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Export Elasticity to Exchange Rates Revisited: Application of Rolling ARDL Estimation to Japanese Exports[*]

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Abstract

This study applies the rolling regression approach to the auto-regressive distributed lag (ARDL) model to investigate how Japanese export quantity responded to the yen's real effective exchange rate (REER) over the sample period from June 1992 to December 2023. We also estimate the export price equation using the rolling ARDL model to examine the time-varying exchange rate pass-through (ERPT) or pricing-to-market (PTM). We reveal that the quantity of Japanese exports is unlikely to respond positively to exchange rate changes, except for the Transport Equipment exports. Such unresponsiveness in export quantity likely changed in 2021 when the yen depreciated rapidly and substantially. We also demonstrate that Japanese exporters tended to stabilize the export price in destination markets, which is a typical PTM behavior. More intriguingly, we observe the complete PTM from around 2022 in response to the sharp yen depreciation. Thus, Japanese exporters have not utilized the yen depreciation to increase their export quantity. However, the exporters have raised the degree of PTM in the yen depreciation period to enjoy larger foreign exchange gains.

Keywords: Japanese exports; exchange rates; autoregressive distributed lag (ARDL) model; rolling regression; exchange rate pass-through

JEL Classification: F14; F31; F32

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1. Introduction

The effect of exchange rate changes on the economy is not an outdated research question. In recent research, Fukui *et al*. (2023) theoretically and empirically investigated whether exchange rate depreciations affect the economy and whether the effect differs across exchange rate regimes. Our study focuses on the recent experience of the Japanese economy. It explores whether and how the yen exchange rate has affected the Japanese economy, especially in terms of the quantity and price of Japanese exports.

As shown in Figure 1, the Japanese trade balance turned into a deficit in 2011 and has not fully returned to a significant surplus even if the yen depreciated substantially against the U.S. dollar (USD) from around 76 in 2011 to about 150 in 2022. Japanese export quantity has not shown any clear increasing trend and exhibited a gradual decline in response to the yen's substantial depreciation. The yen depreciated from around 130 to 150 against the USD in 2023 and much further to 160 in 2024. However, the quantity of Japanese exports continued to decline between 2023 and 2024. A natural question is why the yen depreciation after 2011 did not cause an increase in export quantity.

[Insert Figure 1 around here.]

Japanese export firms have suffered from substantial exchange rate changes as summarized above. Chinn (2013) estimated the Japanese export price elasticity and the import price elasticity from 1990 to 2012 and concluded that a yen depreciation should improve the real trade balance, at least in the long run. Baek (2013) used an auto-regressive distributed lag (ARDL) model to examine the short- and long-run effects of exchange rate changes on trade flows in disaggregating industry data of bilateral trade between Korea and Japan. Thorbecke and Kato (2011, 2012) and Thorbecke and Salike (2018) used a panel dataset to investigate how exchange rates affect exports by the dynamic ordinary least squares (DOLS) estimation.

Rolling regression is often employed in empirical studies to characterize the time-varying nature of economic relationships. As a simple robustness check, regression parameters are estimated using some fraction of the data early in the sample. The fixed fraction is then ‘‘rolled’’ through the sample, so the estimated regression parameters may vary over time. This intuitive procedure is one of the conventional methods to examine the stability of statistical relationships over time. To report rolling regression estimates, researchers often plot error confidence bands around the point estimates to visually infer whether estimated coefficients are statistically significant. Shi *et al*. (2016) showed that the rolling window approach yields the best results compared to the forward and recursive rolling approaches for stationary and possibly integrated systems, respectively. Shi *et al*. (2016) also examined the lag-augmented VAR (LA-VAR) rolling-window approach following Toda and Yamamoto (1995). Shahzad *et al*. (2017) employed the rolling and recursive rolling window Granger causality approaches.

The contribution of this study is to apply the rolling regression approach to the ARDL model to investigate how the response of Japanese export quantity to the yen's real effective exchange rate (REER) has evolved over the sample period from June 1992 to December 2023. We explore likely differences in export quantity responses across industries using the industry-specific export quantity index. We also estimate the export price equation by employing the rolling ARDL model to examine the time-varying exchange rate pass-through (ERPT) or pricing-to-market (PTM).

The rolling ARDL estimation reveals that Japanese export quantity is unlikely to respond positively to exchange rate changes. Only in the Transport Equipment exports did the export quantity respond positively (negatively) to exchange rate depreciation (appreciation) up to the early 2000s. Other industries clearly indicate the unresponsiveness of export quantity to exchange rates during the same period. Such unresponsiveness in export quantity likely changed in 2021 when the yen depreciated rapidly and substantially. We also demonstrate that Japanese exporters tended to stabilize the export price in destination markets, which is a typical PTM behavior, and the degree of PTM was about 50 percent from the mid-2000s. More interestingly, we observe the complete PTM from around 2022 in response to the sharp yen depreciation. Thus, Japanese exporters have not utilized the yen depreciation to increase their export quantity. However, the exporters have raised the degree of PTM in the yen depreciation period to enjoy larger foreign exchange gains.

The remainder of this paper is structured as follows. Section 2 elaborates on the empirical model. Section 3 describes the data for empirical analysis. Section 4 presents the empirical results. Finally, Section 5 concludes this study.

2. Empirical Model

2.1 Export Quantity Equation

2.1.1 Export Demand Elasticity

We employ the conventional export demand function to assess the degree of export quantity responses to exchange rate changes (e.g., Chinn, 2013).

$$x_t = \gamma_0 + \gamma_1 q_t + \gamma_2 y_t^* + \upsilon_t \quad (1)$$

where x_t denotes export quantity, q_t denotes bilateral real exchange rate, y_t^* denotes foreign demand, υ_t denotes error term, a single asterisk (*) denotes a foreign variable, and lowercase letters are assumed to be natural logarithmic. By extending the above "bilateral export" specification to the "export to the world" specification, we obtain:

$$x_t = \beta_0 + \beta_1 q_t^w + \beta_2 y_t^w + \varepsilon_t \quad (2)$$

where q_t^w denotes the reciprocal of the yen's REER ($reer_t$) obtained from the Bank for International Settlements (BIS), which means that an increase in q_t^w represents real effective depreciation of the yen. y_t^w denotes a weighted average of the importing country's demand, and ε_t denotes the error term.

