Aquaculture 574 (2023) 739712

Contents lists available at ScienceDirect

Aquaculture

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

Import demand under price and exchange-rate uncertainties: The case of U. S. Atlantic salmon imports

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ARTICLE INFO

Keywords:
Price risk
Exchange rate volatility
Salmon
Import demand
Rotterdam demand model

ABSTRACT

This study investigates the impacts of price and exchange rate volatilities on Atlantic salmon imports in the U.S. market. We first derive an extended Rotterdam demand model, revealing how risk factors affect import demand through 'adjusted' prices. For example, the theoretical model shows that risk-averse importers add risk premiums as a markup for the cost of risk factors. Moreover, the trade effect of volatility variables depends on own-price elasticities and the degree of substitutability between competing products. Our empirical results reveal that U.S. salmon importers are sensitive to price and exchange rate volatilities; however, these two risk factors have differing impacts on import demand, implying the necessity (or effect) of hedging strategies.

1. Introduction

Aquaculture accounts for approximately half of the global seafood consumption and plays a crucial role in global food security (Anderson et al., 2019; Asche et al., 2022; Deb et al., 2022b; Quagraine et al., 2023). Atlantic salmon (*Salmo salar* L.) has been one of the most successful aquacultural species since its commercial breakthrough in the late 1960s/early 1970s. The annual growth rate of global farmed salmon production was approximately 23% between the early 1970s and 2012 (Landazuri-Tveteraas et al., 2023). In 2020, the share of Atlantic salmon production out of all finfish in marine and coastal aquaculture was approximately 32.6% (FAO, 2022). The success of salmon farming is mainly attributed to technological progress (Rocha Aponte and Tveteras, 2019; Osmundsen et al., 2020; Afewerki et al., 2023), demand growth (Brækkan et al., 2018), and rapid globalization (Zhang and Kinnucan, 2014; Garlock et al., 2020; Asche et al., 2022).

However, aquaculture entails a high-risk production phase and is sensitive to uncertainties along the supply chain. In general, agricultural and fishery commodities are sensitive to raw material prices and economic conditions (Serra and Gil, 2013; Chen et al., 2014; Deb et al., 2022a; Surathkal et al., 2022), are typically traded using flexible pricing strategies (Wang and Barrett, 2007; Carter and Gunning-Trant, 2010), and are affected by high demand fluctuations and production uncertainties due to unpredictable temperature and weather conditions (Zilberman, 2019; Ali et al., 2022).

For salmon farming, the entire production process is exposed to production risk from biophysical factors such as seawater temperature changes (Asheim et al., 2011; Bui et al., 2022; Thyholdt, 2014; Abolofia et al., 2017), toxic algae (Engehagen et al., 2021), sea lice (Abolofia et al., 2017; Bang Jensen et al., 2020; Barrett et al., 2020; Barrett et al., 2022) and other salmon diseases (Asche et al., 2009; Fischer et al., 2017), which affect the patterns of salmon price volatility (Oglend, 2013; Asche and Oglend, 2016; Dahl and Jonsson, 2018; Dahl et al., 2020; Asche et al., 2017).[1] In addition, environmental deterioration associated with salmon farming triggers regulations based on input or output restrictions (Frisk et al., 2020; Warren-Myers et al., 2022), which reduce the probability of optimizing harvest schedules and lead to an inelastic supply and then a high level of price fluctuations (Asche et al., 2022). Price risk may impede the role that aquaculture, including farmed salmon, plays in global food security since price risk accompanied by low delivery reliability challenges all types of markets along the supply chain and consumers (Asche et al., 2019). For food prices in general, price risk leads to decreased production and subsequent higher prices in the future, causing market and social unrest (Bellemare, 2015). The globalization of the salmon industry occurred in tandem with salmon companies becoming publicly traded (Sikveland et al., 2022).

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[1] Uncertainty, risk, and volatility are used interchangeably in this study in reference to the variation of price or exchange rate.

https://doi.org/10.1016/j.aquaculture.2023.739712
Received 9 January 2023; Received in revised form 2 April 2023; Accepted 19 May 2023
Available online 20 May 2023
0044-8486/

Salmon price and its volatility are fundamental factors for stock prices and the valuation of salmon companies more broadly (Zhang et al., 2016; Misund, 2018; Misund and Nygard, 2018; Dahl et al., 2021), indicating the importance of stable salmon prices in the development of the salmon industry (Asche et al., 2018; Zhang and Tveteras, 2022).

For traded goods, prices and their volatilities are partly attributed to exchange rate. Researchers have documented evidence of incomplete exchange rate pass-through to import price for salmon (Xie et al., 2008; Zhang, 2020) and other traded goods (Campa and Goldberg, 2005; Casas, 2020). An incomplete exchange rate pass-through suggests that price variability cannot fully reflect exchange rate changes. Ignoring the various impacts of exchange rate volatility and price volatility may cause ambiguous trade effects of the aggregated price volatility.[2] Collectively, separating exchange rate volatility from import price volatility provides new insights into the understanding of salmon trade flows.

Somewhat surprisingly, although extant empirical studies have evaluated the causes and patterns of salmon price volatility, no studies have investigated the impact of price risk on import demand for farmed salmon and whether there are differences between the impacts of price risk and exchange rate risk on salmon trade. Zhang and Kinnucan (2014) examined the impact of exchange rate volatility on U.S. salmon import demand but have not compared the trade effects of price risk and exchange rate volatility. For other fishery and agricultural products, an increasing number of studies have examined the trade effects of price risk (Zhang et al., 2010; Muhammad, 2012; Ott, 2014; Kandilov, 2008; Zhang, 2015; Zhang and Zheng, 2016; Ceballos et al., 2017; Chavas and Li, 2020) and exchange rate volatility (Awokuse and Yuan, 2005; Wang and Barrett, 2007; Kandilov, 2008; Ali et al., 2022).

This study evaluates the impact of price risk and exchange rate risk on salmon import demand. The case study is the U.S. salmon import market, one of the largest Atlantic salmon markets globally and the second most imported seafood in the U.S. This market is dominated by several source countries (Salazar and Dresdner, 2021), which makes it feasible to conduct empirical analysis using an import demand system model (Muhammad and Jones, 2011; Sha et al., 2015; Zhang, 2020). The dominant exporters include both developing and developed countries, which may cause different patterns of price and exchange rate volatilities. In addition, comparing our findings with those from previous studies on salmon import demand highlights this study's contribution.

This paper first derives a demand system equations model by incorporating risk variables into a conventional Rotterdam demand model. The model reveals that risk variables affect demand through marginal utility, which is further weighted by price effect. This corroborates the detected impact of risk factors on demand (De Grauwe, 1988; Wang and Barrett, 2007; Kandilov, 2008; Zhang, 2015). In other words, risk factors affect demand via 'adjusted prices,' in line with the observed risk preferences of importers (Wolak and Kolstad, 1991; Bergin, 2004; Balg and Metcalf, 2010).

For the empirical analysis of the U.S. salmon import market, we derive elasticities from the estimation results. Elasticity refers to changes in import demand (by percentage) in response to a one-percentage change in prices or risk variables, thereby facilitating a comparison between the trade effects of price and exchange rate volatilities.[3] Our empirical results indicate that price risk and exchange rate risk differently impact the U.S. salmon import demand. We then derive implications from the empirical results.

The remainder of this paper is structured as follows: Section 2 provides a brief literature review, followed by the theoretical framework in Section 3. Next, Section 4 presents data sources, the measure of volatilities, and the empirical model specification. Section 5 discusses the empirical results. Finally, the paper concludes with brief remarks and implications in Section 6.

