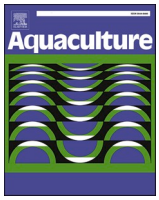
Aquaculture 561 (2022) 738678

Contents lists available at ScienceDirect

Aquaculture

journal homepage: www.elsevier.com/locate/aquaculture



# Impacts of Covid-19 on Norwegian salmon exports: A firm-level analysis

Hans-Martin Straume [a], Frank Asche [b,c,*], Atle Oglend [c], Eirik B. Abrahamsen [c], Anna M. Birkenbach [d], Johannes Langguth [e], Guillaume Lanquepin [f], Kristin H. Roll [c,g]

[a] BI Norwegian Business School, Norway
[b] University of Florida, United States of America
[c] University of Stavanger, Norway
[d] University of Delaware, United States of America
[e] BI Norwegian Business School, Simula Research Laboratory, University of Bergen, Norway
[f] Norwegian Customs, Norway
[g] University of Sout-Eastern Norway, Norway

ARTICLE INFO

*Keywords:*
Covid-19
Salmon
Exports

ABSTRACT

A rapidly growing literature investigates how the recent Covid-19 pandemic has affected international seafood trade along multiple dimensions, creating opportunities as well as challenges. This suggests that many of the impacts of the Covid measures are subtle and require disaggregated data to allow the impacts in different supply chains to be teased out. In aggregate, Norwegian salmon exports have not been significantly impacted by Covid-related measures. Using firm-level data to all export destinations to examine the effects of lockdowns in different destination countries in 2020, we show that the Covid-related lockdown measures significantly impacted trade patterns for four product forms of salmon. The results also illustrate how the Covid measures create opportunities, as increased stringency of the measures increased trade for two of the product forms. We also find significant differences among firms' responses, with large firms with larger trade networks reacting more strongly to the Covid measures. The limited overall impacts and the significant dynamics at the firm level clearly show the resiliency of the salmon supply chains.

## 1. Introduction

As the Covid-19 virus began spreading worldwide in early 2020, international trade was significantly impacted by the strict measures that countries implemented to contain the virus. Numbers from the World Trade Organization (WTO, 2022) indicate that global trade volume declined by 5% during 2020. The first string of literature on the trade implications of Covid-related measures suggests that lockdowns had a negative impact on global value chains (Lafrogne-Joussier et al., 2022), forced firms to shut down and reduced the workforce across different economic sectors (Nicola et al., 2020), and decreased demand for and trade of several products (Bartik et al., 2020; Hayakawa and Mukunoki, 2021; Espitia et al., 2021). The early literature focusing specifically on seafood markets reports similar findings, largely based on qualitative data and indicators (e.g., Link et al., 2020; White et al., 2021; Bassett et al., 2021; Gordon, 2021; Lebel et al., 2021). However, the story is becoming more nuanced as updated data become available, indicating that Covid-related measures created opportunities for some and challenges for others. For instance, Love et al. (2021) finds increased retail sales for seafood in the United States during the pandemic, whereas restaurant sales were down. Yang et al. (2022) report that the lockdowns in China had limited impacts on seafood prices and Asche et al. (2022a) report limited impacts on Norwegian trawlers.

Any firm will try to mitigate the impacts of market shocks by shifting supply among markets, supply chains, and product forms (Asche et al., 2017), making it difficult to discern the true effects of the shocks from aggregate data alone. Consequently, learning about the more subtle impacts of Covid measures requires disaggregated data. In this paper we investigate the effects of Covid measures on Norwegian salmon exports, first using aggregate data, and then using firm-specific trade data and the Oxford Stringency Index (OXI) (Hale et al., 2021) to measure the restrictiveness of the Covid measures in various countries. This allows us

* Corresponding author at: University of Florida, United States of America.
*E-mail addresses:* Hans-Martin.Straume@bi.no (H.-M. Straume), frank.asche@ufl.edu (F. Asche), atle.oglend@uis.no (A. Oglend), eirik.b.abrahamsen@uis.no (E.B. Abrahamsen), abirken@udel.edu (A.M. Birkenbach), langguth@simula.no (J. Langguth), Guillaume.Lanquepin@toll.no (G. Lanquepin), kristin.roll@usn.no (K.H. Roll).

https://doi.org/10.1016/j.aquaculture.2022.738678
Received 23 June 2022; Received in revised form 27 July 2022; Accepted 28 July 2022
Available online 2 August 2022

to parse out the impact of Covid measures on various trade margins, such as value, quantity, unit value, and number of shipments. This is important because the effects of the Covid measures need not show up in all margins. For instance, if exporters reduce the quantity supplied to a given market but compensate by shifting greater supply to other markets, there may not be any price effect. Alternatively, if demand shifts but the quantity supplied is unchanged, one would expect a strong price effect. Most salmon is exported fresh and thus in frequent, small shipments (Asche et al., 2021a), making these supply chains particularly vulnerable to interruptions. As such, the number of shipments is a key indicator of impacts of the Covid measures on the supply chains.

Norwegian salmon exports are of general interest as they can be regarded as a bellwether of the broader effects of Covid restrictions on the international seafood trade. Norway is the largest salmon producer worldwide (Iversen et al., 2020), salmon is the second largest aquaculture species by value (Garlock et al., 2020a, 2020b), and salmon is among the most traded fish species with the most advanced logistics (Kumar and Engle, 2016; Asche and Smith, 2018; Cojocaru et al., 2021; Gephart et al., 2021). Norway exports >95% of its salmon production, with firms tending to focus on a few markets or regions (Gaasland et al., 2020; Oglend et al., 2022) and a significant share is processed further after leaving Norway (Asche et al., 2018; Asche et al., 2022b). Overall, the impact of Covid measures on the Norwegian salmon industry has been moderate. Production increased from 2019 to 2020, which is unsurprising given that the lead time when producing salmon is 14–18 months (Asche et al., 2017), and the decision to produce the fish that were harvested in 2020 was made in 2019, when profitability was high (Dahl et al., 2021; Sikveland et al., 2022). While there was a slight decrease in the export value of salmon in 2020 compared to 2019 (−3%), the volume exported increased by 2% that same year. Between 2020 and 2021, the quantity and value of salmon exports increased by 13% and 16%, respectively.

We estimate the effects of destination-specific lockdown measures for four major salmon product forms: fresh whole, frozen whole, fresh fillets, and frozen fillets. Differentiating by product form can be important as Covid measures may have impacted some supply chains positively, as exemplified by the increased retail sales of fish, while other supply chains, like restaurants, were affected negatively (Love et al., 2021). As the significance of different product forms varies by supply chain (Love et al., 2020, 2022), one would expect the impacts of the Covid measures to also vary by product form.

The paper is organized as follows. Section 2 provides an overview of the Norwegian salmon aquaculture industry. Section 3 describes the data for export and lockdowns, then Section 4 outlines the empirical strategy. In Section 5 we present findings for the overall data, while Section 6 investigates the role of the top exporters and markets before Section 7 concludes.