2.1.2 ARDL Model

We extend equation (2) to the ARDL model, developed by Pesaran *et al.* (2001), to estimate both short-run and long-run responses of Japanese export quantity to exchange rate changes. A conditional error-correction model (ECM) can be shown as:

$$\Delta x_t = \rho_0 + \rho_1 x_{t-1} + \rho_2 q_{t-1}^w + \rho_3 y_{t-1}^w + \sum_{i=1}^{k} \gamma_{1i} \Delta x_{t-i} + \sum_{i=0}^{l} \gamma_{2i} \Delta q_{t-i}^w + \sum_{i=0}^{m} \gamma_{3i} \Delta y_{t-i}^w + v_t \quad (3)$$

Pesaran *et al.* (2001) proposed to conduct the bounds *F*-test, the joint null hypothesis of which is H₀: $\rho_1 = \rho_2 = \rho_3 = 0$. If the null hypothesis is rejected, a long-run equilibrium relationship is found between the variables. Specifically, in Equation (3), the long-run export elasticity to exchange rate changes is calculated as $\beta_1 = -\rho_2 / \rho_1$ and ρ_1 is called the error-correction term (ECT), which represents the speed of adjustment to equilibrium. To ensure the long-run relationship between the variables, Pesaran *et al.* (2001) also proposed to perform another bounds test for cointegration, i.e., the bounds *t*-test, where the null hypothesis is H₀: $\rho_1 = 0$. We conduct both bounds testing procedures in the following rolling approach to the ARDL model.

2.1.3 Rolling Regression of the ARDL Model

We employ the rolling window approach and let T = 379 be the total number of months in the whole sample period. Let M = 60 to fix the rolling window size, i.e., five years. Then the directional dependence is determined for each subsample, and the fixed rolling window moves forward until the last sample's observation is reached. The rolling ARDL model can be shown as:

$$\Delta x_{t,j} = \rho_{0,j} + \rho_{1,j} x_{t-1,j} + \rho_{2,j} q_{t-1,j}^w + \rho_{3,j} y_{t-1,j}^w + \sum_{i=1}^{k} \gamma_{1i,j} \Delta x_{t-i,j} + \sum_{i=0}^{l} \gamma_{2i,j} \Delta q_{t-i,j}^w + \sum_{i=0}^{m} \gamma_{3i,j} \Delta y_{t-i,j}^w + v_{t,j} \quad (4)$$

where j indicates the rolling window number ranging from 1 to $(T - M + 1)$, t ranges from j to T. $\rho_{0,j}$, $\rho_{1,j}$, $\rho_{2,j}$, $\rho_{3,j}$, $\gamma_{1i,j}$, $\gamma_{2i,j}$, $\gamma_{3i,j}$ are the parameters estimated for the j_{th} window. Also, we include dummy variables to account for unusually large estimates of coefficients.[1] To consider possible misspecification or omitted explanatory variables, we include a trend term in a long-run level regression. The conditional ECM of export quantity can be written as:

$$\Delta x_{t,j} = \rho_{0,j} + \rho_{1,j}x_{t-1,j} + \rho_{2,j}q^{w}_{t-1,j} + \rho_{3,j}y^{w}_{t-1,j} + \rho_{4,j}t_j + \sum_{i=1}^{k}\gamma_{1i,j}\,\Delta x_{t-i,j}$$
$$+ \sum_{i=0}^{l}\gamma_{2i,j}\,\Delta q^{w}_{t-i,j} + \sum_{i=0}^{m}\gamma_{3i,j}\,\Delta y^{w}_{t-i,j} + D_{t,j} + v_{t,j} \qquad (5)$$

2.2 Export Price Equation

We extend the rolling ARDL model by replacing the export quantum index with the export unit price index. Let T = 342 be the total number of months in the whole sample period and M = 60 to fix the rolling window size, i.e., five years. The equation (4) can be modified as:

$$\Delta p_{t,j} = \rho_{0,j} + \rho_{1,j}p_{t-1,j} + \rho_{2,j}s^{w}_{t-1,j} + \rho_{3,j}y^{w}_{t-1,j} + \sum_{i=1}^{k}\gamma_{1i,j}\,\Delta p_{t-i,j}$$
$$+ \sum_{i=0}^{l}\gamma_{2i,j}\,\Delta s^{w}_{t-i,j} + \sum_{i=0}^{m}\gamma_{3i,j}\,\Delta y^{w}_{t-i,j} + v_{t,j} \qquad (6)$$

where p_t denotes export unit price, s^{w}_{t} denotes the reciprocal of the yen's NEER $(neer_t)$ obtained from the Bank for International Settlements (BIS), which means that an increase in s^{w}_{t} stands for nominal effective depreciation of the yen. y^{w}_{t} denotes a weighted average of the importing country's demand, and v_t denotes the error term. j indicates the rolling window number ranging from 1 to $(T - M + 1)$, t ranges from j to T, and $\rho_{0,j}$, $\rho_{1,j}$, $\rho_{2,j}$, $\rho_{3,j}$, $\gamma_{1i,j}$, $\gamma_{2i,j}$, $\gamma_{3i,j}$ are the parameters estimated for the j_{th} window. Also, we include dummy variables to account for unusually large estimates of coefficients as we did for export quantity equation. To consider possible misspecification or omitted explanatory variables, we include a trend term in a long-run level regression. The conditional ECM of export unit price can be written as:

$$\Delta p_{t,j} = \rho_{0,j} + \rho_{1,j}p_{t-1,j} + \rho_{2,j}s^{w}_{t-1,j} + \rho_{3,j}y^{w}_{t-1,j} + \rho_{4,j}t_j + \sum_{i=1}^{k}\gamma_{1i,j}\,\Delta p_{t-i,j}$$
$$+ \sum_{i=0}^{l}\gamma_{2i,j}\,\Delta s^{w}_{t-i,j} + \sum_{i=0}^{m}\gamma_{3i,j}\,\Delta y^{w}_{t-i,j} + D_{t,j} + v_{t,j} \qquad (7)$$

This study builds on the existing body of research by introducing a dynamic perspective, using rolling estimation to capture the evolving strategies of Japanese exporters. By analyzing export quantity and price-setting behavior, this research provides new insights into how Japanese

[1] Pesaran *et al*. (2001) included dummies to allow for such unusual estimates of coefficients.

exporters respond to exchange rate changes by adjusting export quantity and prices.