2. Related literature

Salmon production starts with salmon eggs and fry nurtured in freshwater tanks. Hatching takes about 14–20 months. After the juvenile stage, smolts are transferred to open cage enclosures in a natural environment, such as a fjord (Fischer et al., 2017). A cohort of salmon is fed for about 16–22 months before harvesting. Although each stage of salmon farming is risky, the production of farmed salmon in open cages is of primary concern (Asheim et al., 2011; Barrett et al., 2022; Bui et al., 2022).

The biological production process of salmon is exposed to risk from many biophysical factors, such as seawater temperature changes, fish diseases including sea lice, and harmful algal blooms (Asche et al., 2009; Kumbhakar and Tveterås, 2003; Larsen and Vormedal, 2021). Among these biophysical factors, variation in seawater temperature is one of the most important factors influencing salmon growth (Asheim et al., 2011; Bui et al., 2022; Thyholdt, 2014). In addition, seawater temperature affects the life cycle of sea lice, which attach to salmon and cause mortalities (Abolofia et al., 2017; Larsen and Vormedal, 2021; Nilsson et al., 2023). The mandatory delousing operations under sea lice-relevant regulations further damage salmon quality and reduce the growth rate of salmon, affecting harvest strategies and supply (Barrett et al., 2022). The increased use of pharmaceuticals to control mortalities in the freshwater and marine production phases further reduces the growth rate of salmon (Fischer et al., 2017; Overton et al., 2019; Barrett et al., 2020).

A vast amount of literature has explored the patterns and causes of salmon price risk. For example, Asche et al. (2017) verify the impact of temperature shocks on occasional spikes in salmon prices. The Chilean salmon disease crisis, which began in late 2007, substantially reduced the supply from Chile and caused demand shifts, resulting in higher salmon prices from other suppliers in 2009 and 2010, as documented in Oglend (2013). This is consistent with the price volatility spillover of seafood products in global markets (Dahl and Jonsson, 2018). Oglend (2013) further finds the importance of biomass regulation on salmon price volatility, in line with Asheim et al.'s findings (2011) that the biomass and seasonal factors are the crucial drivers of short-term shifts in salmon supply.

Researchers have paid little attention to the trade effect of salmon price risk, although several studies have explored the impact of salmon price risk on salmon farming firms' financial performance and business risk. Asche et al. (2018) find that salmon price variability is positively associated with salmon farming firms' profitability, especially for small firms. Small firms are less likely than large firms to use fixed price contracts, which may raise profitability given the higher price accompanied by high price volatility (Oglend and Sikveland, 2008). Despite its positive impact on profitability, price volatility may affect firm-level cash flows for cautionary payment and earnings management, which further increases salmon farming firms' business hazard (Zhang and Tveteras, 2022). The impact of price risk on salmon import demand, the primary concern of this study, may help explain the above empirical results.

In response to the globalization of salmon products, researchers have investigated the impact of exchange rate on salmon trade flows (Xie et al., 2008; Zhang and Kinnucan, 2014; Garlock et al., 2020; Zhang, 2020). For the U.S. salmon market, Zhang's (2020) simulation results indicate an incomplete exchange rate pass-through into salmon import prices for the dominant exporting countries. An incomplete exchange rate pass-through implies that exchange rate and its volatility are likely important factors influencing trade flows. In a similar vein, Xie et al.'s

[2] In the global soybean market, import demand responds differently to exchange rate risk and commodity price risk of the U.S. and Brazilian soybean (Zhang et al., 2010).

[3] Please see Simonovska and Waugh (2014) for the importance of trade elasticities in the welfare analysis, indicating the need for a future study on price and exchange rate volatility elasticities.

(2008) study suggests that export prices are sensitive to changes in the exchange rate and trade volumes of salmon in the global market, and that exchange rate pass-through is complete for the Chilean peso and the British pound but incomplete for the Norwegian kroner and the U.S. dollar. Moreover, due to the various properties and availabilities of hedging instruments for price risk and exchange rate risk (Nayak and Turvey, 2000; Misund and Asche, 2016; Zilberman, 2019; Zhang, 2020), these two factors may differently impact salmon trade flows. The trade effect of exchange rate volatility also affects demand responses to price changes. Zhang and Kinnucan (2014) evaluate the impact of exchange rate volatility on import demand for salmon in the U.S. market. Their analysis results indicate that omitting exchange rate volatility from the demand model introduces bias to the estimates of price and expenditure elasticities.

Our study also relates to previous salmon demand studies. Muhammad and Jones (2011) find that, in the U.S. salmon import market, import preferences vary between the source countries of Canada and Chile. Sha et al. (2015) and Zhang (2020) apply a two-stage demand model to U.S. salmon imports: the first stage for aggregate imports and the second stage for source-differentiated imports. While Sha et al. (2015) incorporate health information into their model, Zhang (2020) uses the estimated demand elasticities to simulate exchange rate pass-through elasticities. For Atlantic salmon in the world market, Xie et al. (2009) estimate the world demand curves faced by Norway, Chile, and the U.K. These studies can be extended by incorporating price risk and exchange rate volatility into the demand model for salmon imports.

3. Theoretical model

Demand system models assume a multistage budgeting process for allocating expenditure among competing sources (Muhammad and Jones, 2011; Zhang and Kinnucan, 2014). First, total expenditure is allocated over broad groups of goods based on a weakly separable branch of the utility tree. Second, expenditure on a particular good is then allocated between the domestic and imported varieties. Finally, import expenditure is divided among various source countries, from which the import demand models are generated.

The Rotterdam demand model further applies an implicit utility function to derive how prices and expenditure affect trade patterns. The conventional Rotterdam model has been widely used to demonstrate agricultural trade patterns (Duffy, 1987; Muhammad and Jones, 2011; Zhang and Kinnucan, 2014).[4] Building on the conventional version, we incorporate risk variables into the Rotterdam demand model to reveal how risk variables affect import demand, starting with a utility maximization problem[5],[6]:

$$\underset{(q)}{Max}\; u = u(q, v) \tag{1}$$

subject to: $p^{'}q = y$.where u is the utility to be maximized, q is a vector of import volumes from n different source countries, p is the corresponding import price vector, v is a vector of risk variables, and y is the expenditure.

From the first-order conditions of the utility maximization problem, we derive the impact of changes in price (p_j), expenditure (y), or volatility variable (v_j) on the ith product (q_i), namely q_{ij}, q_{iy}, q_{iv_j}. For q_{iv_j}, it is:

$$q_{iv_j} = -\sum_{k=1}^{n} \frac{U_{ik}}{|U|} u_{kv_j} \tag{2}$$

where U is the bordered Hessian matrix; U_{ik} and $|U|$ are cofactor and determinant of U, respectively; $u_{iv_j}\left(=\frac{\partial u_i}{\partial v_j}\right)$ is the impact of v_j on the marginal utility of the ith good.

After obtaining the effects of the exogenous variables (p, y, and v) on import demand, we derive the extended Rotterdam model using a differential approach (Theil, 1980). First, a general import demand equation is expressed as follows:

$$q_i = q_i\,(y, p, v) \tag{3}$$

By taking differentiation of Eq. (3), we obtain:

$$dq_i = \frac{\partial q_i}{\partial y}dy + \sum_{j=1}^{n}\frac{\partial q_i}{\partial p_j}dp_j + \sum_{k=1}^{n}\frac{\partial q_i}{\partial v_k}dv_k \tag{4}$$

Using $\frac{\mathrm{dX}}{\mathrm{X}} = dlnX$ and replacing the parameters in Eq. (4) with the expressions of q_{ij}, q_{iy}, and q_{iv_j}, we obtain the extended Rotterdam demand model in the form:

$$w_i d\,ln\,q_i = a_i d\,ln\,Q + \sum_{j=1}^{n} b_{ij}\left(d\,ln\,p_j - \sum_{k=1}^{n} c_{jk} d\,ln\,v_k\right) \tag{5}$$

where $Q = \frac{y}{\sum_{j=1}^{n} w_j\; ln\; p_j}$ is the real expenditure, $w_i = \frac{p_i q_i}{y}$, $a_i = w_i A_i = \frac{y}{q_i}\frac{\lambda u_i}{|U|}$, $b_{ij} = w_i\,\eta_{ij}^{*} = w_i \frac{p_i}{q_i}\,\frac{\lambda u_{ij}}{|U|}$, and $c_{jk} = u_{jv_k}\frac{v_k}{u_j}$. Here, A_i is the expenditure elasticity, η_{ij}^{*} is the Hicksian price elasticity, and c_{jk} is the elasticity of marginal utility of the jth product with respect to volatility $\mathrm{v_k}$. As such, the estimated coefficients can be converted to the corresponding elasticities.