## 2. The Norwegian aquaculture industry

The Norwegian salmon aquaculture industry has grown rapidly in recent decades, from <10,000 metric tons (mt) in 1980 to 1.5 million mt in 2021 (Hersoug, 2021; Norwegian Directorate of Fisheries, 2022).[1] This is largely due to a number of innovations leading to significant productivity growth in the production process as well as in the supply chains (Asche, 2008; Asche et al., 2018; Bergesen and Tveterås, 2019; Rocha-Aponte, 2020; Iversen et al., 2020). The industry has been highly profitable over time (Misund and Nygård, 2018; Dahl et al., 2021; Sikveland et al., 2022) and likely would have grown even faster in the absence of tight regulations designed to address environmental concerns (Hersoug, 2021; Hersoug et al., 2021; Osmundsen et al., 2020, 2021; Pincinato et al., 2021a, 2021b; Føre et al., 2022). The salmon exports sector is highly diverse export firms vary significantly in terms of size and target markets (Oglend and Straume, 2020; Straume et al., 2020a). Large firms tend to export to more countries, giving them more geographic flexibility, while smaller firms tend to focus on fewer destination countries. However, all destination countries are served by a mix of both large- and small-scale salmon producers.

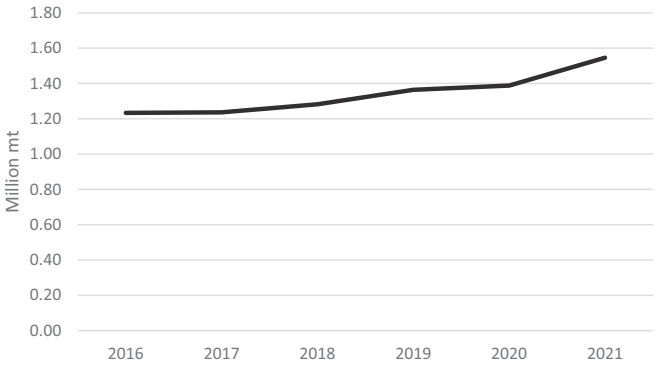



**Fig. 1.** Norwegian salmon production 2016–2021.
Source: Norwegian Directorate of Fisheries (2022).

Fig. 1 shows the growth in Norwegian salmon production in recent years. There is no clear indication that the Covid-19 pandemic exerted a negative effect on the overall production level, which in fact continues to increase. However, the pandemic may still have affected salmon prices, export value, or production at finer scales, such as the firm, product form, or export market level.

Fig. 2 shows overall export values, volumes, and average unit values for salmon exports during the period from January 2016 to May of 2021. The red vertical line represents March 2020, the month when the Norwegian government first implemented strict measure to try to contain the spread of the virus. This is also the month when many of the major destination markets such as the European Union and the United States started to implement severe lockdown measures. From a visual inspection of Fig. 2, one cannot claim that there are any strong effects on any of the three series beginning in March 2020. One could perhaps argue that the drop in unit values lasts a bit longer in the summer of 2020 than the normal seasonal variation, but this could also be explained by other factors, such as producers supplying the markets with a larger biomass than in previous years.

Of the four products, fresh whole salmon is the most important when it comes to both value and volume, accounting for 79% of the export value and 86% of the volume. Fig. 3 shows the evolution of value, volume, and unit value for fresh salmon over the period.[2]

Also, at the product level there are no obvious changes to the yearly patterns of the series as lockdown measures began to intensify around the globe. We conducted a CUSUM-test (Ploberger and Krämer, 1992) for structural breaks in any month from January 2016 until the end of the sample to complement the visual analysis for the aggregate series, as well as for the three series for each of the four product forms. In no case can we reject the null hypothesis of no structural break. Hence, at the aggregate level, the Covid measures do not appear to have had a strong impact on Norwegian salmon exports.

## 3. Customs data and lockdowns

This paper's primary analysis employs highly disaggregated export data collected by the Norwegian customs authorities from the individual

[1] Norwegian salmon aquaculture consists of two species, Atlantic salmon and trout, with salmon currently making up about 95% of total production (Landazuri-Tveteras et al., 2021).

[2] Figures A1-A3 in the appendix provides similar series at the product level for the other three products of interest.

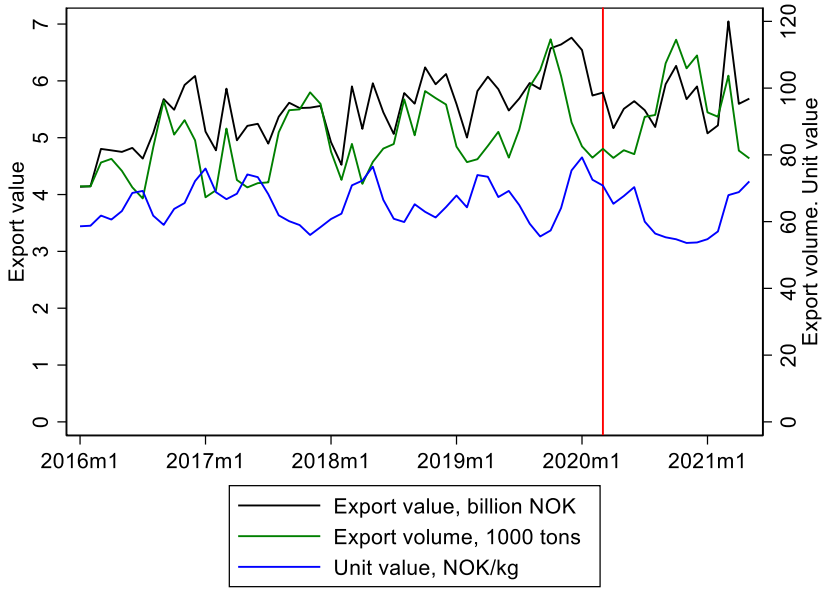



**Fig. 2.** Aggregate Norwegian salmon exports, Jan 2016-May 2021.
Source: Customs Norway; authors' own calculations.

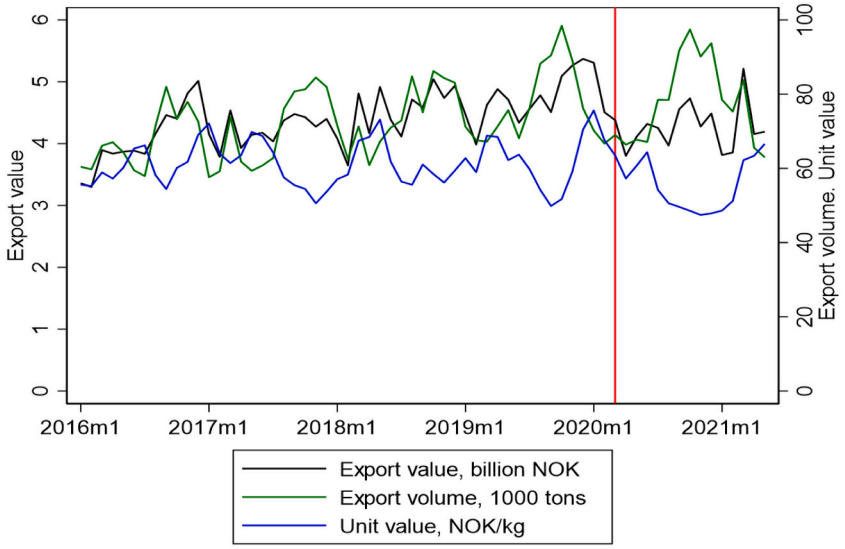



**Fig. 3.** Norwegian salmon exports, fresh whole, Jan 2016-May 2021.
(Source: Customs Norway; authors' own calculations)

exporter's customs declarations. For each shipment across the Norwegian border, the data include information on the product name and its associated Harmonized System (HS) classification code, an anonymous identifier for the Norwegian exporting firm, the destination country, the free-on-board value of the shipment in Norwegian kroner (NOK), and the weight of the shipment in kilos. We restrict our analysis to 2020, as that is the year most countries first implemented lockdown measures. The 2020 data comprise a total of 305,222 shipments involving one of the four salmon products, spanning 131 exporters and 110 destination markets. On average, each exporter makes 15,933 shipments to 45 different destination countries in 2020.

