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"GREEN INVESTMENT UNDER MARKET UNCERTAINTY: SCRUBBER INSTALLATION IN SHIPPING"

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Green Investment Under Market Uncertainty: Scrubber Installation in Shipping

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In 2020, the International Maritime Organization implemented a limit to the sulphur content emitted by vessels. To comply, a vessel should either incur the capital cost to be retrofitted with a scrubber or burn fuels that emit less sulphur but are more expensive. We examine this dilemma by developing a Vector Error Correction Model that links freight rates, fuel prices, and the green investment decision of scrubber installation. The results, across the tanker and dry bulk sectors from 2021 to 2024, suggest that the freight premium of scrubber-fitted vessels positively depends on the spread between very low- and high-sulphur fuel oil prices and negatively on the size of the scrubber-fitted fleet. Scrubber investment, in turn, is determined by the past freight premium and the fuel spread. Being the first to investigate the interplay between green shipping investment and price uncertainty, our findings yield significant industry and policy implications.

Introduction

Shipping is considered as the backbone of the global economy since it accounts for more than 80 percent of world trade in terms of volume (Abadie *et al*., 2017; Clarksons' Shipping Intelligence Network, 2024). Due to its large scale of operations though, it generates around 2.8% of the global greenhouse gas (GHGs) emissions, which are harmful to both human health and the environment (UNCTAD, 2023). Exhaust emissions mostly include gases like carbon monoxide (CO), carbon dioxide (CO2), nitrogen oxides (NOx), sulphur oxides (SOx), water vapor, and hydrocarbons.

In 2005, Annex VI of the International Maritime Organizations' (IMO's) International Convention for the Prevention of Pollution from Ships (MARPOL) capped the SOx emissions from marine fuels to 4.5% (Tran, 2017). This regulation has introduced a dilemma to shipowners regarding whether to equip their fleet with a scrubber or not. Scrubber installation entails a relatively high capital expenditure. On the one hand, once installed with a scrubber, the vessel can burn the cheaper high sulphur fuel oil (HSFO) and earn a time-charter freight premium compared to the non-scrubber-fitted one. On the other hand, not installing a scrubber allows the continuation of normal operations without incurring the extra capital expenditure, although the vessel will be burning the more expensive very low sulphur fuel oil (VLSFO); the difference between VLSFO and HSFO is referred to as fuel spread. To the best of our knowledge, no study has fully explored the interrelationships between the fuel spread, freight premium and green investment decisions of scrubber installation, utilizing actual shipping data.

Ioannis Moutzouris, Ph.D., a co-author of this article, provided a lecture on December 4, 2023, which covered "Financing the Transition to Net Zero Shipping." Dr. Moutzouris is the Onassis Associate Professor of Shipping Finance and Sustainability at Bayes Business School (U.K.), and this lecture took place at Bayes on December 4, 2023.

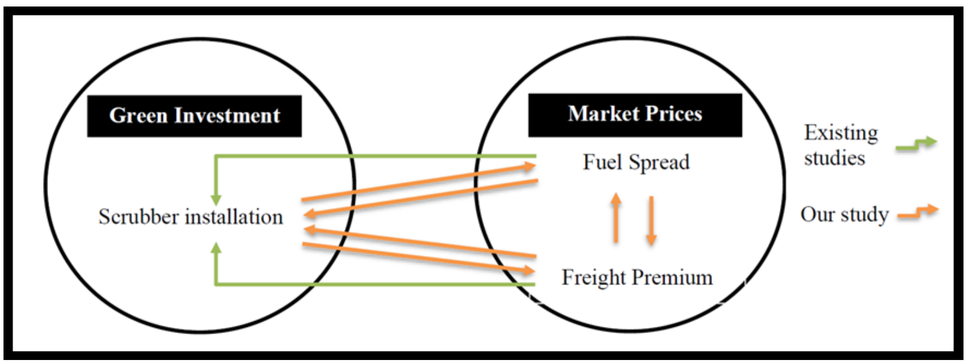
Relevance of the Research Question

As shown in Figure 1 on the next page, our study aims to explore the causality and reverse causality between green investment and market prices, taking the example of scrubber investment in shipping. While most of the existing studies only focus on how market prices influence the decision of scrubber installation, according to supply-and-demand fundamentals, the freight premium should also depend on the availability of scrubber-fitted vessels. Namely, for a given demand for a HSFO-burning fleet, a supply increase of scrubber-fitted vessels relative to non-scrubber-fitted ones is expected to lower the premium paid to charter the scrubber-fitted vessel. At the same time, the increased supply of scrubber-fitted vessels may also affect the availability of fuels, thereby influencing the fuel spread. What is more, there is lack of empirical studies examining the relationship between freight premium and fuel spread. Since scrubbers reduce the fuel costs for the charterer of the vessel, one should expect that the freight premium for a scrubber-fitted vessel positively depends on the spread between the VLSFO and HSFO prices.