Eq. (5) expresses the parameters of volatility in structural forms, showing that changes in the jth "effective" price are equal to the actual price changes minus the summation of changes in the marginal utility of the relevant product following changes in all volatility variables in the demand system. If changes in jth volatility decrease the marginal utility of the jth good, then the demand for the ith good is positively associated with the jth price volatility under the setting that the ith and jth products are substitutable with each other.[7]

The extended demand model reveals the channel through which risk variables affect demand, in line with (i) Balg and Metcalf (2010) and Bergin (2004), who posit that a risk-averse firm would attach a risk premium as an extra markup to cover the costs of currency fluctuations and (ii) Wolak and Kolstad (1991), who postulate that input-price risk premium is the percentage above the market price that a firm would pay for riskless input supply.

Additionally, our theoretical model confirms De Grauwe's (1988) proposition that exchange rate volatility affects import demand through the customers' marginal utility for the goods of interest, and that the direction of this effect depends on the curvature of the underlying utility function. For example, in the likely case where own-risk (v_i) only affects the ith good, the direction of the volatility's impact (c_{ii}) depends solely on the effect of the ith volatility on the marginal utility of the ith product, as the sign of b_{ii} is a priori negative. Therefore, the trade effect of volatility is positive when $c_{ii} > 0$ due to the sufficiently risk-averse behavior of importers, i.e., a more concave utility function. The opposite is true if $c_{ii} < 0$. Hence, whether a risk variable exerts a positive or negative effect on trade volume depends on the direction of its effect on the marginal utility.

Finally, we break down the *aggregated* price volatility into a 'pure'

[4] The derivation of the empirical specification of the Rotterdam model is based on a differential approach, which converts the non-stationary time series to stationary variables, an advantage for empirical applications.

[5] Brown and Lee (2010) apply a similar approach to include preference variables in a demand system model.

[6] We illustrate the detailed derivation with a case of two commodities and two volatility variables. See Appendix A.

[7] The interpretation of the risk factor exerting its role through changes in 'effective prices' is identical to that in the advertising-augmented demand model (Duffy, 1995).

price volatility and an exchange rate volatility, resulting in the following theoretical model:

$$w_i d\ ln\ q_i = a_i d\ ln\ Q + \sum_{j=1}^{n} b_{ij}\left(d\ ln\ p_j - \sum_{k=1}^{n} c_{jk} d\ ln\ vp_k - \sum_{k=1}^{n} d_{jk} d\ ln\ ve_k\right) \quad (6)$$

where vp stands for the import price volatility and ve represents the exchange rate volatility.

Besides general restrictions on the demand equations under demand theory, other specific restrictions regarding importers' risk preferences can be tested. For example, Duffy (1987) assumes no cross effect of preference variables. If Duffy's hypothesis holds, the parameter spaces will be reduced, raising the efficiency of regression results.[8] After testing the cross effects of risk variables, we further test the equivalency of own price volatility and own exchange rate volatility effects.

4. Data and empirical model

4.1. Data sources

The extended Rotterdam demand model outlined above is applied to the U.S. salmon import market. Monthly salmon import data from 2010 to 2019 are extracted from the National Oceanic and Atmospheric Administration (NOAA).[9] Among source countries, Chile and Canada export the largest share of Atlantic salmon by value to the U.S. As shown in Table 1, the U.S. imported salmon products at the value of USD 1706 million in 2010, 18.1% of which were from Chile and 32.9% from Canada. U.S. salmon imports nearly doubled between 2010 and 2019, with a substantial increase in imports from Chile. The average market share of Chile's salmon was 49.9% in 2019, followed by Canada with 18.2%.

We obtain the exchange rate for the sample period from the U.S. Department of Agriculture - Economic Research Service (ERS). Fig. 1 illustrates the patterns of salmon price and exchange rate by exporting country. During the sample period, salmon prices by source country vary substantially, indicating the heterogeneity of production uncertainties for the producers and the demand uncertainties of their salmon products exported to the U.S. Later in the sample period, the high prices for all exporting countries are mainly attributed to the demand and production factors rather than to the appreciated U.S. dollar.

Table 1
U.S. salmon imports and market shares by source country.

Year	Total Imports	Value Share				
	(mill. US $)	Chile	Canada	Norway	U.K.	ROW
2010	1706	18.1%	32.9%	23.7%	6.74%	18.6%
2011	1850	31.4%	29.4%	12.3%	6.50%	20.3%
2012	1619	44.1%	33.5%	8.34%	5.09%	8.92%
2013	2197	50.1%	23.7%	9.32%	4.89%	12.0%
2014	2526	54.1%	17.8%	12.0%	5.17%	11.0%
2015	2304	48.7%	24.2%	14.8%	4.06%	8.29%
2016	2813	46.8%	25.7%	14.5%	3.10%	9.83%
2017	3268	48.1%	21.6%	16.7%	4.04%	9.48%
2018	3554	50.2%	20.2%	17.3%	3.69%	8.60%
2019	3673	49.9%	18.2%	17.4%	3.91%	10.6%
Average	2551	44.2%	24.7%	14.6%	4.72%	11.8%

Notes: Data are obtained from National Oceanic and Atmospheric Administration (NOAA). ROW = The rest of the world.

4.2. Measuring volatilities

To estimate price volatility or exchange rate volatility, we first estimate an autoregressive model (AR) for price or exchange rate. Then, a generalized autoregressive conditional heteroskedasticity (GARCH) is used to estimate the volatility (Engle, 1982). This GARCH model assumes that the variance of the error term from the AR model is serially autocorrelated following an autoregressive moving average process, reflecting the time-varying pattern of the variance. The AR–GARCH method is widely applied in the literature to estimate price and exchange rate volatilities (Wang and Barrett, 2007; Kandilov, 2008; Erdem et al., 2010; Zhang, 2015; Deb et al., 2022b; Surathkal et al., 2022) since it can test whether the movement in the conditional variance of price or exchange rate over time is statistically significant (Pattichis, 2003).

After setting the order of one for the AR part, the AR–GARCH is in the form (using exchange rate as an example)[10];[11]

$$\text{AR } e_{i,t} = \alpha_0 + \alpha_1 e_{i,t-1} + s_{i,t} \quad (7)$$

$$\text{GARCH } ve_{i,t} = \delta_0 + \delta_1 s_{i,t-1} + \delta_2 ve_{i,t-1} + o_{i,t} \quad (8)$$

where e_i is the differential exchange rate variable; ve_i represents the conditional volatility; s_i and o_i are error terms of the AR and GARCH processes, respectively.

To separate exchange rate volatility from price volatility, we follow Campa and Goldberg (2005) and estimate import price against exchange rate (U.S. dollar value per foreign currency) for each exporting country. The residual of the regression is: used to estimate the pure price volatility.[12]

The estimates of the price and exchange rate volatilities by exporting country are illustrated in Fig. 2. During the sample period, exchange rate volatilities track each other well, while the import prices fluctuate more significantly. For Chile and Canada, with their lion's share of total U.S. salmon imports, price and exchange rate are less volatile than those of other suppliers.