3. Data

This study uses the monthly series of the Japanese export quantum (quantity) index by industry, the Japanese export unit price index by industry, the REER of the yen, the NEER of the yen, and the world industrial production index. The sample period for export quantity analysis spans from June 1992 to December 2023, while the sample period for export price analysis ranges from July 1995 to December 2023. We examine the four industries: All Manufacturing, General Machinery, Electrical and Electronic Equipment, and Transport Equipment.

The monthly Japanese export quantity index series by industry (x_t) and the Japanese export unit price index by industry (p_t) are obtained from the Ministry of Finance, Japan. We obtained the yen's REER ($reer_t$) and the yen's NEER ($neer_t$) from the Bank for International Settlements (BIS) to calculate the reciprocal of the REER and NEER, q_t^w and s_t^w, respectively. The world industrial production index (IPI), y_t^w, is constructed by taking a weighted average of IPI series for Japan's 20 major trading partner countries, which is a proxy for import demand. The IPI series are obtained from the CEIC Database. The 20 partner countries are selected based on the criteria that the destination country's share equals one percent or larger in Japan's total exports. Seasonality is adjusted using the Census X12 method.

4. Empirical Results

4.1 Results of Export Quantity Elasticity

We have conducted the rolling ARDL estimation using equation (5). While we can obtain information on both the long-run equilibrium relationship and short-run interactions between variables, our main objective is to investigate the time-varying nature of the long-run export quantity elasticity, i.e., the level response of export quantity to the real effective exchange rate. Since an increase in the real effective exchange rate is defined as yen depreciation, we present a graphical representation of the rolling estimates of export quantity responses to yen depreciation.

Figure 2 presents the results of rolling ARDL estimation for four industries: All Manufacturing, General Machinery, Electrical Equipment, and Transport Equipment. As shown in Figure 1, the quantity of Japanese exports has not responded to the yen depreciation since 2013. Shimizu and Sato (2015) revealed that the Japanese trade balance did not improve in response to exchange rates from the mid-2010s, likely due to drastic changes in Japanese firms' production and sales strategy. Specifically, after experiencing a historically high level of the yen against the

USD (around 75–79 yen vis-à-vis the USD) for more than one year in 2011–12, Japanese export firms shifted their production base, especially for production of export goods with higher price elasticity, to Asia and other destination countries. Thus, even though the yen started to depreciate substantially in 2013 and after, most export goods produced in Japan became less elastic to yen depreciation.

This subsection attempts to assess whether Japanese export quantity responses to the exchange rate have changed, as suggested by the previous studies, by conducting the rolling estimation of the ARDL model over the sample period from June 1992 to December 2023.

[Insert Figure 2 around here]

First, according to Figure 2a, where significantly positive responses of export quantity to exchange rates are shaded in pink, the estimated results of All Manufacturing exports are not significantly positive up to the mid-2000s. After that, we observed short-lived positive and significant responses several times. This means there is little evidence that the Japanese export quantity responds positively to exchange rate changes (yen depreciation). It must be noted, however, that Japanese export quantity responded positively and significantly to yen depreciation from February 2023 to December 2023. This may indicate a likely change in Japanese exporters' quantity-setting behavior.

Second, export quantity responses to the exchange rate differ across industries. Figure 2c shows insignificant export quantity responses for the Electrical Equipment industry in most sample periods. We can observe several short-lived positive and significant responses, but the degree of responses was unusually large in the late 2000s. In the General Machinery industry (Figure 2b), we cannot observe significantly positive responses in export quantity up to the early 2010s. However, two periods indicate significantly positive responses of export quantity: one is from November 2013 to May 2016, and the other is from January 2021 to December 2023, though the latter period does not necessarily show significant responses all the time.

More intriguingly, we found positive and significant responses of export quantity to the exchange rate in the Transport Equipment industry from May 1997 to June 2000 (Figure 2d). After that, we could not observe significantly positive responses of export quantity to exchange rate changes except for several short-lived periods. This suggests that Japanese firms tended to export more (less) in response to yen depreciation (appreciation) up to 2000, and such positive responses weakened from the early 2000s. From April 2023, we can observe a positive and significant response of export quantity to yen depreciation, consistent with what we found in the General Machinery industry.

Finally, we present the bounds F-test and t-test results obtained from the rolling ARDL estimation in Appendix Figures A1 and A2. These results suggest that we could not necessarily find a cointegrating relationship even when the export quantity response was significantly positive to yen depreciation. Thus, the cointegration analysis weakly supports our findings from the export quantity analysis.

4.2 Results of Export Price Elasticity

Next, we conducted the rolling ARDL estimation using equation (7) to investigate the degree of exchange rate pass-through (ERPT) or pricing-to-market (PTM). We aim to explore to what extent Japanese exporters stabilized their export prices in destination markets.

Figure 3 presents the results of export price responses to yen depreciation. First, we cannot find significant responses in All Manufacturing exports in the early 2000s (Figure 3a). However, from the mid-2000s, especially from January 2009 to December 2023, the export price responses were positive and statistically significant in most periods. The magnitude of responses was around 0.5 during that period, which suggests that about 50 percent of exchange rate changes were passed on to importers. From around 2021, the degree of export price responses to yen depreciation rose toward 1.5 and then gradually declined toward 1.0. This result suggests that Japanese exporters raised the degree of local price stability in destination markets in response to a sharp and large depreciation of the yen.

[Insert Figure 3 around here]

Turning to the Electrical Equipment industry (Figure 3c), we can observe significantly positive responses to exchange rate changes in shorter periods: one is from April 2013 to January 2019, and the other is from May 2021 to December 2023, although both periods do not necessarily show significant responses all the time. In the latter period, the degree of positive responses increased to around 2.0 and gradually decreased toward 1.0. Surprisingly, we cannot find significantly positive responses of export prices to the exchange rate from 2000 to early 2013 except for a few shorter periods. As demonstrated by Ito *et al*. (2018), Japanese electric machinery exporters tend to invoice their exports in USD, which leads to PTM at least in the short-run. However, the insignificant responses we found above are not consistent with the strong tendency of USD invoicing in the Electrical Equipment industry.