To that end, our main research questions are (i) whether financial incentives, in the form of freight and fuel prices, drive the investment decision of scrubber installation; and (ii) whether scrubber investment affects these market prices in return.

From a policy perspective, providing rigorous data-driven evidence about the first question can build evidence on whether improved financial performance of vessels drives the industry's investment in green shipping technologies. Answering the second question can have important industry implications by informing shipping and chartering companies' commercial policies as well as shipbrokers' assessments of future freight rates. In addition, examining whether the demand for HSFO-fuelled vessels negatively affects the fuel spread can provide clarity about whether the demand for different marine fuel types affects their prices and availability.

Figure 1
Our Contributions to Green Investment under Market Uncertainty



Data and Initial Findings

We collect weekly frequency data from Clarksons' Shipping Intelligence Network platform for the period, 05/08/2020 to 08/23/2024. The income premium variable (*Δincome*) is generated by differentiating the 1-year time-charter rates between scrubber- and non-scrubber-fitted vessels. The fuel spread variable (*Δfuel*) is estimated by subtracting the prices of HSFO from those of VLSFO. Furthermore, monthly data from May 2020 to August 2024 are gathered to create fleet supply variable (*Δsupply*) by estimating the change in the size of scrubber-fitted fleet among the total fleet development.

The Perron (1997) unit root test suggests that all variables are non-stationary. The Johansen and Juselius (1990, 1992) test indicates cointegration. We then use a Vector Error Correction Model (VECM) to identify the nature of the long-run and short-run relationships between the variables of interest (see Equations 1-3 on the next page.) Using a model based on the difference variables only may imply loss of information on linkages displayed purely over the long run that may prove to be useful for shipowners, charterers and policy makers alike. In the presence of a cointegrating relationship there is always a corresponding error-correction representation that captures the level of disequilibrium in the long-term relationship due to changes in the dependent variable, as well as in the other explanatory variables (Engle and Granger, 1987).

The model equations are defined as:

$$\Delta income_{j,t} = \alpha_{01} + \sum_{i=1}^{q} \alpha_{1,i} \Delta income_{j,t-i} + \sum_{i=1}^{q} \beta_{1,i} \Delta fuel_{t-i} + \sum_{i=1}^{q} \delta_{1,i} \Delta supply_{j,t-i} + \gamma_1 \big(income_{j,t-i} + \theta_1 fuel_{t-i} + \theta_2 supply_{j,t-i} + \theta_{01} + \theta_{02}\big) + \varepsilon_{1,t}, \qquad \text{(Eq. 1)}$$

$$\Delta fuel_{t} = \alpha_{02} + \sum_{i=1}^{q} \alpha_{2,i} \Delta income_{j,t-i} + \sum_{i=1}^{q} \beta_{2,i} \Delta fuel_{t-i} + \sum_{i=1}^{q} \delta_{2,i} \Delta supply_{j,t-i} + \gamma_2 \big(income_{j,t-i} + \theta_1 fuel_{t-i} + \theta_2 supply_{j,t-i} + \theta_{01} + \theta_{02}\big) + \varepsilon_{1,t}, \qquad \text{(Eq. 2)}$$

$$\Delta supply_{j,t} = \alpha_{03} + \sum_{i=1}^{q} \alpha_{3,i} \Delta income_{j,t-i} + \sum_{i=1}^{q} \beta_{3,i} \Delta fuel_{t-i} + \sum_{i=1}^{q} \delta_{3,i} \Delta supply_{j,t-i} + \gamma_3 \big(income_{j,t-i} + \theta_1 fuel_{t-i} + \theta_2 supply_{j,t-i} + \theta_{01} + \theta_{02}\big) + \varepsilon_{1,t} \qquad \text{(Eq. 3)}$$

The short-run dynamics are captured by the coefficients of the differenced variables; and the terms in brackets, $\big(income_{j,t-i} + \theta_1 fuel_{t-i} + \theta_2 supply_{j,t-i} + \theta_{01} + \theta_{02}\big)$, represent the error correction term (ECT), which provides the cointegrating (long-run) relationship between the series. The parameter γ_i measures the speed of adjustment of the series to the long run equilibrium. The model permits inference on both short run and, to a certain extent, long run linkages.