4.3. Empirical model

The demand system model for U.S. salmon imports includes five equations distinguished by source country, namely Chile, Canada, Norway, the U.K., and the rest of the world (ROW), an aggregation of farmed Atlantic salmon imported from other countries. The monthly import price is obtained for each supplier by dividing the total import value in U.S. dollars by the quantity (kilogram).[13] For the ROW, the monthly aggregate value and quantity are used to calculate the import price. In this study, we consider price volatility and exchange rate volatility for the four largest exporters.

As common in the conventional Rotterdam demand model, the differentiation in Eq. (6) is replaced with changes between periods. To account for demand seasonality and to save the degree of freedom, we used the 12-month differenced variables as has been done in previous studies (Muhammad, 2012; Zhang and Kinnucan, 2014). This gives $\Delta\ ln\ x_t = ln\ x_t - ln\ x_{t-12} \approx d\ ln\ x_t$. As such, in accordance with Eq. (6), the

[8] Without the cross-volatility effects, the elasticity of the jth product with respect to v_k is $\frac{c_{jk} b_{ij}}{w_j}$.

[9] We chose the sample period from 2010 to 2019 to avoid structural changes in the US salmon import market due to the 2017 infectious salmon anemia (ISA) outbreaks in Chile and the Covid-19 pandemic.

[10] As Pattichis (2003) points out, the order of the AR process has little impact on the GARCH models.

[11] All codes in this study are written in SAS and R programming software.

[12] We estimate price volatility and exchange rate volatility separately rather than using a multi-GARCH model since an ARCH test rejects the hypothesis that the covariance matrix of price and exchange rate (for each source country) is a function of the past values of two variables.

[13] Salmon import quantity is the whole fish equivalent weight of various product forms such as fresh, frozen, and fillets.

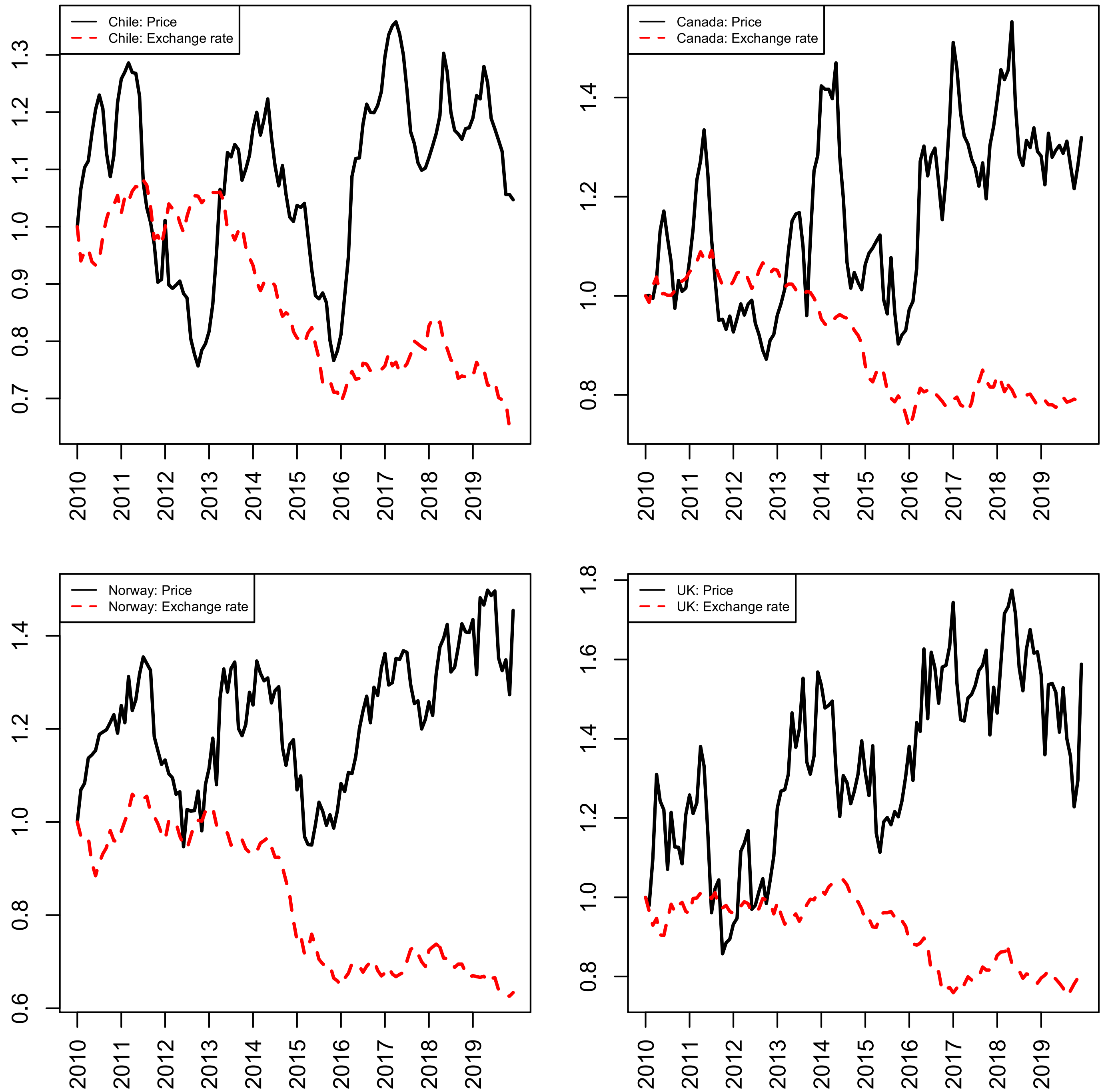

Fig. 1. Monthly import price of salmon versus exchange rate by salmon exporting country (Jan/2010 = 1).

empirical specification of the extended Rotterdam demand model takes the following form:

$$\overline{w}_{i,t}\Delta ln\, q_{i,t} = a_i \Delta ln\, Q_t + \sum_{j=1}^{5} b_{ij}\left(\Delta ln\, p_{j,t} - \sum_{k=1}^{4} c_{jk}\Delta ln\, vp_{k,t} - \sum_{k=1}^{4} d_{jk}\Delta ln\, ve_{k,t}\right) + \varepsilon_{i,t}\; i = 1,2,3,4,5 \tag{9}$$

where i denotes the supplier (Chile = 1, Canada = 2, Norway = 3, the U.K. = 4, and the ROW = 5), t stands for the time subscript (monthly), $\overline{w}_{i,t}$ is the arithmetic mean of the expenditure shares of the ith good in periods t-12 and t, q_i represents import volume, p_i is import price in U.S. dollar, vp_k stands for price variance, ve_k represents exchange rate variance, and ε_i is the error term. Following Theil (1980), changes in real expenditure are measured through a Divisia volume index ($\Delta\, ln\, Q_t = \sum_{j=1}^{5} \overline{w}_{j,t}\Delta\, ln\, q_{j,t}$), and finite logarithmic changes are employed to replace infinitesimal changes in the model.

5. Results

A singularity issue arises when estimating the demand system model due to the adding-up restriction under demand theory.[14] Accordingly, one equation (the ROW) is dropped from the system to avoid the singularity issue. The relevant coefficients are recovered based on demand

[14] The other two restrictions, symmetry and homogeneity, are imposed when estimating the model.