We can observe similar responses of export prices for both the General Machinery and Transport Equipment industries. The degree of positive responses is somewhat higher in the Transport Equipment industry (Figure 3d) than in the General Machinery industry (Figure 3b). From late 2021, both industries show a rise in export price responses to the exchange rate, suggesting an increase in PTM in response to a sharp yen depreciation.

Finally, we also present the bounds *F*-test and *t*-test results obtained from the rolling ARDL estimation in Appendix Figures A3 and A4, suggesting that a cointegrating relationship cannot necessarily be found even when the export price response was significantly positive to yen depreciation. Thus, the cointegration analysis weakly supports our findings from the export price analysis.

5. Concluding Remarks

Our empirical results of rolling ARDL estimation clearly show that Japanese export quantity is far less likely to respond positively to exchange rate changes over the sample period from June 1992 to December 2023. Only in the Transport Equipment exports did the export quantity respond positively (negatively) to exchange rate depreciation (appreciation) up to the early 2000s. Other industries clearly indicate the unresponsiveness of export quantity to exchange rates in the 1990s and 2000s. Thus, we could not find clear evidence that the unresponsiveness of export quantity to exchange rates changed over the sample period, except for the Transport Equipment industry. Such unresponsiveness in export quantity likely changed in 2021 when the yen depreciated rapidly and substantially.

We also estimated the export price equation using the rolling ARDL model to examine the time-varying ERPT or PTM. We demonstrated that Japanese exporters tended to stabilize the export price in destination markets, a typical PTM behavior. More intriguingly, we observed the complete PTM from around 2021 in response to the sharp yen depreciation. Thus, Japanese exporters have not utilized the yen depreciation to increase their export quantity. However, the exporters have raised the degree of PTM in the yen depreciation period to enjoy larger foreign exchange gains.

Whereas presenting the intriguing findings, we need to conduct additional empirical work. First, the disaggregated export quantity data by sub-sectors needs to be analyzed. We investigated the export quantity and price-setting behavior of All Manufacturing and three major machinery industries, which are too aggregated. Second, destination breakdown data on export quantity and prices is worth analyzing, and such data are available from the Japanese Ministry of Finance. Third, and more importantly, we need to examine why Japanese exporters' quantity and price-setting behavior has changed over the sample period. These additional works would shed light on how Japanese exports respond to exchange rate changes.

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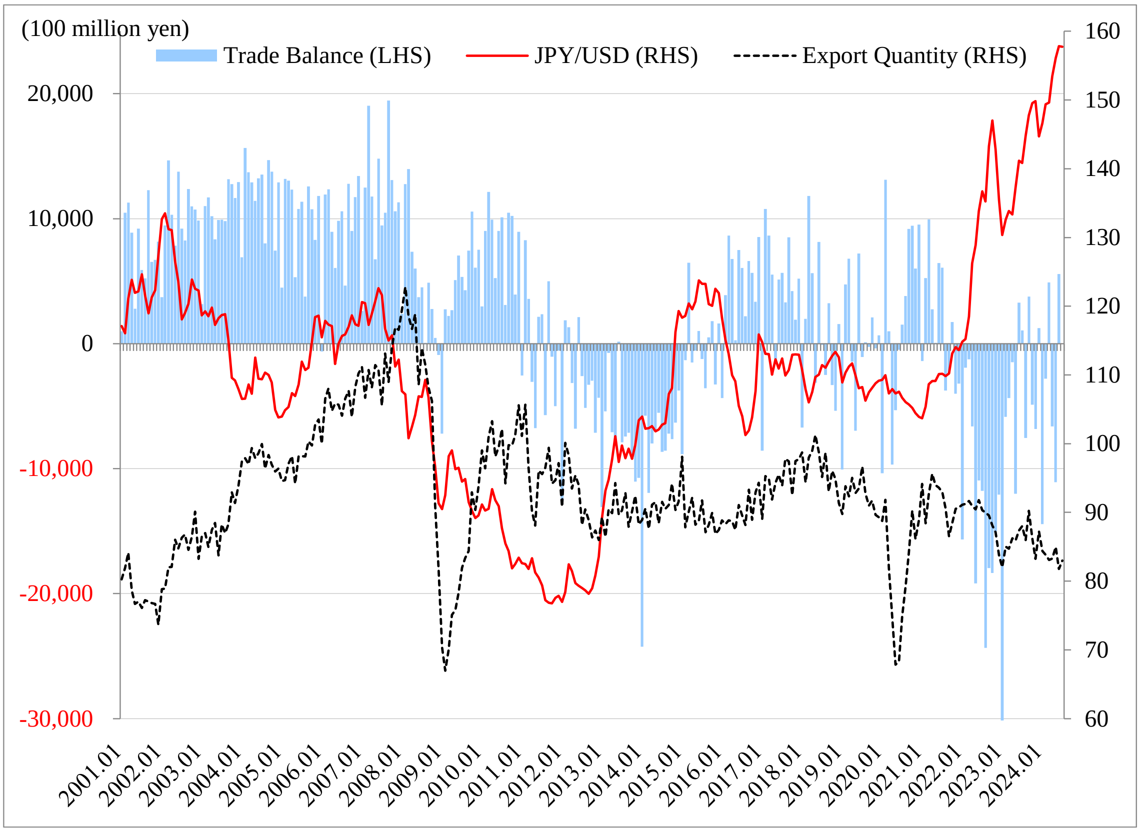
Figure 1. Japan's Trade Balance, Yen's Exchange Rate, and Export Quantity

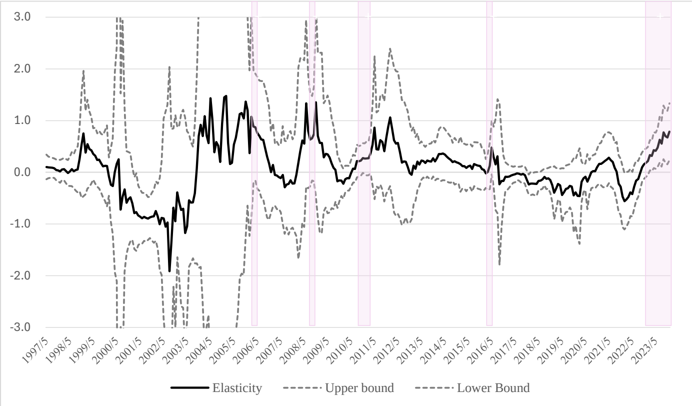


Note: The monthly data spans from January 2001 to July 2024. Japan's trade balance is in terms of 100 million yen (left-hand side axis). The bilateral nominal exchange rate of the yen vis-à-vis the U.S. dollar and the Japan's export quantity index (2010 = 100) are measured by the right-hand side axis.