Methodology and Main Empirical Results

The estimation results in Tables 1a and 1b on the next two pages suggest that the model can capture a large fraction of the variation in the income, fuel, and supply variables since all adjusted R-squared values are above 80%, with most approaching 90%.

Furthermore, all gamma coefficients (Column γ=1,2,3) are small in magnitude and statistically significant, indicating an adequate specification of the VECM model. Their negative signs imply that, when there is a positive (negative) deviation from the long-run equilibrium, the respective variable(s) will decrease (increase) to revert to it. For example, the income premium is expected to decrease following an increase in the previous period.

Table 1a
Results of VECM (Tanker Market)

$$\Delta income_{j,t} = \sum_{i=1}^{q} a_i \Delta income_{j,t-i} + \sum_{i=1}^{q} a_i \Delta fuel_{t-i} + \sum_{i=1}^{q} a_i \Delta supply_{j,t-i} + \gamma_1 \left(income_{j,t-i} + \theta_1 fuel_{t-i} + \theta_2 supply_{j,t-i} + \theta_{01} + \theta_{02} \right) + \varepsilon_{1,t} \quad \text{(Eq. 1)}$$

$$\Delta fuel_{t} = \sum_{i=1}^{q} a_i \Delta income_{j,t-i} + \sum_{i=1}^{q} a_i \Delta fuel_{t-i} + \sum_{i=1}^{q} a_i \Delta supply_{j,t-i} + \gamma_2 \left(income_{j,t-i} + \theta_1 fuel_{t-i} + \theta_2 supply_{j,t-i} + \theta_{01} + \theta_{02} \right) + \varepsilon_{1,t} \quad \text{(Eq. 2)}$$

$$\Delta supply_{j,t} = \sum_{i=1}^{q} a_i \Delta income_{j,t-i} + \sum_{i=1}^{q} a_i \Delta fuel_{t-i} + \sum_{i=1}^{q} a_i \Delta supply_{j,t-i} + \gamma_3 \left(income_{j,t-i} + \theta_1 fuel_{t-i} + \theta_2 supply_{j,t-i} + \theta_{01} + \theta_{02} \right) + \varepsilon_{1,t} \quad \text{(Eq. 3)}$$

