)	(2.81)	(3.00)
Dynamic positioning class 2	0.061***	0.061***	0.219***	0.226***
	(5.81)	(5.84)	(5.58)	(5.83)
Remotely operated vehicle support	0.025**	0.025**	0.064	0.060
	(2.45)	(2.48)	(1.17)	(1.09)
Ice Class	0.041***	0.041***	0.014	0.013
	(4.11)	(4.08)	(0.39)	(0.36)
Built in Northwest Europe	0.029***	0.029***	0.028	0.029
	(3.87)	(3.90)	(1.09)	(1.12)
Activity: cargo run	−0.104***	−0.105***		
	(−5.22)	(−5.23)		
Activity: supply	−0.013	−0.013	−0.021	−0.016
	(−0.60)	(−0.61)	(−0.40)	(−0.31)
Region: Northwest Europe	−0.134***	−0.134***	−0.048	−0.048
	(−3.03)	(−3.05)	(−1.23)	(−1.25)
Week fixed effects	YES		YES	
Client fixed effects	YES		YES	
Number of observations	12,579	12,579	3765	3765
R^2	0.944	0.944	0.941	0.941

Note: estimates from linear regression models, with robust standard errors in parentheses. Significance levels are 1% (***), 5% (**) and 10% (*).

managerial perspective this is a highly interesting research question, though due to the lack of asset values in this specialized market it is challenging to answer.

4. Conclusion

In this paper, we have investigated the existence of an energy efficiency premium/discount in contracts for the chartering of Offshore Support Vessels (OSV) by applying hedonic pricing models with time fixed effects to account properly for market conditions. We find that energy efficiency is a significant determinant of dayrates in the spot market for AHTS vessels and term market for PSVs, but that rates are positively related to energy consumption or fuel expenditure. This suggests a structure where vessels with lower energy efficiency (i.e. higher absolute fuel consumption or fuel expenditures relative to the fleet average) obtain higher dayrates in the chartering market. This occurs even though the client pays for the fuel, i.e. this is not a compensation to the shipowner for higher fuel costs.

If we had not considered the special structure of the OSV markets, as outlined in the introduction, our findings could easily be interpreted as a market failure[15]. However, particularly in the AHTS spot market, vessels are hired for extremely short-term, complex marine operations dealing with highly capital-intensive drilling and production rigs (Gaspar et al., 2012, 2015). In this context, due to the extremely high cost of non-performance (e.g. the inability to move a drilling rig), the ability of a vessel to operate safely and timely in a wide range of weather conditions will trump the relatively modest savings from having an energy-efficient vessel. As a consequence, if energy efficiency is a selection criteria used by contractors, it expectedly has a rather limited impact on the final choice in non-transport related shipping markets such as OSV. When exploring the impact on vessel utilization, we also find that energy efficiency is penalized.

Nevertheless, environmental considerations are not entirely foreign for OSV clients, as evidenced by increasing interest in hybrid

[15] See Rehmatulla and Smith (2015) and Acciaro et al. (2013) for a detailed account of market failures in shipping as it applies to energy efficiency.

Table 5
Log of contracted days per year PSV 1989–2015.
Source: Authors' calculations.

Variables	AHTS spot (1A)	AHTS term (1B)	PSV spot (2A)	PSV term (2B)
Fuel consumption (log)	0.222***	0.027	−0.105	0.106**
	(2.79)	(0.58)	(−0.93)	(2.47)
Brake horsepower (log)	0.651***	0.021		
	(4.98)	(0.40)		
Deck area (log)			0.194	0.049
			(1.47)	(0.93)
Age (/10)	0.247*	0.033	−0.156	−0.184***
	(1.78)	(0.67)	(−1.18)	(−4.47)
Age^2 (/100)	−0.174***	−0.041**	0.064	0.022*
	(−3.08)	(−2.49)	(1.55)	(1.69)
Diesel electric engine	0.103	0.035	−0.155	0.005
	(0.62)	(0.33)	(−1.37)	(0.14)
Dynamic positioning class 1	0.031	−0.017	0.149	0.049
	(0.30)	(−0.42)	(1.59)	(1.09)
Dynamic positioning class 2	0.030	−0.164***	0.043	−0.081
	(0.20)	(−3.09)	(0.40)	(−1.61)
Remotely operated vehicle support	−0.451**	−0.250***	0.072	−0.095
	(−2.05)	(−2.60)	(0.47)	(−1.21)
Ice Class	0.022	0.037	−0.004	−0.051
	(0.30)	(0.78)	(−0.04)	(−0.98)
Built in Norwest Europe	0.107	0.085**	0.078	0.071**
	(1.46)	(1.96)	(0.95)	(1.97)
Region: Northwest Europe	−0.077	−0.214***	−0.115	−0.151***
	(−0.56)	(−3.42)	(−0.85)	(−4.00)
Constant	−3.413***	4.566***	2.173***	4.574***
	(−3.22)	(10.22)	(2.98)	(13.41)
Year fixed effects	YES	YES	YES	YES
Number of observations	1866	6144	1710	5870
Log likelihood	0.349	0.063	0.293	0.060

Note: estimates from linear regression models, with standard errors clustered at the vessel level in parentheses. Significance levels are 1% (***), 5% (**) and 10% (*).

battery-diesel solutions for propulsion (Lindstad et al., 2017). Such solutions could remove the economic reward for energy inefficiency in the future. Future research in this area should account for vessel availability in the chartering process. In reality, a charterer may only select its candidate vessel from a small available subset of the overall fleet, i.e. those vessels that are not under contract elsewhere at the time. Ideally, this would require the full employment history of every vessel, including the actual date of redelivery under a contract and any periods of unemployment. The actual contract duration cannot always be observed from the fixture data we have at hand, as the end date may be tied to a marine operation of unknown duration, such as the drilling of a well. With this in mind, the observed choice of vessels (in terms of a rate premium or higher utilization) may be partly determined by vessel availability, which is exogenous, and not only reflect the preferences of the charterer.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.trd.2019.04.006.

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