Though Covid effects are not clearly evident in the aggregate series, this does not preclude impacts on individual exporters. We therefore investigate the potential effect of destination-specific lockdowns on trade margins at the firm level for exporters. As our measure for lockdown severity in different destination markets, we employ the Oxford Stringency Index (OXI) constructed by the University of Oxford (Hale et al., 2021).[3] The OXI was calculated based on nine different metrics[4] for 180 different countries and updated daily over the period of interest. Each of the nine metrics takes a value between 0 and 100, and the OXI is calculated as the mean across these scores. A higher OXI indicates stricter government responses, involving, for example, more widespread closures and event cancellations. In cases where there is regional

[3] The OXI is also used by Bricongne et al. (2021) to investigate the effect of lockdowns in foreign markets on overall French exports. They find that, as a destination country goes into full lockdown, the midpoint growth rate of exports for a firm is reduced by 0.7%.

[4] School closures; workplace closures; cancellation of public events; restrictions on public gatherings; closures of public transport; stay-at-home requirements; public information campaigns; restrictions on internal movements; and international travel controls.

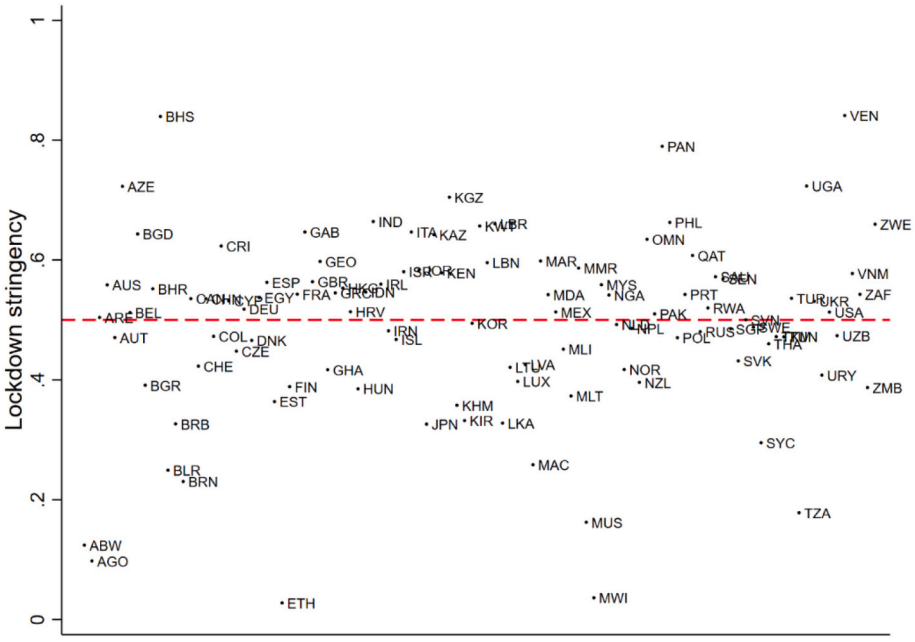



**Fig. 4.** Average lockdown stringency by destination market, 2020.
Source: Hale et al. (2021). The destinations are sorted alphabetically on the x-axis.

**Table 1**
Number of exporters, destination markets, shipments, and average value and volume per shipment, 2019 and 2020.

| | 2019 | | | | | 2020 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | # Exporters | # Markets | # Shipments | Avg. value (1000 NOK) | Avg. volume (mt) | # Exporters | # Markets | # Shipments | Avg. value (1000 NOK) | Avg. volume (mt) |
| January | 89 | 83 | 14,556 | 379 | 0.38 | 91 | 78 | 14,806 | 435 | 0.44 |
| February | 86 | 83 | 13,596 | 364 | 0.36 | 87 | 80 | 13,450 | 420 | 0.42 |
| March | 90 | 90 | 14,337 | 400 | 0.40 | 85 | 76 | 13,126 | 433 | 0.43 |
| April | 85 | 86 | 14,384 | 417 | 0.42 | 83 | 68 | 11,792 | 432 | 0.43 |
| May | 97 | 83 | 15,066 | 382 | 0.38 | 82 | 72 | 11,972 | 454 | 0.45 |
| June | 90 | 84 | 13,833 | 390 | 0.39 | 88 | 74 | 12,078 | 462 | 0.46 |
| July | 91 | 81 | 15,041 | 372 | 0.37 | 83 | 76 | 13,664 | 396 | 0.40 |
| August | 92 | 86 | 16,270 | 361 | 0.36 | 81 | 75 | 13,202 | 388 | 0.39 |
| September | 89 | 89 | 16,114 | 359 | 0.36 | 87 | 82 | 14,966 | 393 | 0.39 |
| October | 86 | 90 | 17,287 | 376 | 0.38 | 88 | 81 | 16,042 | 387 | 0.39 |
| November | 91 | 84 | 16,257 | 404 | 0.40 | 86 | 81 | 15,030 | 373 | 0.37 |
| December | 86 | 84 | 14,827 | 450 | 0.45 | 84 | 81 | 16,041 | 363 | 0.36 |

variation in policies within a given country, the OXI of the strictest region is used. Importantly, the OXI only measures the stringency of Covid measures and not their success in containing the spread of the virus. While the latter might be inferred from metrics like new case numbers and deaths attributed to Covid-19 by destination country,[5] these measures are less relevant to trade than the composite OXI. Following (Bricongne et al., 2021), we divide the OXI by 100 to rescale it to the range [0,1]. Fig. 4 shows the average lockdown stringency in different destination markets for salmon in 2020.

Fig. 4 includes countries which received at least one shipment of salmon from Norwegian firms in 2020. Among destination countries, Ethiopia (ETH) and Malawi (MWI) had the lowest average OXI value, with Venezuela (VEN), Panama (PAN), and the Bahamas (BHS) being the highest. None of these countries at the OXI extremes are important destination markets in Norwegian salmon exports. Ranked by total value over the four products, the ten largest destinations for salmon in 2020 were Poland (POL), France (FRA), Denmark (DNK), the United States (USA), Spain (ESP), the Netherlands (NLD), the United Kingdom (GBR), Italy (ITA), Germany (DEU), and Sweden (SWE). Together, these ten destination markets make up approximately 72% of the total export value in Norwegian salmon products. While most are located around the average lockdown stringency, there is some variation. For example, while Italy had an average OXI of around 0.6 in 2020, Denmark and Poland were both around 0.45.

