Nonlinearities in Exchange Rate Pass-Through:

New Evidence from Firms' Predicted Exchange Rates

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ABSTRACT

This dissertation consists of three research papers that study the nonlinearities of exchange rate pass-through in Japanese exports. In particular, this dissertation proposes a new approach to distinguish currency depreciation and appreciation regimes by using firm predicted exchange rates.

The conventional "zero-threshold" approach, i.e. based on whether the change in the exchange rate is positive or negative, does not necessarily provide an appropriate threshold to distinguish between currency appreciation and depreciation periods. During this yen appreciation period, we observe numerous small and short-lived depreciations, which are considered to be yen depreciation periods by the conventional zero-threshold approach. In the clear appreciation trend, however, exporters are unlikely to revise their expected exchange rate in response to such small and short-lived depreciations. Second, exporters' pricing behaviors may be revised when the degree of changes in the realized exchange rate exceeds that of exporters' expectations. The conventional threshold approach, which uses the realized exchange rate changes, fails to capture the exporters' expectations of the future exchange rate.

Therefore, this Ph.D. dissertation is conducted under two main objectives. First, it investigates throughout the possibility of asymmetric exchange rate pass-through in Japanese exports, which has not been fully considered in the literature, especially when taking into account the large yen fluctuations from 2007 to 2015. Second, it proposes a new threshold specification approach using firms' predicted exchange rates, taking exporters' expectations into consideration, to overcome the drawback of conventional threshold.

The dissertation consists of three independent research papers. The first research paper estimates a proxy for firm predicted exchange rate and applies to the Threshold Structural

Near-Vector Autoregressive Model (Threshold SVAR). The second research paper utilizes firm predicted exchange rate data in the Bank of Japan's Tankan data to apply to the Nonlinear Autoregressive Distributed Lag (NARDL) Model. In these two papers, the PTM in short run is confirmed to be symmetric, while the PTM in long run is asymmetric among industry and between currency regimes. The results of these paper give an insight to explain the unresponsiveness of the Japanese trade balance to the yen depreciation from late 2012. In the third paper, we explore further our variable of interest – firms' predicted exchange rates, by investigating its characteristics and determinants. We also get some information of nonlinearities on the way firms adjust their exchange rate prediction, which is highly possibly related to the asymmetry of exchange rate pass-through in Japanese exports. However, to make any final conclusion, many more studies that are outside the scope of this study need to be done to examine especially the link between firm predicted exchange rate revision and exchange rate pass-through level.

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1 Introduction

Since Japan adopted a floating exchange rate in 1971, the Japanese economy has faced a large yen appreciation period three times. The latest period corresponds to the subprime mortgage crisis in 2007, witnessing a sharp fall in the yen vis-à-vis the US dollar from around 120 in 2007 to the post-WWII record high of 75.32 yen/USD in 2011. In late 2012, however, the Japanese government initiated his economic stimulus package, known as "Abenomics," targeting steady currency depreciation. This put an end to the yen appreciation trend and dramatically turned the yen toward large depreciation.

Accompanied with the unprecedented appreciation of the yen in 2011–12, the Japanese trade deficit starting from early 2011 raised a serious concern among policymakers. Even after the yen appreciation trend has been successfully reversed into large yen depreciation, as shown in Figure 2.2, Japan continued to record a large trade deficit up to early 2015. The Japanese trade deficit started to decline in 2015, but it was unlikely due to the J-curve effect, because Japanese real exports did not exhibit a clear upward trend in response to the sharp depreciation of the yen. The reduction of the Japanese trade deficit is likely due to a sharp decline in the world oil price from the mid-2014. Thus, it has still been a matter of major concern why Japanese exports have become less responsive to exchange rate depreciation, which is closely related to the pricing strategy of Japanese exporters in reaction to such large fluctuations in the yen from 2007.