	Estimated Model					Cointegrating equation				
	$\gamma = 1,2,3$	$\Delta income_{j,t}$	$\Delta fuel_t$	$\Delta supply_{j,t}$	$\bar{R}^2$	[1	θ_1	θ_2	θ_{01}	θ_{02}]
$j =$ **VLCC**					0.896	[1	0.0658[a]	-2.3278[a]	-0.0058	1.7496]
							(0.000)	(0.001)		
$\Delta income_{j,t-1}$	-0.0012[a]	0.0234[c]	0.9918[b]	0.0010[c]						
	(0.000)	(0.061)	(0.038)	(0.055)						
$\Delta fuel_{t-1}$	-0.0051[a]	0.8516[a]	0.3507[c]	0.003[b]						
	(0.001)	(0.007)	(0.087)	(0.028)						
$\Delta supply_{j,t-4}$	-0.0019[a]	-2.0348[a]	-1.0683[b]	- 0.0028[c]						
	(0.003)	(0.008)	(0.034)	(0.076)						
$j =$ **Suezmax**					0.873	[1	0.0593[a]	-3.8787[a]	-0.0016	0.6685]
							(0.005)	(0.001)		
$\Delta income_{j,t-1}$	-0.0075[a]	0.0359[a]	0.9566[b]	0.0057[b]						
	(0.008)	(0.007)	(0.030)	(0.035)						
$\Delta fuel_{t-1}$	-0.0603[b]	0.7019[c]	0.3560[a]	0.0006[b]						
	(0.035)	(0.061)	(0.008)	(0.041)						
$\Delta supply_{j,t-4}$	-0.0012[a]	-3.8062[a]	-1.8846[a]	-0.0039[c]						
	(0.005)	(0.007)	(0.001)	(0.068)						
$j =$ **Aframax**					0.810	[1	0.0604[c]	- 5.1945[c]	-0.0006	0.1194]
							(0.052)	(0.076)		
$\Delta income_{j,t-1}$	-0.0043[a]	0.1365[c]	0.2156[c]	0.0002[c]						
	(0.006)	(0.067)	(0.074)	(0.074)						
$\Delta fuel_{t-1}$	-0.0073[b]	0.3920[a]	0.3735[b]	0.0023[b]						
	(0.045)	(0.007)	(0.041)	(0.021)						
$\Delta supply_{j,t-4}$	-0.0010[c]	-2.4557[a]	-0.9782[b]	-0.0032[a]						
	(0.071)	(0.003)	(0.050)	(0.063)						
$j =$ **Panamax**					0.894	[1	0.0319[a]	-2.7158[a]	-0.0007	0.0793]
							(0.001)	(0.008)		
$\Delta income_{j,t-1}$	-0.0061[a]	0.0241[c]	0.3672[b]	0.0002[b]						
	(0.004)	(0.057)	(0.045)	(0.030)						
$\Delta fuel_{t-1}$	-0.0092[b]	0.9211[b]	0.3507[a]	0.0003[b]						
	(0.030)	(0.033)	(0.009)	(0.046)						
$\Delta supply_{j,t-4}$	-0.0095[a]	-1.4419[a]	-0.9272[b]	-0.0012[c]						
	(0.005)	(0.007)	(0.037)	(0.076)						
$j =$ **Handysize**					0.889	[1	0.0014[a]	-4.6173[a]	-0.0018	1.2819]
							(0.008)	(0.000)		
$\Delta income_{j,t-1}$	-0.0072[a]	0.0337[c]	0.7389[c]	0.0002[c]						
	(0.009)	(0.071)	(0.076)	(0.054)						
$\Delta fuel_{t-1}$	-0.0058[a]	0.9948[b]	0.3730[c]	0.0003[b]						
	(0.001)	(0.031)	(0.075)	(0.035)						
$\Delta supply_{j,t-4}$	-0.0064[b]	-2.5148[a]	-1.0034[c]	-0.0016[c]						
	(0.015)	(0.001)	(0.062)	(0.073)						

Superscripts a, b, and c denote significance at the 1, 5, and 10 percent level, respectively. Values in (.) are standard errors.

Table 1b
Results of VECM (Dry Bulk Market)

$$\Delta income_{j,t} = \sum_{i=1}^{q} a_i \Delta income_{j,t-i} + \sum_{i=1}^{q} a_i \Delta fuel_{t-i} + \sum_{i=1}^{q} a_i \Delta supply_{j,t-i} + \gamma_1 (income_{j,t-i} + \theta_1 fuel_{t-i} + \theta_2 supply_{j,t-i} + \theta_{01} + \theta_{02}) + \varepsilon_{1,t} \quad \text{(Eq. 1)}$$

$$\Delta fuel_{t} = \sum_{i=1}^{q} a_i \Delta income_{j,t-i} + \sum_{i=1}^{q} a_i \Delta fuel_{t-i} + \sum_{i=1}^{q} a_i \Delta supply_{j,t-i} + \gamma_2 (income_{j,t-i} + \theta_1 fuel_{t-i} + \theta_2 supply_{j,t-i} + \theta_{01} + \theta_{02}) + \varepsilon_{1,t} \quad \text{(Eq. 2)}$$

$$\Delta supply_{j,t} = \sum_{i=1}^{q} a_i \Delta income_{j,t-i} + \sum_{i=1}^{q} a_i \Delta fuel_{t-i} + \sum_{i=1}^{q} a_i \Delta supply_{j,t-i} + \gamma_3 (income_{j,t-i} + \theta_1 fuel_{t-i} + \theta_2 supply_{j,t-i} + \theta_{01} + \theta_{02}) + \varepsilon_{1,t} \quad \text{(Eq. 3)}$$