Table 1 compares the monthly number of exporters, markets, and shipments as well as average value and quantity of salmon between 2019 and 2020. Apart from the difference between May 2019 and May 2020, no large differences are evident in the numbers of exporters between the two years. We see that, starting in March 2020, the numbers of destination markets are markedly lower than the corresponding months in 2019. The number of destination markets served returns to near-2019 levels late in the fall of 2020. Looking at numbers of shipments, there is a noticeable drop in April and May 2020 compared to the same month the previous year. Though monthly shipment numbers pick up again after April 2020, they are still lower than their 2019 counterparts for the remainder of 2020. However, the average quantity and value per shipment increase.

[5] The correlation between the OXI and new cases of Covid-19 is 0.27, and 0.14 for the number of deaths.

**Table 2**
Product-level trade margins and lockdown stringency, 2020.

| | All exporters | | | |
|---|---|---|---|---|
| | Export value | # Shipments | Average unit value | Average volume |
| Fresh whole | | | | |
| Lockdown stringency | −0.206*** | −0.181*** | −0.009*** | −0.015 |
| | (0.025) | (0.021) | (0.003) | (0.013) |
| Observations | 60,951 | 60,951 | 60,951 | 60,951 |
| $R^2$ | 0.863 | 0.820 | 0.904 | 0.907 |
| Fresh fillet | | | | |
| Lockdown stringency | 0.274*** | −0.000 | 0.053*** | 0.221*** |
| | (0.029) | (0.019) | (0.004) | (0.020) |
| Observations | 46,072 | 46,072 | 46,072 | 46,072 |
| $R^2$ | 0.920 | 0.900 | 0.906 | 0.912 |
| Frozen whole | | | | |
| Lockdown stringency | 0.051*** | −0.015* | −0.011** | 0.077*** |
| | (0.018) | (0.009) | (0.005) | (0.014) |
| Observations | 26,814 | 26,814 | 26,814 | 26,814 |
| $R^2$ | 0.925 | 0.877 | 0.833 | 0.922 |
| Frozen fillet | | | | |
| Lockdown stringency | −0.080*** | −0.010 | 0.021*** | −0.090*** |
| | (0.028) | (0.010) | (0.006) | (0.024) |
| Observations | 43,436 | 43,436 | 43,436 | 43,436 |
| $R^2$ | 0.935 | 0.966 | 0.913 | 0.881 |

Robust standard errors in parentheses.
All regressions include a constant, firm-month, and destination country fixed effects.
*** $p < 0.01$.
** $p < 0.05$.
* $p < 0.10$.

## 4. Margins of trade

A major question in the literature on international trade and firm dynamics is how trade evolves along various margins (Alessandria et al., 2021). The basic idea is that established exporters can grow either by adding markets, products, or customers to their trade portfolio, or by intensifying activity in relations that are already established by increasing shipment frequency, prices, or volumes. Similarly, reduction in trade can occur along the same dimensions. Knowing how these margins evolve over time is important for understanding trade patterns (e.g., aggregate export of salmon to different markets). Better access to microdata has made it possible for researchers to suggest different approaches as to how total sales at the firm level can be attributed to different margins of trade. Some relevant examples for trade in general are Bernard et al. (2007), Lawless (2010), Hornok and Koren (2015), Asche et al. (2021b), and Landazuri-Tveteraas et al. (2021a, 2021b). Specific to seafood, Straume et al. (2020b) investigates if trade margins for aquaculture products differ from trade margins in wild seafood products beyond just total export value. The results indicate that, relative to sales of wild fish, sales of aquaculture products are more responsive to transportation costs and income level in the destination country. Yang et al. (2021) provides a similarly motivated analysis of trade dynamics for shrimp, while Yang et al. (2020) provide a similar analysis for China.

The empirical strategy in this paper builds on Mayer and Ottaviano (2007) and Asche et al. (2021b). First, we decompose total export value at the product level from a firm ($i$) to a destination ($d$) in a given month ($t$), $EX_{i,\,d,\,t}$, into three distinct margins of trade as follows:

$$EX_{i,d,t} = N_{i,d,t} \bullet \overline{p}_{i,d,t} \bullet \overline{x}_{i,d,t} \quad (1)$$

$N_{i,\,d,\,t}$ represents the total number of shipments from exporter $i$ to destination $d$ in a given month $t$ of 2020, while $\overline{p}_{i,d,t}$ and $\overline{x}_{i,d,t}$, are the corresponding average unit values and volumes, respectively, of the product type. To investigate the effect of destination-specific lockdown stringency on total export value for the four products, as well as on the three margins of trade, we estimate the following linear regression model on all four elements of Eq. 1 (1):

$$X_{i,d,t} = \beta_1 + \beta_2 lockdown_{d,t} + \delta_d + \gamma_{i,t} + u_{i,d,t} \quad (2)$$

$X_{i,d,t}$ represents the export value, or the three different margins of trade while $lockdown_{d,t}$ is the destination-specific stringency measure as captured by the OXI. To control for destination-specific characteristics, such as transportation costs and the economic size of the destination market (GDP), we include destination-specific fixed effects $\delta_d$. We also control for unobservable shocks to the exporting firm by including a firm-month fixed effect, $\gamma_{i,t}$. Finally, $u_{i,d,t}$ is a stochastic error term. Note that since the decompositions of margins are an identity, the estimate of each coefficient from the regression of the margins sum up to the estimate in total export value (Hornok and Koren, 2015).

## 5. Trade margins and lockdown stringency

The results from the margin regressions are presented in Table 2. Given that the dependent variable is in the range [0,1] and the independent variables are in logs, the interpretation of coefficients is straightforward. For instance, the coefficient of −0.206 on lockdown stringency in the export value regression for fresh whole salmon means that the average effect on the sales of an exporter of fresh salmon of a destination going into full lockdown would be a reduction in sales of 20.6%.

From Table 2 it is clear that lockdown stringency influences exports, as it is statistically significant in all equations. Interestingly, however, the sign and strength of the effect vary by product form. On average, the export value increases for fresh fillets and whole frozen salmon as the stringency of Covid restrictions in destination markets increases. For both products, the main driver of the positive relationship between lockdowns and export value is increased volumes. The effects on unit value are the opposite for the two products: firms selling fresh fillets were able to charge a price premium in the markets most hit by restrictions, suggesting growth in the demand for fresh fillets. Exporters of whole frozen salmon experienced reductions in both the number of shipments and unit value as lockdowns intensified. But the increase in average quantity more than offset these two negative effects to generate net growth in export value.

For both fresh whole and frozen fillets of salmon, the overall effect on export value from increased lockdown stringency is found to be negative. For fresh whole salmon, the negative effect on export value is primarily driven by a reduction in shipping frequency, highlighting the importance of this margin for a highly perishable product. We also document a significant negative but numerically small effect on unit values. For the frozen fillets, the exporters have managed to gain a price premium in the markets with strict lockdowns, partly due to the reduction in average export volumes. The latter negative effect is three times as large as the positive effect from lockdowns on unit values.

The fact that the price effects have different signs is notable, as a number of studies have reported that the salmon market is highly integrated (Landazuri-Tveteraas et al., 2021a, 2021b; Salazar and Dresdner, 2021). However, Landazuri-Tveteraas et al. (2018) show that the degree of price transmission varies significantly between product forms, and, as such, this result highlights the fact that the short-run dynamics vary by product form.