In the literature of exchange rate pass-through (ERPT), Japanese exporter's pricing strategy has been investigated in the context of yen appreciation. Nonlinearities or asymmetries of ERPT have not been investigated in previous studies on Japanese exporter's ERPT except

for a few studies such as Knetter (1994) that investigated a possible asymmetry of ERPT in Japanese exports and imports using the H.S.7-digit commodity data. In his study, a positive change in the home currency exchange rate (S_t), $\Delta \ln S_t > 0$, was considered the depreciation period, whereas a negative change ($\Delta \ln S_t < 0$) was included in the appreciation period. This approach, the so-called "zero-threshold" approach, has been used by most studies on nonlinear or asymmetric ERPT of exports and imports in other countries (e.g., Mahdavi, 2002; Pollard and Coughlin, 2004; Yang, 2007; Bugamelli and Tedeschi, 2008; and Bussiere, 2012). However, the "zero-threshold" approach does not necessarily provide an appropriate threshold to distinguish between currency appreciation and depreciation periods. First, during this yen appreciation period, we observe numerous small and short-lived depreciations, which are considered to be yen depreciation periods by the conventional zero-threshold approach. In the clear appreciation trend, however, exporters are unlikely to revise their expected exchange rate in response to such small and short-lived depreciations. Second, exporters' pricing behaviors may be revised when the degree of changes in the realized exchange rate exceeds that of exporters' expectations. The conventional threshold approach, which uses the realized exchange rate changes, fails to capture the exporters' expectations of the future exchange rate.

Therefore, this Ph.D. dissertation is conducted under two main objectives. First, it investigates throughout the possibility of asymmetric exchange rate pass-through in Japanese export, which has not been fully considered in the literature, especially when taking into account the large yen fluctuation from 2007 to 2015. Second, it proposes a new threshold specification approach using firm predicted exchange rate, taking exporters' expectation into consideration, to overcome the drawback of conventional threshold. The dissertation consists of three independent research papers. The first research paper estimates a proxy for firm

predicted exchange rate and applies to the Threshold Structural Near-Vector Autoregressive Model (Threshold SVAR). The second research paper utilizes firm predicted exchange rate data in the Bank of Japan's Tankan data to apply to the Nonlinear Autoregressive Distributed Lag (NARDL) Model. The third paper explores the characteristic and determinants of the firm predicted exchange rate published in Tankan data.

The first research paper examines the question whether Japanese exporters choose a different pricing behavior between yen appreciation and depreciation periods, and whether their pricing strategy has changed in recent years. We develop a new approach to distinguishing between the yen appreciation and depreciation periods more appropriately by estimating time-varying thresholds as a proxy for expected future exchange rates. We also take into consideration a different pattern of invoice currency choice across industries, because the degree of exchange rate risk or uncertainty that exporters face is likely to be affected by the currency choice. Based on the results of impulse response functions of a structural near-vector autoregressive (near-VAR) model with time-varying thresholds, we calculate the PTM ratio that measures the degree of PTM or ERPT, which reveals the strong symmetry of PTM or ERPT between yen appreciation and depreciation periods over the sample period. More specifically, Japanese exports are almost complete PTM initially, but exhibit a gradual decline in PTM, whereas the magnitude and speed of the decline differ across industries. From the 2000s, however, Japanese major machinery industries, i.e., general machinery, electric machinery, and transport equipment, show a strong tendency of PTM even in the long-run, while other industries exhibit a sharp and large decline in PTM.

The second research paper employs the NARDL to investigate the possible nonlinearity of the exporter's pricing behavior. Utilizing the BOJ's predicted exchange rates and the new

threshold approach for the estimation of the NARLD model, we present new empirical evidence of Japanese PTM or ERPT behavior. Specifically, we find evidence of long-run asymmetry in PTM in four of seven exporting industries and in all manufacturing industries. While most industries exhibit incomplete but relatively strong PTM during the yen appreciation period, the transport equipment and general machinery industries, which are known to have strong export competitiveness, tend to conduct full PTM during the yen depreciation period. In contrast, other industries with less-differentiated products significantly lower (increase) the degree of PTM (ERPT) during the yen depreciation period. In the short run, however, almost full and symmetric PTM is found across all industries for all sample periods, which is consistent with the findings of previous studies that firms' short-run PTM or ERPT behaviors are strongly affected by the invoice currency choice. Given that at least two of the three main manufacturing industries in Japan do not pass through yen depreciation to their export prices, it is hard to reasonably expect a decline in export prices in response to currency depreciation. Although trade balance is not solely determined by such a price factor, our empirical results at least partly answer the question as to why the Japanese trade balance has been unresponsive to the yen depreciation from late 2012.