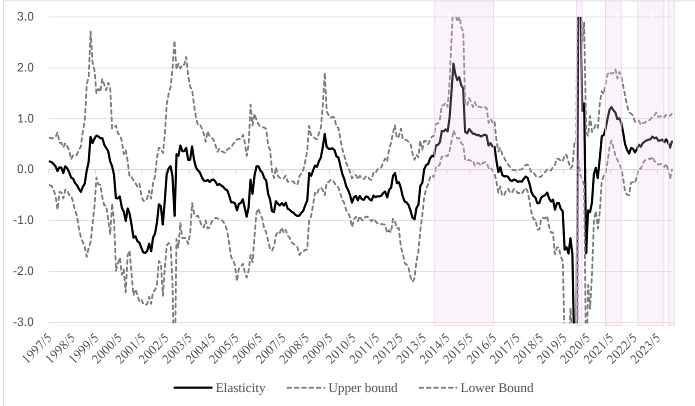
Source: IMF, International Financial Statistics (IFS); Japan's Ministry of Finance website.

Figure 2. Japanese Export Quantity Elasticity to Exchange Rates

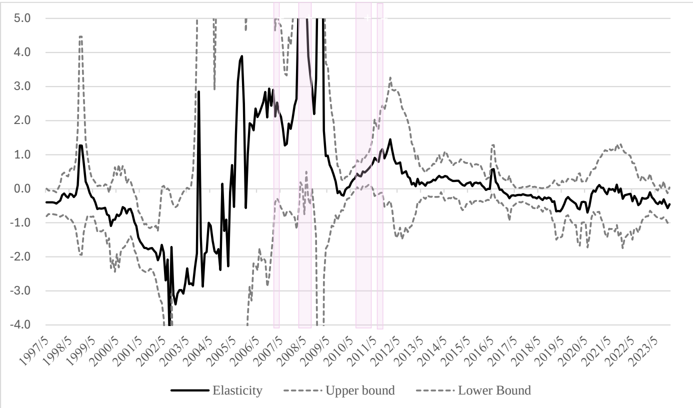
2a. All Manufacturing



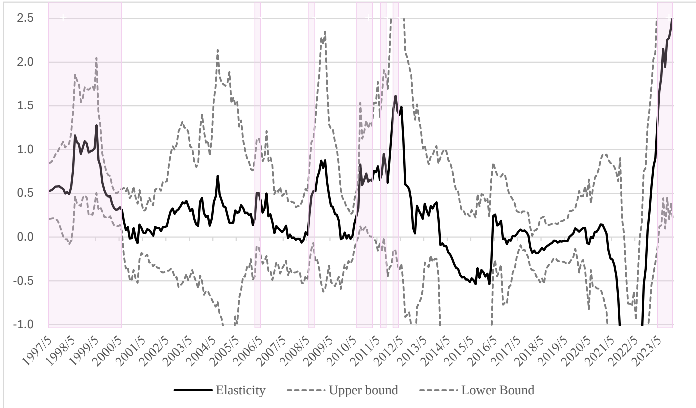
2b. General Machinery



2c. Electrical Equipment



2d. Transport Equipment

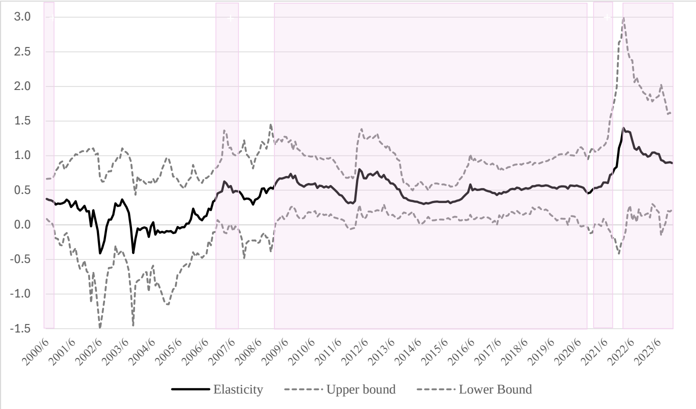


Note: The upper and lower bounds denote plus and minus two standard errors. Shaded areas in pink show the statistical significance at least at the 5% level.

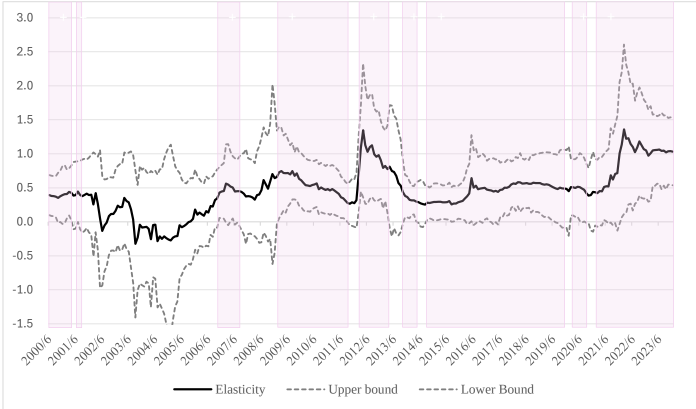
Source: Authors' estimation.