**Table 3**
Product-level trade margins and lockdown stringency, 2020, top 10% exporters and top 10 markets.

| | Top 10% exporters | | | | Top 10 markets | | | |
|---|---|---|---|---|---|---|---|---|
| | Export value | # Shipments | Average unit value | Average volume | Export value | # Shipments | Average unit value | Average volume |
| | Fresh whole | | | | Fresh whole | | | |
| Lockdown stringency | −0.768*** | −0.766*** | −0.014*** | 0.012 | −0.228*** | −0.226*** | 0.004* | −0.006 |
| | (0.031) | (0.027) | (0.003) | (0.012) | (0.022) | (0.021) | (0.002) | (0.009) |
| Observations | 57,921 | 57,921 | 57,921 | 57,921 | 23,790 | 23,790 | 23,790 | 23,790 |
| $R^2$ | 0.831 | 0.790 | 0.877 | 0.854 | 0.875 | 0.838 | 0.968 | 0.952 |
| | Fresh fillet | | | | Fresh fillet | | | |
| Lockdown stringency | 0.160*** | −0.050** | 0.057*** | 0.153*** | −0.001 | −0.012 | 0.020*** | −0.009 |
| | (0.035) | (0.021) | (0.005) | (0.023) | (0.047) | (0.036) | (0.006) | (0.017) |
| Observations | 40,363 | 40,363 | 40,363 | 40,363 | 23,790 | 23,790 | 23,790 | 23,790 |
| $R^2$ | 0.918 | 0.915 | 0.888 | 0.873 | 0.847 | 0.821 | 0.945 | 0.850 |
| | Frozen whole | | | | Frozen whole | | | |
| Lockdown stringency | 0.317*** | 0.088** | −0.051** | 0.280*** | −0.047** | −0.055*** | 0.009*** | −0.001 |
| | (0.064) | (0.043) | (0.020) | (0.045) | (0.019) | (0.016) | (0.003) | (0.009) |
| Observations | 8139 | 8139 | 8139 | 8139 | 23,790 | 23,790 | 23,790 | 23,790 |
| $R^2$ | 0.778 | 0.634 | 0.776 | 0.782 | 0.926 | 0.903 | 0.971 | 0.949 |
| | Frozen fillet | | | | Frozen fillet | | | |
| Lockdown stringency | −0.480*** | −0.025* | 0.149*** | −0.604*** | −0.176*** | −0.078*** | −0.061*** | −0.037*** |
| | (0.024) | (0.014) | (0.008) | (0.020) | (0.031) | (0.021) | (0.008) | (0.014) |
| Observations | 35,889 | 35,889 | 35,889 | 35,889 | 23,790 | 23,790 | 23,790 | 23,790 |
| $R^2$ | 0.912 | 0.913 | 0.838 | 0.777 | 0.811 | 0.895 | 0.859 | 0.841 |

Robust standard errors in parentheses.
All regressions include a constant, firm-month, and destination country fixed effects.
*** $p < 0.01$.
** $p < 0.05$.
* $p < 0.10$.

## 6. Top exporters and markets

The findings presented above are average effects across all exporters and markets, which may cause the impacts on the most economically significant subsets—the largest exporters and top destination markets—to be obscured. Thus, we separately analyze the effect of destination-specific lockdowns on the top 10% exporters of each aquaculture product, as well as for the export from the top 10% exporters to the top 10 destination markets in 2020. In our data, the top 10% exporters together account for 83.5% of export value. At the product level, this corresponds to 74.5% for fresh whole salmon, 87.7% for fresh fillets, 67.4% for frozen whole salmon, and 49% for frozen fillets. We follow the same empirical strategy outlined in Section 5. Table 3 reports the product-level results for the top 10% exporters, as well as the export from these firms to the top ten destination markets for salmon in 2020.

Some clear differences from the aggregate analysis are immediately evident. Compared to the results presented in Table 2, the top exporters of fresh fillets and frozen whole salmon also manage to increase their export value as lockdowns escalate. However, here the increase is much stronger for frozen salmon and somewhat weaker for fresh fillets. The margins that drive the result for exporters of fresh fillets are increased prices and volumes, while they are larger average volumes and increased shipment frequency for frozen whole salmon. Compared to the findings reported in Table 2, the overall negative effect on export value for the top 10% exporters of fresh whole salmon is more than twice as large as in the overall data, suggesting that the large firms are better able to shift their exports to different markets. This may not be too surprising given that the larger firms tend to serve a higher number of markets (Straume et al., 2020a), giving them more flexibility. This is in line with the general literature which shows that more diverse units in terms of products, technology, networks, etc. are generally more resilient to shocks (Balland et al., 2022).

While we reported a significant reduction in prices for fresh whole salmon in Table 3, we find that the top 10% of exporters manage to obtain higher prices to the top ten markets. This suggests the importance of deeper relationships and possibly more fixed prices in longer-term contracts (Larsen and Asche, 2011). It is also of interest to note that the increased export value of fresh fillets does not occur in the largest markets.

## 7. Concluding remarks

Love et al. (2021) show how impacts of Covid measures in the United States are mixed, as demand increased in supply chains serving the retail sector where sales increased by about 30% and was reduced in supply chains serving the restaurant sector. This suggests that many of the impacts of the Covid measures can be subtle, and that there are opportunities as well as challenges. To better understand the impacts, disaggregated data that allow the researcher to distinguish among different supply chains and firm types are necessary.

This paper investigates the impact of Covid measures on Norwegian salmon exports. Salmon is among the most traded seafood species (Anderson et al., 2018), and Norway is the largest producer and is highly export-oriented, with >95% of its production being exported (Oglend et al., 2022). Our dataset registered exports of salmon to 110 countries in 2020. In aggregate, we find no statistically significant impacts of the Covid measures on the exports of the four main product forms. This is not too surprising with respect to the exported quantity, as the long production time means that the fish harvested in 2020 were already in the pens. That there is no significant price and revenue effect, suggest that, overall, there have not been any significant supply chain

interruptions.[6] To the extent that there have been challenges in some supply chains, the exporters have been able to offset these losses by finding alternative markets.

Using the Oxford Stringency Index (OXI) (Hale et al., 2021) as a measure for lockdown stringency, we find that Covid measures have had a significant impact on export value as well as different margins of trade. However, the effects vary for the four product forms. In particular, for fresh fillets and whole frozen salmon, export value increases with stricter Covid measures, suggesting that the measures improve the competitive situation for these products, while for whole fresh and frozen fillets, export value is reduced. We also find that the ten largest export firms react more strongly to the Covid measures, highlighting the greater flexibility of larger firms that serve many countries to shift supply. This is not very surprising as more diverse units in terms of products, technology, networks, etc. are more resilient to shocks in general (Balland et al., 2022).

Overall, the limited aggregate effect of the Covid lockdown measures shows the resiliency of the salmon supply chains and exporters' flexibility to adapt to demand shocks. As Covid has likely provided the largest demand shock the seafood market has experienced, this is good news for the global seafood trade system. It is also interesting to contrast this with supply shocks due to fish diseases or environmental factors, which have a strong price effect (Asche et al., 2017). As such, the lack of diversification on the supply side of the market—with production concentrated in only a few countries—appears to pose a greater risk to resiliency in the salmon supply than on the demand side, where the high number of destination markets give exporters ample options for evading shocks in any one market.[7]

## Author statement

All authors have contributed to the article throughout the entire process, from idea to final manuscript.