The third research paper uses the BOJ's *Tankan* survey data to reveal the characteristic as well as the determinants of firm-level exchange rate predictions. The analysis revealed that, first, Japanese firms adjust their exchange rate prediction errors more quickly (slowly) in yen appreciation (depreciation) period. Second, the adjustment speed of exchange rate prediction is positively correlated with a firm's degree of export dependency in the yen depreciation period. Third, in contrast, the adjustment speed is found to have negative relationship with a

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firm's profitability performance in the yen depreciation period, with small-size firms tending to increase the adjustment speed in response to an unanticipated depreciation of the yen.

The message of three research papers is consensus. While the first two papers examine the nonlinearities of exchange rate pass-through using different models, in both papers we are able to confirm that the PTM level in short run are mostly complete and symmetric. Meanwhile, the PTM level in long run is found to be nonlinear between currency regimes and among industries. The results of the third paper also suggest an asymmetry in the way firms adjust their exchange rate prediction in regard to their export and profit ratio. These results give a hint to explain the reason for asymmetric exchange rate pass-through between currency regimes.

Table 1: Overview of the three research papers

	First	Second	Third
Objectives	Investigate the nonlinearities in exchange rate pass-through using new threshold approach of firm predicted exchange rates		Investigate the characteristics and determinants of firm predicted exchange rate
Method	- Rolling threshold estimation - Threshold structural near vector autoregressive model	Nonlinear Autoregressive Distributed Lag	Panel analysis with fixed effect model
Industries	8	8	10
Period	1985M1-2014M12	1997M4-2015M12	1997Q2-2016Q1

			1999Q2-2016Q1
Sub sample	first period: 1985M1-1999M12 second period: 2000M1-2014M12	first period: 1997M4-2006M12 second period: 2007M1-2015M12	
Results	- PTM behavior is almost symmetric between currency regimes - PTM is industry-different and such difference become larger in the second period - 3 major industries (Machinery, Electric, Transportation) tend to exhibit a strong tendency of PTM in long run, while other industries (Chemical, Metal) tend to show a	- PTM behavior is symmetric between currency regimes in short run. - PTM in the long run shows asymmetry in second period - In yen depreciation regime, all industries adopt the same pricing strategy, i.e. not fully but rather strong PTM. In yen appreciation regime, 2 major industries (Machinery, Transportation) raise their PTM to full level, while other industries	- asymmetry is found regarding the way firms adjust their exchange rate predictions, i.e. higher adjustment speed in yen appreciation regime. - Japanese firms are more likely to update their exchange rate prediction in yen depreciation regime if they have high export ratio. - When having high profitability in the yen depreciation, large and medium firms tend to

	greater degree of ERPT in long run.	(Chemical, Metal, All manufacturing) try to pass through more.	adjust their exchange rate prediction slowly, while small enterprises tend to speed up their adjustment.

Invoice Currency Choice, Nonlinearities and Exchange Rate Pass-Through

2.1 Introduction

The Japanese trade deficit starting from early 2011 as well as unprecedented appreciation of the yen in 2011–12 has raised a serious concern among the policy makers. Prime Minister Shinzo Abe initiated an economic-stimulus package, so-called *Abenomics*, from the end of 2012, which successfully reversed the yen appreciation trend (Figure 2.1). However, as shown in Figure 2.2, Japan continued to record a large trade deficit up to early 2015. The Japanese trade deficit started to decline in 2015, but it was unlikely due to the J-curve effect, because Japanese real exports did not exhibit a clear upward trend in response to the sharp depreciation of the yen. The reduction of the Japanese trade deficit is likely due to a sharp decline in the world oil price from the mid-2014. Thus, it has still been a matter of major concern why Japanese exports become less responsive to exchange rate depreciation, which is closely related to the pricing strategy of Japanese exporters.