Figure 3. Japanese Export Price Elasticity to Exchange Rates

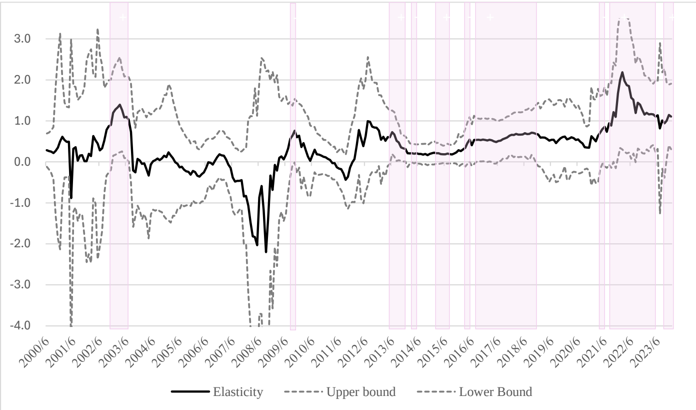
3a. All Manufacturing



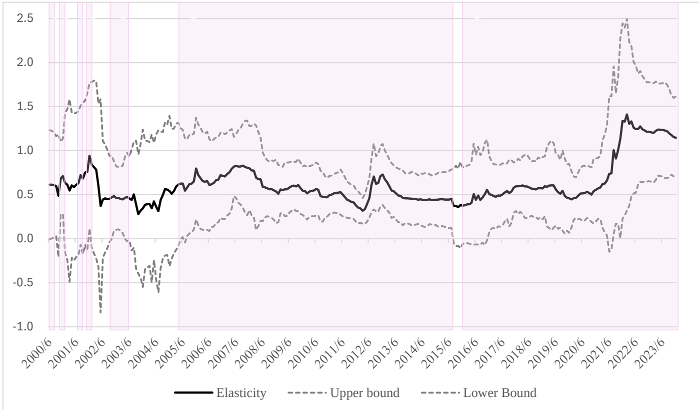
3b. General Machinery



3c. Electrical Equipment



3d. Transport Equipment

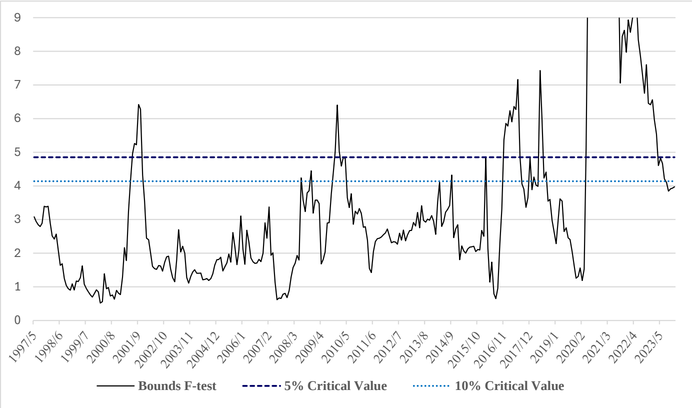


Note: The upper and lower bounds denote plus and minus two standard errors. Shaded areas in pink show the statistical significance at least at the 5% level.

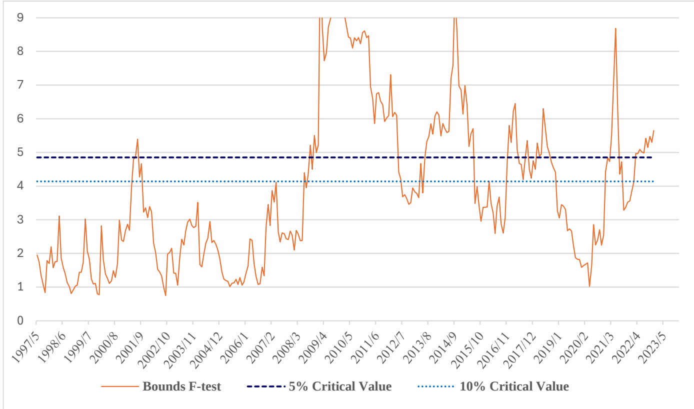
Source: Authors' estimation.

Appendix Figure A1. Bounds *F*-Test for Rolling ARDL Estimation of Japanese Export Quantity

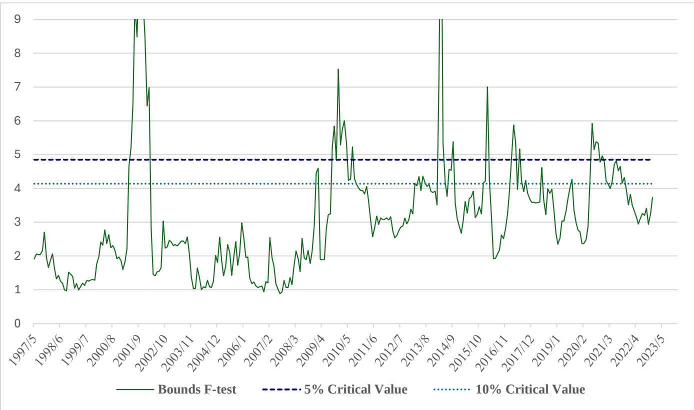
A1a. All Manufacturing



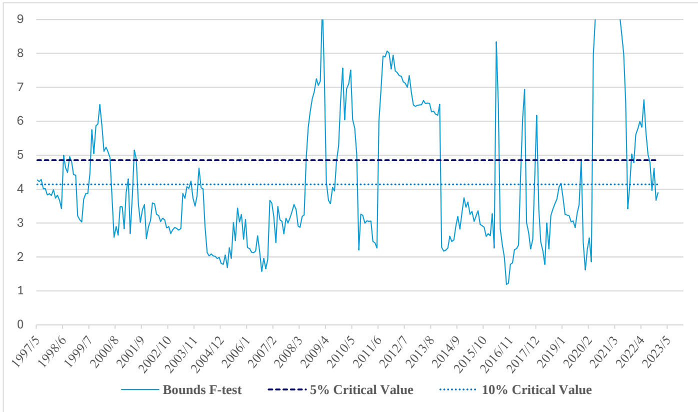
A1b. General Machinery



A1c. Electrical Equipment



A1d. Transport Equipment

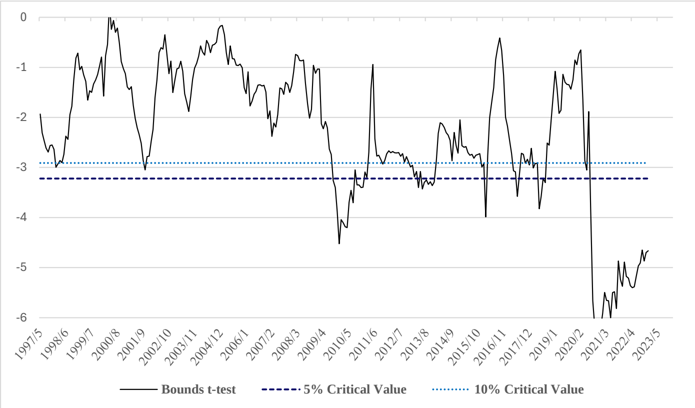


Note: The estimated bounds *F*-statistics are reported based on the rolling ARDL estimation. 5 percent and 10 percent critical values are reported by dotted lines.