	Estimated Model					Cointegrating equation				
	$\gamma = 1,2,3$	$\Delta income_{j,t}$	$\Delta fuel_{j,t}$	$\Delta supply_{j,t}$	$\bar{R}^2$	[1	θ_1	θ_2	θ_{01}	θ_{02}]
$j =$ **Capesize (Atlantic)**					0.893	[1	0.8762[b] (0.042)	-3.7820[b] (0.039)	-0.0020	0.4584]
$\Delta income_{j,t-1}$	-0.0386[a] (0.005)	0.0752[c] (0.078)	0.0567[c] (0.090)	0.0052[c] (0.065)						
$\Delta fuel_{t-1}$	-0.0052[b] (0.011)	1.6048[a] (0.006)	0.2482[c] (0.068)	0.0033[c] (0.070)						
$\Delta supply_{j,t-4}$	-0.0043[a] (0.003)	-2.6530[a] (0.005)	-0.5630[c] (0.078)	-0.0022[c] (0.081)						
$j =$ **Capesize (Pacific)**					0.882	[1	0.6791[a] (0.001)	-3.9716[a] (0.001)	-0.0059	0.7893]
$\Delta income_{j,t-1}$	-0.0043[a] (0.000)	0.3125[c] (0.083)	0.0630[c] (0.065)	0.0014[c] (0.080)						
$\Delta fuel_{t-1}$	-0.0004[a] (0.008)	1.1772[b] (0.038)	0.1870[c] (0.052)	0.0027[c] (0.065)						
$\Delta supply_{j,t-4}$	-0.0071[a] (0.009)	-2.5910[a] (0.007)	-0.6920[b] (0.040)	-0.0045[c] (0.085)						

Superscripts a, b, and c denote significance at the 1, 5, and 10 percent level, respectively. Values in (.) are standard errors.

In Tables 1a and 1b, both fuel and supply are statistically significant in explaining the income premium (Equation 1; Column $\Delta income_{j,t}$) in each segment. Specifically, if the fuel spread increases by 1%, owners and charterers can expect a 0.4% to 1.6% increase in the income premium in the next week, *ceteris paribus*. In line with shipping economic theory, when the fuel variable increases, that is the more expensive it becomes to pay for VLSFO compared to HSFO, charterers are willing to pay relatively more to lease a scrubber-fitted vessel since it will substantially reduce their fuel costs.

If the scrubber-fitted fleet has increased by 1%, the income premium is expected to roughly decrease by 1.4% to 3.8% in the subsequent period, all else equal. The reason is that there is relatively more supply to accommodate the charterers' need for such vessels. The coefficient of the income variable is much smaller in magnitude, ranging from 0.0% to 0.3%, suggesting that changes in the fuel and supply variables have much stronger effects on income compared to its past values. These findings can inform companies' chartering policies while shipbrokers can incorporate that information in their assessments of the future time-charter rates and advise their clients accordingly.

Practitioners and policymakers alike have raised concerns regarding the current and future price differential between VLSFO and HSFO and whether there will be sufficient supply of both fuels in the future to accommodate the needs of the maritime industry. The results from Equation 2 (Column $\Delta fuel_t$) help shed light on that question. Namely, if the share of the scrubber-fitted fleet increases by 1%, the industry can expect a significant decrease in the fuel spread, ranging from 0.6% to 1.9%, all else equal. This is due to an increasing number of such vessels that are associated with higher demand for HSFO relative to VLSFO, which *ceteris paribus*, results in a narrower fuel spread. Furthermore, a 1% increase in the income premium results in a 0.06% to 0.99% increase in the fuel spread. An explanation is that, when the premium required to charter a scrubber-fitted vessel has increased, charterers become keener to explore the alternative option of employing a non-scrubber-fitted vessel. As the latter burns VLSFO though, the higher demand for it drives the fuel spread up. The effect that past fuel spread has on its future value is relatively stable across segments, ranging from 0.19% to 0.37%, which further demonstrates the high volatility of the spread. Evidently, the supply of the scrubber-fitted fleet plays the most significant role in the determination of the fuel spread since it determines the relative demand for HSFO and VLSFO.

In summary, the findings suggest that both the income and fuel variables are positively and significantly related to the size of the scrubber-fitted fleet. As the income from scrubber-fitted vessels increases compared to non-scrubber-fitted ones, it becomes more financially attractive to install a scrubber. Moreover, the supply of scrubber-fitted vessels negatively affects the future size of the respective fleet. As more vessels become equipped with a scrubber, the shipowner might perceive that there is less residual demand for those by charterers but also that the resulting increased demand for HSFO could reduce the availability of the fuel and raise its price compared to VLSFO.

Further Discussion and Conclusions

This paper selects scrubber installation as a representative technological investment to assess the relationship between green shipping investment and market uncertainty. Since January 2020 and the implementation of IMO's sulphur cap regulation, vessel owners are faced with the dilemma of either incurring the capital expenditure to retrofit a vessel with a scrubber system or switching to a more expensive fuel that is compliant with the 0.5% sulphur content.