In the literature of exchange rate pass-through (ERPT), Japanese exporter's pricing strategy has been investigated in the context of yen appreciation. Previous studies have argued that Japanese exporters tend to choose a pricing-to-market (PTM) strategy by stabilizing export prices in the local currency, even though this squeezes their profit margin during periods when the yen appreciates.[1] An importer's currency is typically chosen when Japanese exporters

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[1] See for example, Marston (1990), Parsons and Sato (2008), and Yoshida (2010).

perform the PTM behavior.[2] However, during the period of yen depreciation, Japanese exporters can enjoy large exchange gains by pursuing the PTM strategy, given that they invoice their exports in the importer's currency. When the yen depreciates, exporters can also raise the degree of ERPT by lowering export prices in the importer's currency. This improves export price competitiveness while maintaining a certain level of profit margins, which might have some positive effect on trade balance, whereas trade balance is not solely determined by the exporter's pricing behavior.

The main purpose of this study is to examine the question whether Japanese exporters choose a different pricing behavior between yen appreciation and depreciation periods, and whether their pricing strategy has changed in recent years. We develop a new approach to distinguishing between the yen appreciation and depreciation periods more appropriately by estimating time-varying thresholds as a proxy for expected future exchange rates. We also take into consideration a different pattern of invoice currency choice across industries, because the degree of exchange rate risk or uncertainty that exporters face is likely to be affected by the currency choice.

Nonlinearities or asymmetries of ERPT have not been investigated in previous studies on Japanese exporter's ERPT except for a few studies such as Knetter (1994) that investigated a possible asymmetry of ERPT in Japanese exports and imports using the H.S.7-digit commodity data. In his study, a positive change in the home currency exchange rate (S_t), $\Delta \ln S_t > 0$, was considered the depreciation period, whereas a negative change ($\Delta \ln S_t < 0$) was included in the appreciation period. This approach, the so-called "zero-threshold"

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[2] See Sato (2003) and Ito *et al.* (2012).

approach, has been used by most studies on nonlinear or asymmetric ERPT of exports and imports in other countries (e.g., Mahdavi, 2002; Pollard and Coughlin, 2004; Yang, 2007; Bugamelli and Tedeschi, 2008; and Bussiere, 2012). More recent studies apply the nonlinear autoregressive distributed lag (NARDL) model developed by Shin *et al*. (2014), to model both short- and long-run asymmetry of ERPT (e.g., Delatte and López-Villavicencio, 2012; Fedoseeva and Werner, 2016; and Brun-Aguerre *et al*., 2017). Whereas the NARDL model has an advantage in considering both short- and long-run ERPT/PTM, these studies typically use the zero-threshold approach, which does not necessarily provide an appropriate threshold to distinguish between currency appreciation and depreciation periods.

For instance, Figure 2.1 shows that the yen appreciated substantially vis-à-vis the US dollar from 158.5 in April 1990 to 83.7 in April 1995. During this yen appreciation period, we observe numerous small and short-lived depreciations, which are considered the yen depreciation periods by the conventional zero-threshold approach. In the clear appreciation trend, however, exporters are unlikely to revise their expected exchange rate in response to such small and short-lived depreciations.