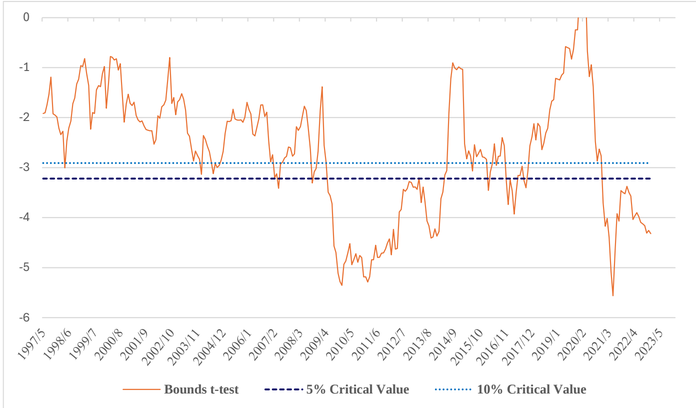
Source: Authors' estimation.

Appendix Figure A2. Bounds *t*-Test for Rolling ARDL Estimation of Japanese Export Quantity

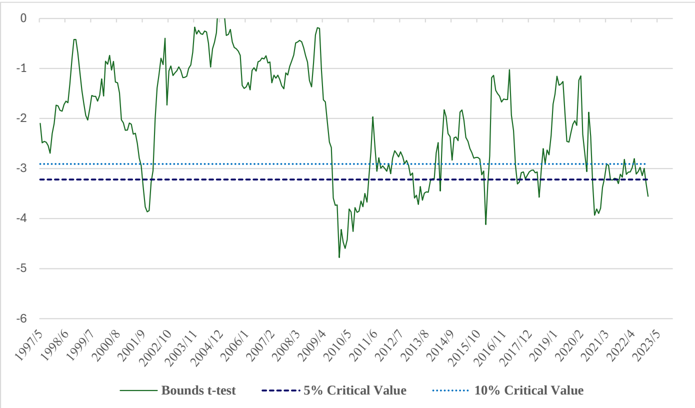
A2a. All Manufacturing



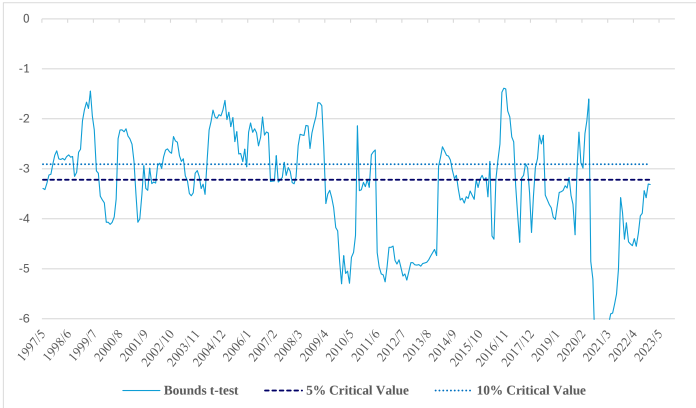
A2b. General Machinery



A2c. Electrical Equipment



A2d. Transport Equipment

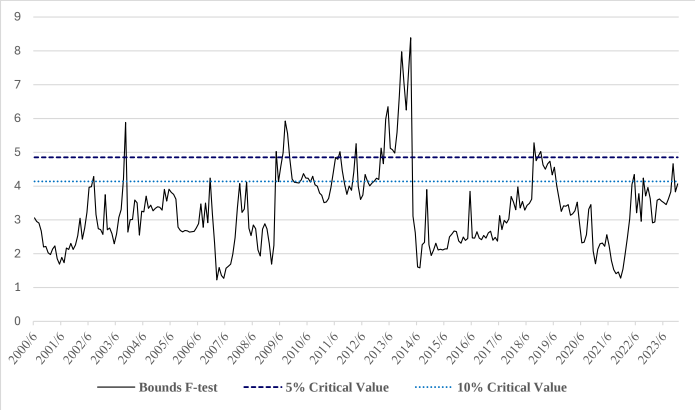


Note: The estimated bounds *t*-statistics are reported based on the rolling ARDL estimation. 5 percent and 10 percent critical values are reported by dotted lines.

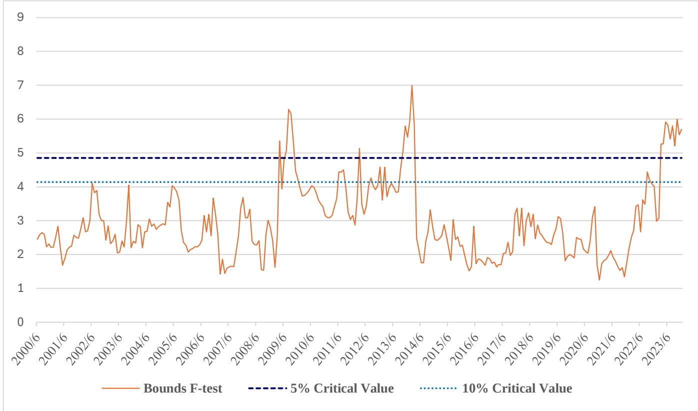
Source: Authors' estimation.