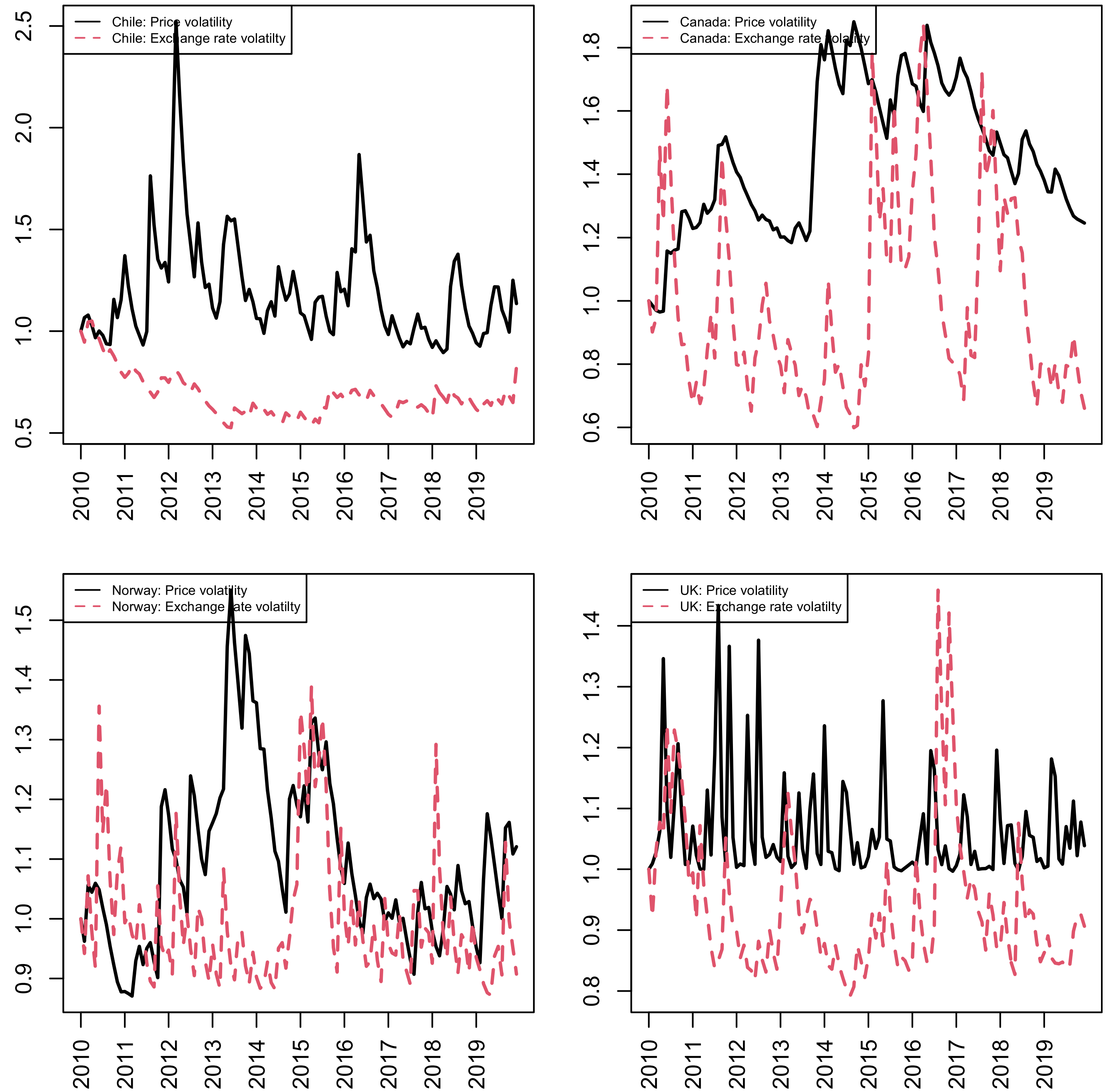

Fig. 2. Monthly price and exchange volatilities by salmon exporting country (Jan/2010 = 1).

constraints. The preliminary estimation results using Zellner's seemingly unrelated regression (SUR) (Zellner, 1962) indicate evidence of autocorrelation. Accordingly, we apply the General Method of Moments (GMM) approach (Wooldridge, 2001) to estimate the Newey-West covariance matrix to control for autocorrelation as well as heteroskedasticity.

We first estimate the complete specification of the extended Rotterdam demand model, i.e., Eq. (8). According to the log-likelihood ratio (LLR) test results, we reject the hypothesis that there are cross effects of price and exchange rate volatilities for each equation and all equations jointly. Therefore, we focus on the extended Rotterdam demand model without cross effects of volatility variables. Table 2 reports the estimation results.

As shown in Table 2, all coefficients of expenditure and prices except for one are significant in each equation.[15] This indicates that the extended Rotterdam demand model fits the data well since the conventional Rotterdam model (see Table B1 in Appendix B) has several insignificant coefficients.

Table 2 also demonstrates that the coefficients of price volatility are all significant except for the one in the Chilean equation, and that all four coefficients of exchange rate volatilities are significant. For Chile, the trade effect of the aggregated price volatility is mainly attributed to changes in exchange rate. The insignificant trade effect of Chilean

[15] We did not report the estimation results for the ROW equation (for the aggregation of small suppliers) since we mainly focus on the impacts of price and exchange rate volatilities on imports from the top suppliers.

Table 2
Estimation results of the extended Rotterdam model with price and exchange rate volatilities (1 = Chile, 2 = Canada, 3 = Norway, 4 = U.K.)

Variable	Eq. (1)		Eq. (2)		Eq. (3)		Eq. (4)	
Δ *ln* Q	0.543	***	0.115	***	0.188	***	0.023	***
	(0.015)		(0.012)		(0.009)		(0.008)	
Δ *ln* p_1	−0.631	***	0.155	***	0.210	***	0.074	***
	(0.029)		(0.011)		(0.017)		(0.005)	
Δ *ln* p_2	0.155	***	−0.362	***	−0.065	***	−0.005	
	(0.011)		(0.01)		(0.006)		(0.002)	
Δ *ln* p_3	0.210	***	−0.065	***	−0.106	***	0.012	***
	(0.017)		(0.006)		(0.011)		(0.003)	
Δ *ln* p_4	0.074	***	−0.005		0.012	***	−0.054	***
	(0.005)		(0.002)		(0.003)		(0.002)	
Δ *ln* p_5	0.191	***	0.277	***	−0.050	***	−0.027	***
	(0.008)		(0.006)		(0.005)		(0.001)	
Δ *ln* vp_1	−0.019		−0.019		−0.019		−0.019	
	(0.019)		(0.019)		(0.019)		(0.019)	
Δ *ln* vp_2	−0.745	***	−0.745	***	−0.745	***	−0.745	***
	(0.034)		(0.034)		(0.034)		(0.034)	
Δ *ln* vp_3	−0.606	***	−0.606	***	−0.606	***	−0.606	***
	(0.043)		(0.043)		(0.043)		(0.043)	
Δ *ln* vp_4	0.392	***	0.392	***	0.392	***	0.392	***
	(0.116)		(0.116)		(0.116)		(0.116)	
Δ *ln* ve_1	−0.228	***	−0.228	***	−0.228	***	−0.228	***
	(0.068)		(0.068)		(0.068)		(0.068)	
Δ *ln* ve_2	0.074	***	0.074	***	0.074	***	0.074	***
	(0.122)		(0.122)		(0.122)		(0.122)	
Δ *ln* ve_3	0.535	***	0.535	***	0.535	***	0.535	***
	(0.081)		(0.081)		(0.081)		(0.081)	
Δ *ln* ve_4	−0.596	***	−0.596	***	−0.596	***	−0.596	***
	(0.174)		(0.174)		(0.174)		(0.174)	

Notes: ***, **, and * indicate significance at the 0.01, 0.5 and 0.1 level, respectively. Robust standard errors are in the parentheses; in each regression equation, the dependent variable is expenditure share-weighted imported volume in the 12-month difference ($\overline{w}_{i,t}\Delta ln\, q_{i,t}$), Δ stands for the 12-month difference operator, *Q* represents the real expenditure, *p* is import price, *vp* is the volatility of import price, and *ve* is exchange rate volatility.

salmon's price volatility may, on the one hand, be attributed to information symmetry between exporters and importers and to the use of fixed price contracts. On the other hand, it may take time for U.S. importers to respond to Chilean salmon's price volatility since Chile is the largest supplier. For each of the other three top exporters, price volatility and exchange rate volatility have opposite effects on imports. For example, price volatility negatively affects the import demand for Canadian and Norwegian salmon products, while exchange rate volatility has a positive impact on demand for these products. However, this comparison is inverted for salmon from the U.K.