Moreover, different from the previous studies, we emphasize that the exchange rate *level* itself can also strongly affect the exporter's pricing behavior. As shown in Figure 2.1, Japan experienced an unprecedented level of yen appreciation (i.e., 75–80 yen vis-à-vis the US dollar) from 2011 to 2012. During that period, even a small change (e.g., one percent appreciation) of the yen is likely to have stronger impact on the exporter's pricing behavior. In contrast, when the yen fluctuates at around, for example, 120 yen vis-à-vis the US dollar, the corresponding degree of yen appreciation will have smaller effect on the exporter's pricing decision. Thus, previous studies using the zero-threshold approach disregard such *level* effects

on the exporter's pricing behavior especially when distinguishing between the yen appreciation and depreciation periods.[3] We develop a new method of threshold specification by estimating the time-varying thresholds as a proxy for the expected future exchange rates in *level*.[4]

In this study, we estimate a structural near-vector autoregressive (near-VAR) model with time-varying thresholds to analyze possible asymmetric responses of export prices to the exchange rate shock between yen appreciation and depreciation periods. Based on the results of impulse response functions, we calculate the PTM ratio that measures the degree of PTM or ERPT, which reveals the strong symmetry of PTM or ERPT between yen appreciation and depreciation periods over the sample period. More specifically, Japanese exports are almost complete PTM initially, but exhibit a gradual decline in PTM, whereas the magnitude and speed of the decline differ across industries. From the 2000s, however, Japanese major machinery industries, i.e., general machinery, electric machinery, and transport equipment, show a strong tendency of PTM even in the long-run, while other industries exhibit a sharp and large decline in PTM. Since major machinery industries account for about two-thirds of Japanese total exports, their strong PTM behavior is likely to be related to the unresponsiveness of the Japanese trade balance to the large depreciation of the yen in recent years.

The remainder of this paper is organized as follows: Section 2.2 elaborates the empirical model to show how to obtain the time-varying thresholds and also to estimate the

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[3] Fedosseva and Werner (2016) use the one standard deviation of exchange rate changes as a threshold to divide large appreciation, depreciation, and "inaction" band. Verheyen (2013) also employs the two thresholds approach in estimating the NARDL model, though analyzing not the ERPT but the exchange rate impact on EMU exports to the United States. Whereas this inaction band approach is useful, it is intrinsically based on the zero threshold model

[4] Murase (2013) conducts a nonlinear estimation of ERPT by defining exchange rate volatility as a threshold variable. Although it is a useful approach, we assume the exchange rate in *level* to be a threshold variable in the present research.

structural near-VAR model with time-varying thresholds. Section 2.3 describes the data for empirical analysis. Section 2.4 presents and interprets the results of the structural near-VAR estimation with time-varying thresholds. Finally, Section 2.5 concludes this study.

2.2 Empirical Model

2.2.1 Expected Exchange Rate and Invoice Currency Choice

In the ERPT literature, exporters are typically assumed to set an export price before the exchange rate is known, while they export their goods to importers at the *ex post* realized price after the exchange rate is known (Donnenfeld and Zilcha, 1991; Friberg, 1998; Bacchetta and van Wincoop, 2005). In practice, at the time of the pricing decision, exporters expect the future exchange rate that is based on the available information on the prior distribution of the random exchange rate. When the new information arrives, expectations of the future exchange rate are updated. In this paper, we regard the time-varying thresholds as the expected future exchange rate (henceforth, expected exchange rates). If the actual exchange rate is higher (lower) than the threshold, exporters are assumed to be in the currency depreciation (appreciation) period.

At the stage of pre-set pricing, exporters also choose the invoice currency. Previous studies theoretically show that exporter's expected profit is conditional on the choice of invoice currency (Giovannini, 1988; Donnenfeld and Zilcha, 1991) and demonstrate which invoice currency, the exporter's, importer's or third currency, yields the highest expected profits under

the exchange rate uncertainty (Friberg, 1998; Bacchetta and van Wincoop, 2005). The invoice currency choice in Japanese exports is in practice quite different across industries, reflecting the product differentiation and the degree of market competition, which is empirically investigated by the previous studies such as Ito *et al*. (2012). If exporters choose a different invoice currency, the degree of exchange rate risk or uncertainty that exporters face can be different (Ito *et al*., 2016). But, to our knowledge, such difference has not been considered in the previous studies on the asymmetric ERPT.