Appendix Figure A3. Bounds F-Test for Rolling ARDL Estimation of Japanese Export Prices

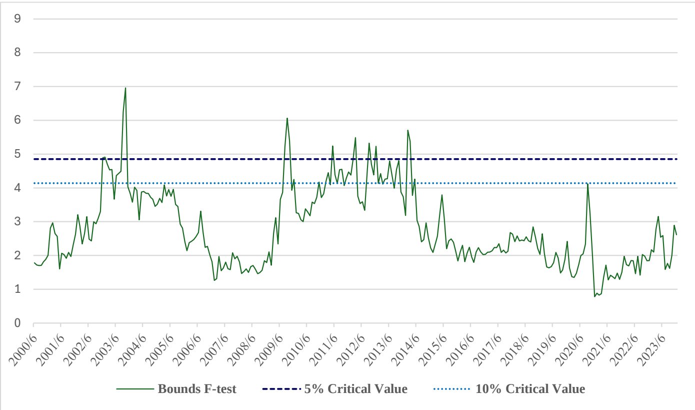
A3a. All Manufacturing



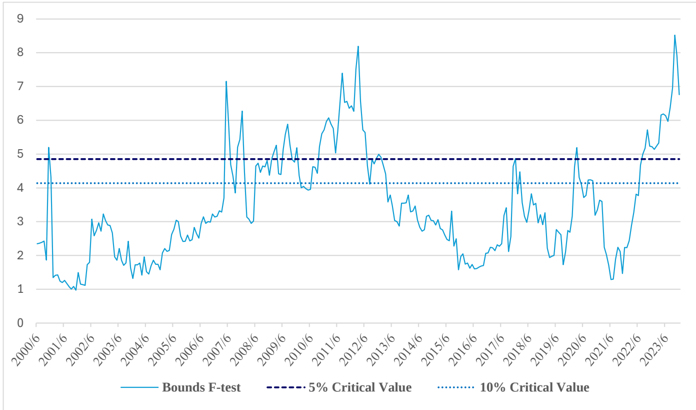
A3b. General Machinery



A3c. Electrical Equipment



A3d. Transport Equipment

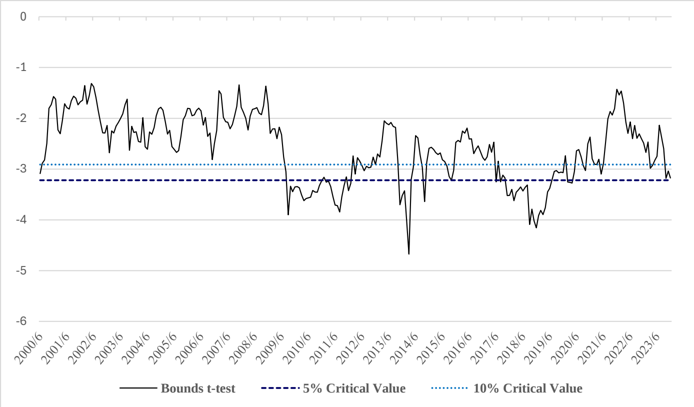


Note: The estimated bounds F-statistics are reported based on the rolling ARDL estimation. 5 percent and 10 percent critical values are reported by dotted lines.

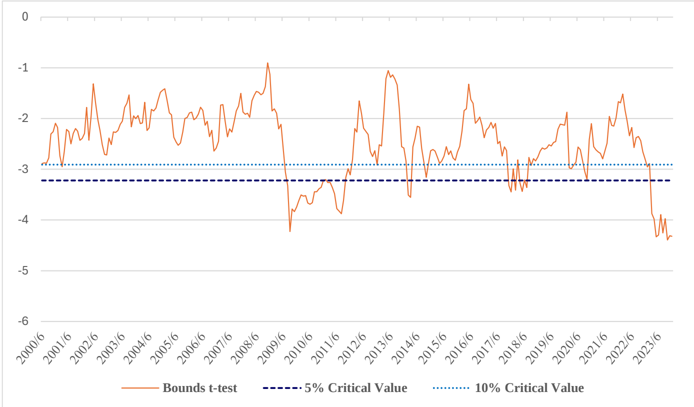
Source: Authors' estimation.

Appendix Figure A4. Bounds *t*-Test for Rolling ARDL Estimation of Japanese Export Prices

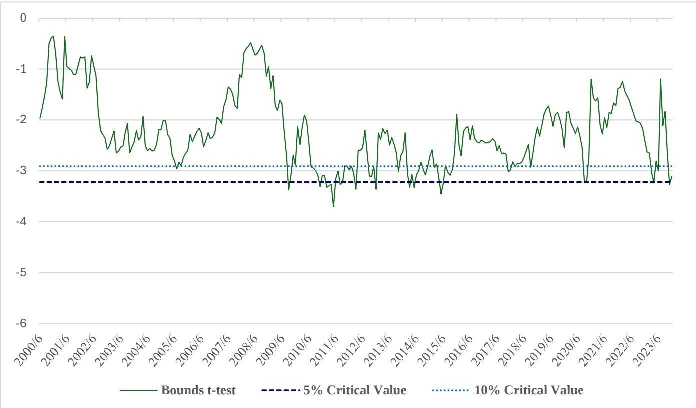
A4a. All Manufacturing



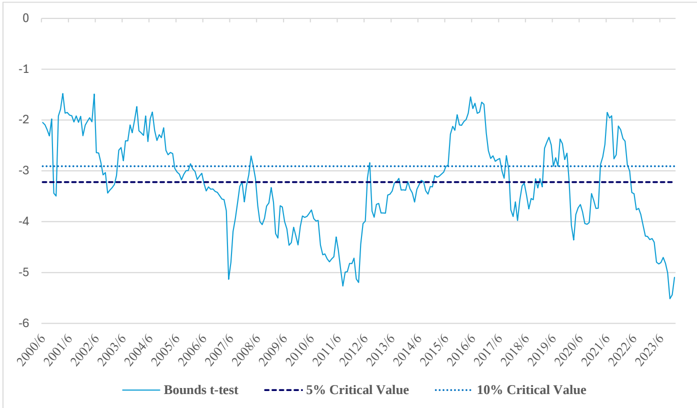
A4b. General Machinery



A4c. Electrical Equipment



A4d. Transport Equipment



Note: The estimated bounds *t*-statistics are reported based on the rolling ARDL estimation. 5 percent and 10 percent critical values are reported by dotted lines.

Source: Authors' estimation.