We further estimate the extended Rotterdam model with the aggregated price volatility (see Table B2 in Appendix B). The results indicate that the aggregated price volatility is insignificant for the U.K. and significant for Chile at the 0.1 level. To conclude, for the U.S. salmon import market, the extended Rotterdam model with both price volatility and exchange rate volatility fits the data better than either the conventional Rotterdam demand model or the extended Rotterdam demand model with aggregated price volatilities.

Finally, we test the hypothesis of the equivalence of price volatility and exchange rate volatility by using the LLR test approach. The

Table 3
Demand elasticities (1 = Chile, 2 = Canada, 3 = Norway, 4 = U.K.)

	Elasticity of			
	q_1	q_2	q_3	q_4
with respect to:				
Q	1.234	0.462	1.286	0.486
p_1	-1.433	0.623	1.437	1.562
p_2	0.352	-1.455	-0.445	-0.106
p_3	0.477	-0.261	-0.725	0.253
p_4	0.168	-0.020	0.082	-1.140
vp_1	-0.027	0.012	0.027	0.030
vp_2	0.262	-1.084	-0.331	-0.079
vp_3	0.289	-0.158	-0.439	0.154
vp_4	-0.066	0.008	-0.032	0.447
ve_1	-0.327	0.142	0.328	0.356
ve_2	-0.026	0.108	0.033	0.008
ve_3	-0.255	0.140	0.388	-0.136
ve_4	0.100	-0.012	0.049	-0.679

Notes: Shaded elasticities are not significant, *q* is import volume, *Q* represents the real expenditure, *p* is import price, *vp* is the volatility of import price, and *ve* is exchange rate volatility.

hypothesis is rejected for each pair of volatilities and all the pairs jointly, indicating importers' various preferences for price risk and exchange rate risk, probably due to the applications and availability of different risk-management tools for mitigating price and exchange rate risks.

Next, we analyze the elasticities of expenditure, price, and risk variables derived from the estimation results from the extended Rotterdam model with both price and exchange rate volatilities.

5.1. Expenditure and price elasticities

As seen in Table 3, the expenditure elasticity is greater than one for Chile and Norway at a value of 1.234 and 1.286, respectively. Holding other factors constant, the rising expenditure on salmon imports during the sample period contributes substantially to the imports of Chilean and Norwegian salmon. On the other hand, imports from Canada and the U.K. are less sensitive to changes in total import expenditure. For example, a one-percent expenditure growth would increase import volumes of salmon from Canada and the U.K. by 0.462% and 0.486%, respectively.

The own-price elasticities range between −0.725 (for Norway) and − 1.455 (for Canada). Since we aggregate data on frozen and fresh salmon products, the different import demand responses with respect to own-price changes are likely related to product composition for these large suppliers. The small own-price elasticity for Norway and the U.K. is probably due to a large proportion of fresh salmon imported from these two countries. Chile and Canada have a greater price elasticity than Norway and Canada. This is not surprising as Chile and Canada export a large share of frozen salmon to the U.S., which is more storable and highly substitutable.

Most of the cross-price elasticities are significant and positive, suggesting the competition between any pairs of salmon products. It is noticeable that the cross-price elasticities of salmon products from Canada and Norway are negative, suggesting a complementary relationship.

5.2. Volatility elasticities

Since the coefficient of Chilean price volatility is not significant, we focus on the other three price volatilities and the four exchange rate volatilities. The significant coefficients of price volatility and exchange rate volatility indicate that those risk variables affect import demand via 'adjusted' price. The strength of changes in demand in response to the own-risk factor depends upon the own-price effects. Similarly, the cross-volatility effects are subject to the substitutability between those two products of interest. For example, an increase in the U.K.'s salmon price variance would expand its 'adjusted' price, consequently affecting the demand for Canadian salmon. As such, the impact of the U.K.'s price volatility on the demand for Canadian salmon depends on the import demand elasticity of Canada's salmon with respect to the U.K.'s price.

Uncertainty from own-currency realignments exerts a significant effect on imports from Chile (−0.327), Canada (0.108), Norway (0.388), and the U.K. (−0.679). Although the negative impacts of exchange rate volatilities on import demand are consistent with the findings in Wang and Barrett (2007) and Kandilov (2008), the positive impact of exchange rate volatility provides supportive evidence for De Grauwe's (1988) hypothesis that increased exchange rate risk would cause firms to import more to avoid a future worse possible outcome.

Compared to exchange rate volatility, price volatility has a more significant impact on trade flows regarding both own-volatility and cross-volatility effects. The own-price variance negatively affects salmon imports from Canada and Norway (−1.084 and − 0.493, respectively) and positively affects salmon imports from the U.K. (0.447). The different responses of import demand to price and exchange rate volatilities can likely be explained by market shares, transportation costs, or information availability. For example, the insignificant impact of own-price volatility and the weak impact of own exchange rate volatility for Chile are likely related to a higher tolerance for the uncertainty of salmon imports from Chile, the primary supplier to the U.S. market.

The cross-volatility effects are ambiguous and depend on the substitutability between products. Import demand for Chilean salmon reacts positively to the price volatilities of Canadian and Norwegian salmon and the U.K.'s exchange rate volatility but responds negatively to the U.K.'s price volatility and to Canadian and Norwegian currency volatilities.

These empirical findings imply two arguments, which shed light on the trade effect of risk variables. First, demand elasticities with respect to risk factors are generally small in absolute values since the impacts of risk variables are weighted by price effects. Second, the substantial differences between the trade effects of price volatility and exchange rate volatility may explain the insignificant effect of the aggregated price volatility in the previous studies.

6. Conclusions

The rapid development of the global seafood market is greatly attributed to the growing aquaculture industry. Atlantic salmon is one of the most valued seafood species and the U.S. is one of the largest salmon import markets. To investigate how risk factors affect U.S. salmon import demand, this paper derives an extended Rotterdam demand model by incorporating risk variables into the model. The theoretical model shows that risk factors affect demand via 'adjusted prices,' in line with the fact that risk-averse firms add a proportional markup on actual prices. We further separate price risk and exchange rate volatility in the demand model, contributing to the literature by examining different impacts of price and exchange rate volatilities on trade flows.

This study's empirical findings sustain the conjecture that price and exchange rate volatilities are factors influencing the U.S. import demand for farmed salmon since the elasticities of price and exchange rate volatilities are significant in most cases. The magnitudes of the volatility elasticities are relatively small. Under the theoretical framework, the effect of risk factors is associated with marginal utility, which is further weighted by price effects. Additionally, price and exchange rate volatilities affect import demand in different ways, indicating diverse risk management strategies within a particular exporting country and among all exporting countries more broadly. For a particular exporting country, the differences between the trade effects of price and exchange rate volatilities are potentially related to importers' abilities to manage risks and the availability of hedging instruments. For example, salmon price risk can be mitigated through fixed price/volume contracts or financial contracts, while a portfolio of hedging arrangements designed to reduce the adverse effects of exchange fluctuations is available for most traders. For salmon products from those exporting countries, U.S. importers may take an interrelated risk management strategy. For example, U.S. salmon importers replace Canadian and Norwegian salmon with salmon from the U.K. and Chile when exchange rate volatilities are high; however, they replace the U.K. salmon with Canadian and Norwegian salmon when salmon prices become volatile.