## Declaration of Competing Interest

This project was financed by the Research Council of Norway (CT #324685). The authors declare no conflict of interests related to this article.

## Data availability

The data that has been used is confidential.

*Acknowledgement*

Financial support from the Research Council of Norway (CT#324685) is acknowledged. Any opinion expressed in the paper is the authors', and not necessarily the opinion of Norwegian Customs or the Research Council of Norway.

## Appendix A

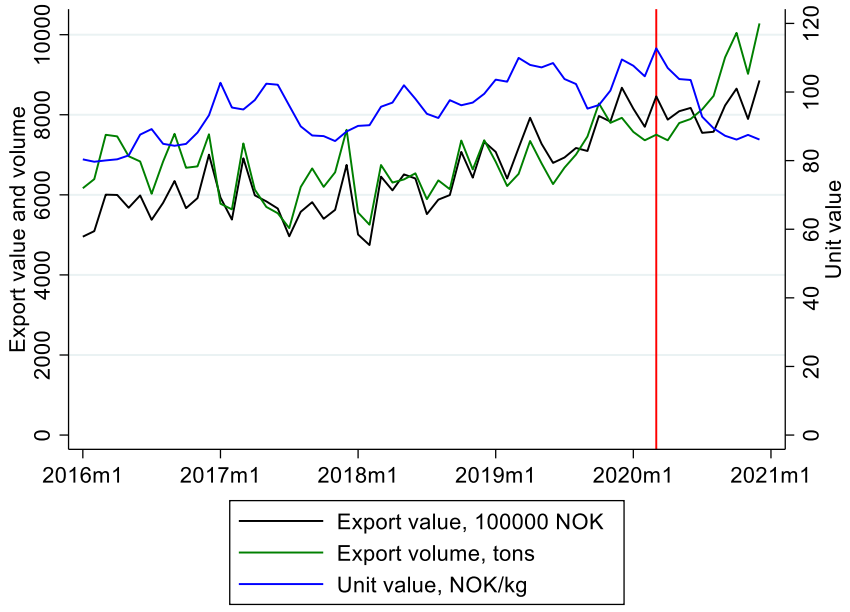



**Fig. A1.** Norwegian salmon exports, fresh fillets, Jan 2016-May 2021.
Source: Customs Norway; authors' own calculations.

[6] With the long lead time when producing salmon, one would not expect production to decline until the second half of 2021 and 2022 in response to negative market shocks (Asche et al., 2018). Given the structure of the production process, feed use and smolt release can be regarded as leading indicator. However, as noted in the introduction production was up also in 2021 and the smolt release also appears to increase, indicating that production will not be reduced in 2023.

[7] Aquaculture is a risky production process, as demonstrated for a number of species–e.g., Ankamah-Yeboah et al. (2021), Dahl and Oglend (2014), Engle et al. (2021), Garlock et al., (2020), Khan et al. (2018), Moor et al. (2022), Petesch et al. (2021), and Theodorou et al. (2020)–but most species have more source countries than salmon (Garlock et al., 2020; 2022).

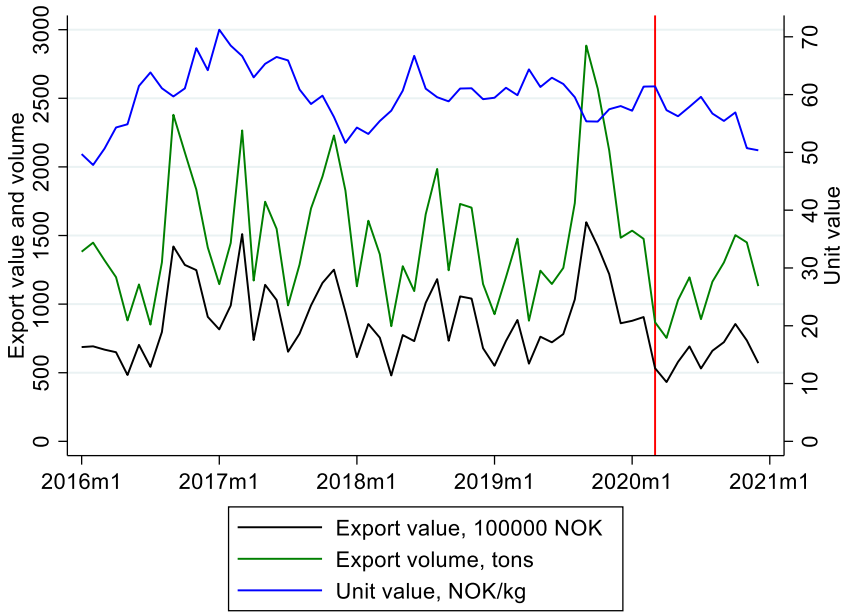



**Fig. A2.** Norwegian salmon exports, frozen whole, Jan 2016-May 2021.
Source: Customs Norway; authors' own calculations.

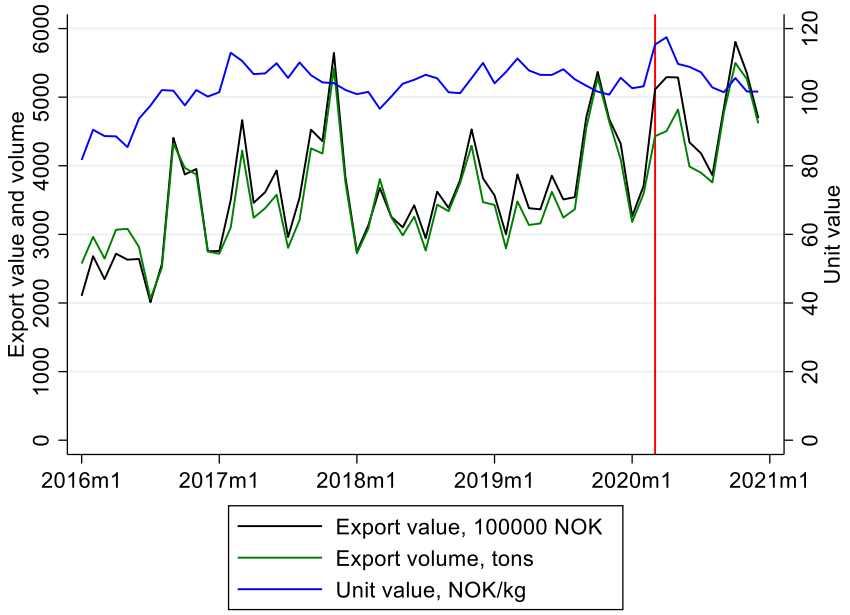



**Fig. A3.** Norwegian salmon exports, frozen fillets, Jan 2016-May 2021.
Source: Customs Norway; authors' own calculations.

## References


Alessandria, G., Arkolakis, C., Ruhl, K.J., 2021. Firm dynamics and trade. Ann. Rev. Econ. 13, 253–280.

Anderson, J.L., Asche, F., Garlock, T., 2018. Globalization and commoditization: the transformation of the seafood market. J. Commod. Mark. 12, 2–8.