Various studies have evaluated scrubber installation from an investment appraisal perspective; however, to the best of our knowledge, this paper is the first to employ data-driven empirical analysis to examine the dynamic interactions between fuel prices, freight rates, and the composition of the fleet. The results from our Vector Error Correction Model suggest that there is both a short- and a long-run cointegrating relationship among the fuel spread, the income premium, and the size of the scrubber-fitted fleet.

We are the first to empirically analyze the determinants of the decision to invest in a scrubber-fitted vessel. Using actual data across various oil tanker and dry bulk segments from 2021 to 2024, we find that a 1% increase in either the income premium or the fuel spread results in a 0.0002%-0.0057% rise in the scrubber-fitted fleet size. Furthermore, we are the first to document that the oversupply of a green shipping asset reduces its market attractiveness. Our findings suggest that both the income premium and the fuel spread are heavily affected by the supply of the scrubber-fitted fleet: a 1% increase in the share of the scrubber-fitted fleet decreases the income premium by 1.4-3.8% and decreases the fuel spread by 0.6%-1.9%. Finally, while the literature argues that there should be a positive relationship between the fuel spread and the income premium, this paper is the first to confirm it based on data observations. Namely, a 1% increase in the fuel spread increases the income premium by 0.4-1.6%.

According to this evidence, market prices – as freight rates and fuel prices – are among the major determinants of green investment and, reversely, changes in the adoption of green technologies at an industry level can impact the future profitability of such investments. Additionally, there is a bidirectional causality between freight rates and fuel prices in the context of green investment. These findings demonstrate the dynamic and volatile environment within which shipping companies need to undertake their green investment decisions.

As such, our paper contributes to the green finance and sustainable shipping literatures with profound implications for practitioners and policymakers. Shipowners and financiers need to base their investment decisions not only on historical income and costs but also on the impacts from the industry-level adoption of green technologies. While the widespread adoption of a green technology may render the corresponding infrastructure financially affordable, the oversupply of it could drive down its future profitability.

When advocating for net zero shipping, policymakers shall be aware of the difficulties posed by market uncertainties faced by shipping investors. There needs to be a clear pathway that decreases the market uncertainty associated with green investment. Explicit guidance, such as a fixed timeline or a predetermined selection of green technologies, can streamline the net zero process and stabilize market prices, thereby mitigating market uncertainties.

Endnotes

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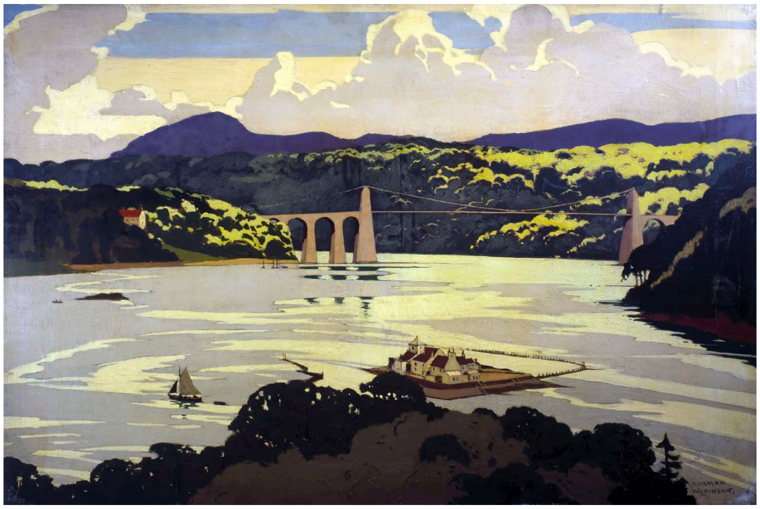

The Summer 2025 *CID* cover is cropped from the following artwork, whose complete image is above. Original oil painting by Norman Wilkinson for use on a London Midland and Scottish Railway (LMS) poster. The road suspension bridge over the Menai Straits was designed by Thomas Telford (1757–1834) and was built between 1818 and 1826 by Dorman, Long and Co Ltd. The overall length of the bridge is 1000 feet and the central span measures 579 feet. The bridge deck was damaged by a gale in 1839 and the deck was replaced in 1893 with a steel one. Major repairs were carried out in 1940. It is near the Britannia tubular railway bridge designed by Robert Stephenson (1803–1859). Credit © Science Museum Group (U.K.).

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