This study focuses on salmon to highlight the importance of considering price and exchange rate volatilities when investigating trade flows of aquaculture species. Our study reveals risk management strategies among the U.S. salmon importers and provides suggestions for both importers and exporters of other aquaculture species to control trade risk along the supply chain, ensuring the sustainable development of the global aquaculture industry. In sum, the application of our methods to other aquaculture species and then the derived implications for importers and exporters regarding risk management represent important insights on the use of instrumental tools and hedging strategies to mitigate trade uncertainties. The stable trade flows of aquaculture species further strengthen their role in global food security.

CRediT authorship contribution statement

Dengjun Zhang: Conceptualization, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Funding acquisition. **Yingkai Fang:** Conceptualization, Formal analysis, Writing – original draft, Writing – review & editing. **Yiyang Liu:** Conceptualization, Writing – review & editing.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Dengjun Zhang reports financial support was provided by Research Council of Norway.

Data availability

Data will be made available on request.

Acknowledgments

This work was supported by the Research Council of Norway under Grant number 338112. The authors are grateful to the editor and reviewers for their valuable comments, and to Henry Kinnucan, Frank Asche, Andrew Muhammad, and Henry Thompson for their helpful comments on early drafts of this study.

Appendix A. Appendix

In this Appendix, we derive the extended Rotterdam model from a utility maximization problem for a case of two commodities and two risk variables:

$$\underset{(q_1,q_2)}{Max}\ u = u(q_1, q_2, v_1, v_2) \tag{A.1}$$

subject to: $p_1q_1 + p_2q_2 = y$where u is the utility to be maximized, q_1 and q_2 are products from source countries, p_1 and p_2 are the corresponding import prices, v_1 and v_2 are risk variables, and y is the conditional expenditure.

The maximizing problem can be rewritten as:

$$\underset{(q_1,q_2,\lambda)}{Max}\ u = u(q_1, q_2, v_1, v_2) - \lambda(y - p_1q_1 - p_2q_2)\ (\text{A.1}^{'})$$

where λ is the Lagrange multiplier.

The first-order conditions of the utility maximization problem are:

$$p_1q_1 + p_2q_2 = y\ (\text{derivative A.1}^{'} \text{ with respect to } \lambda) \tag{A.2}$$

$$\lambda p_1 + u_1 = 0\ (\text{derivative A.1}^{'} \text{ with respect to } q_1) \tag{A.3a}$$

$$\lambda p_2 + u_2 = 0\ (\text{derivative A.1}^{'} \text{ with respect to } q_2) \tag{A.3b}$$

where $u_1\left(=\frac{\partial u}{\partial q_1}\right)$ and $u_2\left(=\frac{\partial u}{\partial q_2}\right)$ are marginal utilities for these two products, respectively.

In order to evaluate how prices affect the equilibrium quantity, we derivate Eq. (A.2) and (A.3) with respect to p_1 and p_2 and solve the equations to get:

$$q_{11} = \frac{\lambda(-q_1U_1 + U_{12})}{|U|} \tag{A.4a}$$

$$q_{12} = \frac{\lambda(-q_2U_1 + U_{12})}{|U|} \tag{A.4b}$$

where U_1, U_2, and U_{12} are cofactors of the bordered Hessian matrix U, and $|U|$ is determinant of U. Here, we denote $q_{11}^* = \frac{\lambda U_{11}}{|U|}$ and $q_{12}^* = \frac{\lambda U_{12}}{|U|}$ and rewrite Eqs. (A.4a) and (A.4b)as:

$$q_{11} = \frac{-\lambda q_1U_1}{|U|} + q_{11}^*\ (\text{A.4a}^{'})$$

$$q_{12} = \frac{-\lambda q_2U_1}{|U|} + q_{12}^*\ (\text{A.4b}^{'})$$

The effects of y on q_1 is:

$$q_{1y} = \frac{\lambda U_1}{|U|} \tag{A.5}$$

The impact of v_1 on $q_1$is revealed by first differentiating the first-order equations with respect to v_1 to yield:

$$U.\begin{bmatrix} -\lambda_{v_1}/\lambda \\ q_{1v_1} \\ q_{2v_1} \end{bmatrix} = \begin{bmatrix} 0 \\ -u_{1v_1} \\ -u_{2v_1} \end{bmatrix} \tag{A.6}$$

where $\lambda_{v_1}\left(=\frac{\partial \lambda}{\partial v_1}\right)$ and $u_{1v_1}\left(=\frac{\partial u_1}{\partial v_1}\right)$ represent the effects of v_1 on the Lagrange multiplier and the marginal utility of the first product, respectively; q_{1v_1} is the effect of the volatility on the first product.

Next, from Eq. (A.6), we solve q_{1v_1}:

$$q_{1v_1} = -\sum_{k=1}^{n} \frac{U_{1k}}{|U|} u_{kv_1} = -\frac{U_{11}}{|U|}u_{1v_1} - \frac{U_{12}}{|U|}u_{2v_1} \tag{A.7}$$

Using $q_{11}^* = \frac{\lambda U_{11}}{|U|}$ and $q_{12}^* = \frac{\lambda U_{12}}{|U|}$, we rewrite Eq. (A.7) as:

$$q_{1v_1} = -q_{11}^*\frac{u_{1v_1}}{\lambda} - q_{12}^*\frac{u_{2v_1}}{\lambda} \text{ (A.7'a)}$$

Following the same method as above, we obtain q_{1v_2} as:

$$q_{1v_2} = -q_{11}^*\frac{u_{1v_2}}{\lambda} - q_{12}^*\frac{u_{2v_2}}{\lambda} \text{ (A.7'b)}$$

After obtaining the results of the effects of the exogenous variables (p, y, and v) on the demand for q_1, we derive the extended Rotterdam model by using a differential approach. First, the import demand equation for q_1 is expressed as follows, which are solutions to Eq. (A.2) and (A.3)

$$q_1 = q_1(y, p_1, p_2, v_1, v_2) \tag{A.8}$$

By taking the total differentiation of Eq. (A.8), we obtain:

$$dq_1 = \frac{\partial q_1}{\partial y}dy + \frac{\partial q_1}{\partial p_1}dp_1 + \frac{\partial q_1}{\partial p_2}dp_2 + \frac{\partial q_1}{\partial v_1}dv_1 + \frac{\partial q_1}{\partial v_2}dv_2 \tag{A.9}$$

Multiplying the two sides of Eq. (A.9) by $\frac{w_1}{q_1}$ and with some manipulation yields:

$$w_1\frac{dq_1}{q_1} = w_1\frac{y}{q_1}\frac{\partial q_1}{\partial y}\frac{dy}{y} + w_1\frac{p_1}{q_1}\frac{\partial q_1}{\partial p_1}\frac{dp_1}{p_1} + w_1\frac{p_2}{q_1}\frac{\partial q_1}{\partial p_2}\frac{dp_2}{p_2} + w_1\frac{v_1}{q_1}\frac{\partial q_1}{\partial v_1}\frac{dv_1}{v_1} + w_1\frac{v_2}{q_1}\frac{\partial q_1}{\partial v_2}\frac{dv_2}{v_2} \text{ (A.9'a)}$$

where $w_1 = \frac{p_1 q_1}{y}$.