Ankamah-Yeboah, I., Nielsen, R., Llorente, I., 2021. Capital structure and firm performance: agency theory application to Mediterranean aquaculture firms. Aquac. Econ. Manag. 25, 367–387.

Asche, F., 2008. Farming the sea. Mar. Resour. Econ. 23 (4), 527–547.

Asche, F., Smith, M.D., 2018. Induced innovation in fisheries and aquaculture. Food Policy 76, 1–7.

Asche, F., Oglend, A., Kleppe, T., 2017. Price dynamics in biological production processes exposed to environmental shocks. Am. J. Agric. Econ. 99 (5), 1246–1264.

Asche, F., Cojocaru, A., Roth, B., 2018. The development of large-scale aquaculture production: a comparison of the supply chains for chicken and Salmon. Aquaculture 493, 446–455.

Asche, F., Straume, H.-M., Vårdal, E., 2021a. Perish or prosper: trade patterns for highly perishable seafood products. Agribusiness. 37 (4), 876–890.

Asche, F., Oglend, A., Straume, H.M., 2021b. Tools of the trade: trade flexibility with respect to margins and buyers. Empir. Econ. 61 (4), 1959–1983.

Asche, F., Sogn-Grundvåg, G., Zhang, D., 2022a. Large-scale fisheries during the COVID-19 pandemic: the case of the oceangoing groundfish fleet in Norway. Mar. Policy 105223.

Asche, F., Yang, B., Gephart, J.A., Smith, M.D., Anderson, J.L., Camp, E.V., Straume, H.-M., 2022b. China's seafood imports: not for domestic consumption? Science. 375 (6579), 386–388.

Balland, P.A., Broekel, T., Diodato, D., Giuliani, E., Hausmann, R., O'Clery, N., Rigby, D., 2022. The new paradigm of economic complexity. Res. Policy 51 (3), 104450.

Bartik, A.W., Bertrand, M., Cullen, Z., Glaeser, E.L., Luca, M., Stanton, C., 2020. The impact of COVID-19 on small business outcomes and expectations. Proc. Natl. Acad. Sci. 117 (30), 17656–17666.

Bassett, H.R., Lau, J., Giordano, C., Suri, S.K., Advani, S., Sharan, S., 2021. Preliminary lessons from COVID-19 disruptions of small-scale fishery supply chains. World Dev. 143, 105473.