Using $\frac{dX}{X} = dlnX$, Eq. (A.9'a) is restated as:

$$w_1 dlnq_1 = w_1\frac{y}{q_1}\frac{\partial q_1}{\partial y}dlny + w_1\frac{p_1}{q_1}\frac{\partial q_1}{\partial p_1}dlnp_1 + w_1\frac{p_2}{q_1}\frac{\partial q_1}{\partial p_2}dlnp_2 + w_1\frac{v_1}{q_1}\frac{\partial q_1}{\partial v_1}dlnv_1 + w_1\frac{v_2}{q_1}\frac{\partial q_1}{\partial v_2}dlnv_2 \text{ (A.9'b)}$$

Replacing the partial derivatives in Eq. (A.9'b) with Eq. (A.4), (A.5) and (A.7) yields

$$w_1 dlnq_1 = w_1\frac{\lambda U_1}{|U|}\frac{y}{q_1}dlny + w_1\frac{p_1}{q_1}\left(\frac{-\lambda q_1 U_1}{|U|} + q_{11}^*\right)dlnp_1 + w_1\frac{p_2}{q_1}\left(\frac{-\lambda q_2 U_1}{|U|} + q_{12}^*\right)dlnp_2 - w_1\frac{v_1}{q_1}q_{11}^*\frac{u_{1v_1}}{\lambda}dlnv_1 - w_1\frac{v_1}{q_1}q_{12}^*\frac{u_{2v_1}}{\lambda}dlnv_1 - w_1\frac{v_2}{q_1}q_{11}^*\frac{u_{1v_2}}{\lambda}dlnv_2 - w_1\frac{v_2}{q_1}q_{12}^*\frac{u_{2v_2}}{\lambda}dlnv_2 \text{ (A.9'c)}$$

Reorganizing terms in Eq. (A.9'c) gives rise to:

$$w_1 dlnq_1 = w_1\frac{\lambda U_1}{|U|}\frac{y}{q_1}\left(dlny - \frac{q_1}{y}\frac{p_1}{q_1}q_1 dlnp_1 - \frac{q_1}{y}\frac{p_2}{q_1}q_2 dlnp_2\right) + w_1\frac{p_1}{q_1}q_{11}^*\left(dlnp_1 - \frac{v_1}{u_1}u_{1v_1}dlnv_1 - \frac{v_2}{u_1}u_{1v_2}dlnv_2\right) + w_1\frac{p_2}{q_1}q_{12}^*\left(dlnp_2 - \frac{v_1}{u_2}u_{2v_1}dln\,v_1 - \frac{v_2}{u_2}u_{2v_2}dlnv_2\right)$$

(A.9'd)

From Eq. ('A.9d), we obtain the empirical specification of the extended Rotterdam model in the form (illustrated by the demand equation for q_1):

$$w_1 d\ ln\ q_1 = a_i d\ ln\ Q + b_{11}(dlnp_1 - c_{11}dlnv_1 - c_{12}dlnv_1) + b_{12}(dlnp_2 - c_{21}dlnv_2 - c_{22}dlnv_2) \tag{A.10}$$

where $Q = \frac{y}{\sum_{j=1}^{n} w_j\ ln\ p_j}$ is the real expenditure, $w_1 = \frac{p_1 q_1}{y}$, $a_1 = w_1\frac{\lambda U_1}{|U|}\frac{y}{q_1} = w_1 A_1$, $b_{11} = w_1\frac{p_1}{q_1}q_{11}^* = w_1\eta_{11}^*$, $b_{12} = w_1\frac{p_2}{q_1}q_{12}^* = w_1\eta_{12}^*$, $c_{11} = \frac{u_1}{v_1}u_{1v_1}$, $c_{12} = \frac{v_2}{q_1}u_{1v_2}$, $c_{21} = \frac{v_1}{u_2}u_{2v_1}$, and $c_{22} = \frac{v_2}{u_2}u_{2v_2}$.

Appendix B. Appendix

Table B1
Estimation results of the conventional Rotterdam model (1 = Chile, 2 = Canada, 3 = Norway, 4 = U.K.)

Variable	Eq. (1)		Eq. (2)		Eq. (3)		Eq. (4)	
Δ *ln* Q	0.551	***	0.041	*	0.184	***	0.023	*
	(0.042)		(0.026)		(0.028)		(0.012)	
Δ *ln* p_1	−0.495	***	0.017		0.200	***	0.016	***
	(0.065)		(0.032)		(0.042)		(0.008)	
Δ *ln* p_2	0.017		−0.222	***	−0.023		0.037	***
	(0.032)		(0.031)		(0.023)		(0.006)	
Δ *ln* p_3	0.200	***	−0.023		−0.142	***	0.045	
	(0.042)		(0.023)		(0.033)		(0.007)	
Δ *ln* p_4	0.016		0.037	**	0.045		−0.066	***
	(0.008)		(0.006)		(0.007)		(0.008)	
Δ *ln* p_5	0.263	***	0.191	***	−0.079		−0.031	*
	(0.028)		(0.024)		(0.013)		(0.005)	

Notes: ***, **, and * indicate significance at the 0.01, 0.5 and 0.1 level, respectively. Robust standard errors are in the parentheses. For each equation, the dependent variable is expenditure share-weighted imported volume in the 12-month difference ($\overline{w}_{i,t}\Delta ln\ q_{i,t}$), Δ stands for the 12-month difference operator, Q represents the real expenditure, and p is import price.

Table B2
Estimation results of the extended Rotterdam model with the aggregated price volatilities (1 = Chile, 2 = Canada, 3 = Norway, 4 = U.K.)

Variable	Eq. (1)		Eq. (2)		Eq. (3)		Eq. (4)	
$\Delta\ ln$ Q	0.543	***	0.137	***	0.191	***	0.022	***
	(0.03)		(0.025)		(0.018)		(0.009)	
$\Delta\ ln\ p_1$	−0.574	***	0.112	***	0.202	***	0.052	***
	(0.034)		(0.02)		(0.027)		(0.008)	
$\Delta\ ln\ p_2$	0.112	***	−0.318	***	−0.062	***	0.002	
	(0.020)		(0.041)		(0.027)		(0.004)	
$\Delta\ ln\ p_3$	0.202	***	−0.062	***	−0.122	***	0.040	***
	(0.027)		(0.014)		(0.026)		(0.009)	
$\Delta\ ln\ p_4$	0.052	***	0.002		0.040	***	−0.059	***
	(0.008)		(0.004)		(0.009)		(0.006)	
$\Delta\ ln\ p_5$	0.207	***	0.265	***	−0.057	***	−0.035	**
	(0.02)		(0.027)		(0.016)		(0.007)	
$\Delta\ ln\ vp_1$	−0.056	*	−0.056	*	−0.056	*	−0.056	*
	(0.032)		(0.032)		(0.032)		(0.032)	
$\Delta\ ln\ vp_2$	−1.160	***	−1.160	***	−1.160	***	−1.160	***
	(0.087)		(0.087)		(0.087)		(0.087)	
$\Delta\ ln\ vp_3$	−0.496	***	−0.496	***	−0.496	***	−0.496	***
	(0.087)		(0.087)		(0.087)		(0.087)	
$\Delta\ ln\ vp_4$	0.097		0.097		0.097		0.097	
	(0.009)		(0.009)		(0.009)		(0.009)	

Notes: ***, **, and * indicate significance at the 0.01, 0.5 and 0.1 level, respectively. Robust standard errors are in the parentheses. For each equation, the dependent variable is expenditure share-weighted imported volume in the 12-month difference ($\overline{w}_{i,t}\Delta ln\ q_{i,t}$), Δ stands for the 12-month difference operator, Q represents the real expenditure, p is import price, and vp is the *aggregated* volatility of import price.

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