Bergesen, O., Tveterås, R., 2019. Innovation in seafood value chains: the case of Norway. Aquac. Econ. Manag. 23 (3), 292–320.
Bernard, A.B., Jensen, J.B., Redding, S.J., Schott, P.K., 2007. Firms in international trade. J. Econ. Perspect. 21 (3), 105–130.
Bricongne, Jean-Charles, Carluccio, Juan, Fontagné, Lionel, Gaulier, Guillaume, Stumpner, Sebastian, 2021. From macro to micro: Heterogeneous exporters in the pandemic. Banque de France, Paris.
Cojocaru, A.L., Iversen, A., Tveteras, R., 2021. Differentiation in the Atlantic salmon industry: a synopsis. Aquac. Econ. Manag. 25 (2), 177–201.
Dahl, R.E., Oglend, A., 2014. Fish Price volatility. Mar. Resour. Econ. 29, 305–322.
Dahl, R.E., Oglend, A., Yahya, M., 2021. Salmon stock market prices revealing Salmon Price information. Mar. Resour. Econ. 36, 173–190.
Engle, C., van Senten, J., Parker, M., Webster, D., Clark, C., 2021. Economic tradeoffs and risk between traditional bottom and container culture of oysters on Maryland farms. Aquac. Econ. Manag. 25, 472–503.
Espitia, A., Mattoo, A., Rocha, N., Ruta, M., Winkler, D., 2021. Pandemic trade: COVID-19, remote work and global value chains. In: The world Economy.FAO (2021). FAO yearbook. Fishery and aquaculture statistics 2019/FAO annuaire. Statistiques des pêches et de l'aquaculture 2019/FAO anuario. Estadísticas de Pesca y acuicultura 2019. Rome/Roma.
Føre, H.M., Thorvaldsen, T., Osmundsen, T.C., Asche, F., Tveterås, R., Fagertun, J.T., Bjelland, H.V., 2022. Technological innovations promoting sustainable salmon (Salmo salar) aquaculture in Norway. Aquacul. Rep. 24, 101115.
Gaasland, I., Straume, H.M., Vårdal, E., 2020. Agglomeration and trade performance–evidence from the Norwegian salmon aquaculture industry. Aquac. Econ. Manag. 24 (2), 181–193.
Garlock, T., Asche, F., Anderson, J.L., Bjørndal, T., Kumar, G., Lorenzen, K., Tveteras, R., 2020a. A global blue revolution: aquaculture growth across regions, species, and countries. Rev. Fish. Sci. Aquacult. 28 (1), 107–116.
Garlock, T.M., Nguyen, L., Anderson, J.L., Musumba, M., 2020b. Market potential for Gulf of Mexico farm-raised finfish. Aquac. Econ. Manag. 24 (2), 128–142.
Garlock, T.M., Asche, F., Anderson, J.L., Ceballos, A., Love, D.C., Osmundsen, T.C., Pincinato, R.B., 2022. Aquaculture: the missing contributor in the food security agenda. Global Food Sec. 32, 100620.
Gephart, J.E., Golden, C.D., Asche, F., Belton, B., Brugere, C., Froehlich, H.E., Allison, E. H., 2021. Scenarios for global aquaculture and its role in human nutrition. Rev. Fish. Sci. Aquacult. 29 (1), 122–138.
Gordon, D.V., 2021. Price and revenue projections under alternative policy shocks due to the coronavirus: Canadian lobster and snow crab. Mar. Policy 130, 104556.
Hale, T., Angrist, N., Goldszmidt, R., Kira, B., Petherick, A., Phillips, T., Tatlow, H., 2021. A global panel database of pandemic policies (Oxford COVID-19 government response tracker). Nat. Hum. Behav. 5 (4), 529–538.
Hayakawa, K., Mukunoki, H., 2021. The impact of COVID-19 on international trade: evidence from the first shock. J. Jpn. Int. Econ. 60, 101135.
Hersoug, B., 2021. Why and how to regulate Norwegian salmon production? – the history of maximum allowable biomass (MAB). Aquaculture 545, 737144.
Hersoug, B., Olsen, M.S., Gauteplass, A.Å., Osmundsen, T., Asche, F., 2021. Serving the industry or undermining the regulatory system? The use of special purpose licenses in Norwegian salmon aquaculture. Aquaculture. 543, 736918.
Hornok, C., Koren, M., 2015. Per-shipment costs and the lumpiness of international trade. Rev. Econ. Stat. 97 (2), 525–530.
Iversen, A., Asche, F., Hermansen, Ø., Nystøyl, R., 2020. Production cost and competitiveness in major salmon farming countries 2003–2018. Aquaculture 522, 735089.
Khan, A., Guttormsen, A., Roll, K.H., 2018. Production risk of pangas (Pangasius hypophthalmus) fish farming. Aquac. Econ. Manag. 22, 192–208.
Kumar, G., Engle, C.R., 2016. Technological advances that led to growth of shrimp, salmon, and tilapia farming. Rev. Fish. Sci. Aquacult. 24 (2), 136–152.
Lafrogne-Joussier, R., Martin, J., Mejean, I., 2022. Supply shocks in supply chains: evidence from the early lockdown in China. IMF Econ. Rev. 1–46.
Landazuri-Tveteraas, U., Asche, F., Gordon, D.V., Tveteraas, S., 2018. Price transmission in French and UK Salmon Markets. Aquac. Econ. Manag. 22 (1), 131–149.
Landazuri-Tveteraas, U., Asche, F., Straume, H.-M., 2021a. Dynamics of buyer-seller relations in Norwegian wine imports. J. Wine Econ. 16 (1), 68–85.
Landazuri-Tveteraas, U., Oglend, A., Steen, M., Straume, H.-M., 2021b. Salmon trout: the forgotten cousin? Aquac. Econ. Manag. 25 (2), 159–176.
Larsen, T.A., Asche, F., 2011. Contracts in the Salmon aquaculture industry: an analysis of Norwegian Salmon exports. Mar. Resour. Econ. 26 (2), 141–149.
Lawless, M., 2010. Deconstructing gravity: trade costs and extensive and intensive margins. Can. J. Econ. 43 (4), 1149–1172.
Lebel, L., Soe, K.M., Phuong, N.T., Navy, H., Phousavanh, P., Jutagate, T., Lebel, B., 2021. Impacts of the COVID-19 pandemic response on aquaculture farmers in five countries in the Mekong region. Aquac. Econ. Manag. 25 (3), 298–319.
Link, J.S., Werner, F.E., Werner, K., Walter, J., Strom, M., Seki, M.P., Moline, K., 2020. A NOAA fisheries science perspective on the conditions during and after COVID-19: challenges, observations, and some possible solutions, or why the future is upon us. Can. J. Fish. Aquat. Sci. 999, 1–12.
Love, D.C., Asche, F., Conrad, Z., Young, R., Harding, J., Neff, R., 2020. Food sources and expenditures for seafood in the United States. Nutrients. 12 (6), 1810.
Love, D.C., Allison, E.H., Asche, F., Belton, B., Cottrell, R.S., Froehlich, H.E., Zhang, W., 2021. Emerging COVID-19 impacts, responses, and lessons for building resilience in the seafood system. Global Food Sec. 28 (March), 100494.
Love, D.C., Asche, F., Young, R., Nussbaumer, E.M., Anderson, J.L., Botta, R., Thorne-Lyman, A.L., 2022. An overview of retail sales of seafood in the United States, 2017-2019. Rev. Fish. Sci. Aquacult. 30 (2), 259–270.
Mayer, T., Ottaviano, G., 2007. The happy few: new facts on the internationalisation of European firms. In: Bruegel-CEPR EFIM2007 Report, Bruegel Blueprint Series, 3.
Misund, B., Nygård, R., 2018. Big fish: valuation of the World's largest Salmon farming companies. Mar. Resour. Econ. 33 (3), 245–261.
Moor, J., Ropickki, A., Garlock, T.M., 2022. Clam aquaculture profitability under changing environmental risks. In: Forthcoming in Aquaculture Economics and Management.
Nicola, M., Alsafi, Z., Sohrabi, C., Kerwan, A., Al-Jabir, A., Iosifidis, C., Agha, R., 2020. The socio-economic implications of the coronavirus pandemic (COVID-19): a review. Int. J. Surg. 78, 185–193.
Norwegian Directorate of Fisheries, 2022. Statistics for Aquaculture. Available from. https://www.fiskeridir.no/English/Aquaculture/Statistics (Accessed April 22, 2022).
Oglend, A., Straume, H.-M., 2020. Futures market hedging efficiency in a new futures exchange: effects of trade partner diversification. J. Futur. Mark. 40 (4), 617–631.
Oglend, A., Asche, F., Straume, H.-M., 2022. Estimating pricing rigidities in bilateral transactions markets. Am. J. Agric. Econ. 104 (1), 209–227.
Osmundsen, T.C., Amundsen, V.S., Alexander, K.A., Asche, F., Bailey, J., Finstad, B., Salgado, H., 2020. The operationalisation of sustainability: sustainable aquaculture production as defined by certification schemes. Glob. Environ. Chang. 60, 102025.
Osmundsen, T.C., Karlsen, K.M., Robertsen, R., Hersoug, B., 2021. Shared waters—shared problems: the role of self-governance in managing common pool resources. Aquac. Econ. Manag. 25 (3), 275–297.
Petesch, T., Dubik, B., Smith, M.D., 2021. Implications of disease in shrimp aquaculture for wild-caught shrimp. Mar. Resour. Econ. 36 (2), 191–209.
Pincinato, R.B., Asche, F., Roll, K.H., 2021a. Escapees in salmon aquaculture: A multi-output approach. Land Econ. 97 (2), 425–435.
Pincinato, R.B., Asche, F., Bleie, H., Skrudland, A., Stormoen, M., 2021b. Factors influencing production loss factors in salmonid farming. Aquaculture. 532, 736034.
Ploberger, W., Krämer, W., 1992. The CUSUM test with OLS residuals. Econometrica 271–285.
Rocha-Aponte, F., 2020. Firm dispersion and total factor productivity: are Norwegian salmon producers less efficient over time? Aquac. Econ. Manag. 24 (2), 161–180.
Salazar, L., Dresdner, J., 2021. Market integration and price leadership: the U.S. Atlantic salmon market. Aquac. Econ. Manag. 25 (3), 243–268.
Sikveland, M., Tveteras, R., Zhang, D., 2022. Profitability Differences between Public and Private Firms: The Case of Norwegian Salmon Aquaculture. Forthcomming in Aquaculture Economics and Management.
Straume, H.-M., Landazuri-Tveteraas, U., Oglend, A., 2020a. Insights from transaction data: Norwegian aquaculture exports. Aquac. Econ. Manag. 24 (3), 255–272.
Straume, H.M., Anderson, J.L., Asche, F., Gaasland, I., 2020b. Delivering the goods: the determinants of Norwegian seafood exports. Mar. Resour. Econ. 35 (1), 83–96.
Theodorou, J.A., Moutopoulos, D.K., Tzovenis, I., 2020. Semi-quantitative risk assessment of Mediterranean mussel (Mytilus galloprovincialis L.) harvesting bans due to harmful algal bloom (HAB) incidents in Greece. Aquac. Econ. Manag. 24, 273–293.
White, E.R., Froehlich, H.E., Gephart, J.A., Cottrell, R.S., Branch, T.A., Agrawal Bejarano, R., Baum, J.K., 2021. Early effects of COVID-19 on US fisheries and seafood consumption. Fish Fish. 22 (1), 232–239.
WTO, 2022. https://www.wto.org/english/news_e/pres22_e/pr902_e.htm (Accessed 10.5.2022).
Yang, B., Anderson, J.L., Asche, F., 2020. Determinants of China's seafood trade patterns. Mar. Resour. Econ. 35 (2), 97–112.
Yang, B., Anderson, J.L., Fang, Y., 2021. Trade duration of Chinese shrimp exports. Aquac. Econ. Manag. 25 (3), 269–284.
Yang, B., Asche, F., Li, T., 2022. Consumer behavior and food prices during the COVID-19 pandemic: evidence from Chinese cities. Econ. Inq. 60 (3), 1437–1460.