In this paper, we construct the nominal effective exchange rate (NEER) based not on the trade weighted average but on the invoice currency share. As will be explained in Section 2.3, the contract currency-based NEER (henceforth, contract-NEER) of the yen can be calculated by the Japanese export price indices published by the Bank of Japan (BOJ).[5] Since the BOJ publishes the industry-breakdown data on export price indices, we can construct the *industry-specific* contract-NEER, which enables us to capture more correctly the degree of exchange rate risk that exporters of each industry face.

2.2.2 Estimation of the Time-Varying Threshold

To estimate thresholds, we employ the following conventional ERPT model proposed by Goldberg and Knetter (1997):

$$p_t = \alpha + \delta x_t + \gamma e_t + \psi Z_t + \varepsilon_t, \qquad (1)$$

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[5] Contract-NEER was first developed by Ceglowski (2010).

where all variables are in a natural logarithm, p denotes the price for the sample product, x represents the primary "control" variable, e denotes the exchange rate, and Z includes other control variables in the model. The first-difference specification of the above empirical model is often used in previous studies, such as those by Campa and Goldberg (2005) and Ceglowski (2010).

The above model can be extended to the following threshold autoregressive (TAR) model to estimate a threshold, θ_t, using an indicator function, I_t:

$$
\begin{aligned}
\Delta p_t^{x,i} = I_t\left(c_1 + \sum_{k=1}^{n}\alpha_{1k}\Delta p_{t-k}^{x,i} + \sum_{k=0}^{m}\beta_{1k}\Delta e_{t-k} + \sum_{k=0}^{l}\gamma_{1k}\Delta p_{t-k}^{ip,i} + \sum_{k=0}^{r}\delta_{1k}\Delta ipi_{t-k}\right) \\
+ \left(1-I_t\right)\left(c_2 + \sum_{k=1}^{n}\alpha_{2k}\Delta p_{t-k}^{x,i} + \sum_{k=0}^{m}\beta_{2k}\Delta e_{t-k} + \sum_{k=0}^{l}\gamma_{2k}\Delta p_{t-k}^{ip,i} + \sum_{k=0}^{r}\delta_{2k}\Delta ipi_{t-k}\right) + \varepsilon_t
\end{aligned}
\tag{2}
$$

Suppose the upper-case letter, E, indicates an exchange rate variable in level (i.e., $e = \ln E$), while lower-case letters are in natural logarithm. I_t is defined as $I_t = 1$ if $E_t > \theta_t$, and $I_t = 0$ if $E_t \leq \theta_t$. p^x denotes the yen-based export price index; e represents the contract-NEER, an increase (decrease) of which is defined as depreciation (appreciation) of the yen;[6] p^{ip} denotes the domestic input price index as a proxy for production cost; and ipi indicates the world industrial production index as a proxy for world demand. Δ denotes the first difference operator. Superscript i indicates an industry, and subscripts $t - k$ with k running from 1 or 0 to n,m,l,r denote a lag of the export price, the exchange rate, the input price, and the world

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[6] This definition differs from the conventional definition of effective exchange rates. In the next section, we show how to construct the contract-NEER.

industrial production, respectively. Lag length is determined by regressing the export price on lags of the export price, exchange rate, input price, and world industrial production, with maximum lag length of 12 for all variables, based on the Akaike Information Criterion (AIC). ε_t denotes an error term.

Following Chan (1993), we estimate an unknown threshold θ using the contract-NEER series in level (E_t). Specifically, in estimating TAR model (2), we use a four-year window where the observations of E_t are reordered from the smallest to the largest. We then repeat estimation of the TAR model by using each value of E_t as a potential threshold. Finally, we choose the value of threshold, E_t, that yields the lowest residual sum of squares, which is treated as the threshold of the seventh month to the end month of the four-year window to consider not only backward-looking aspects but also forward-looking aspects.[7] If E_t exceeds a threshold level (θ_t), it is considered to be a yen depreciation period; otherwise, it is considered to be a yen appreciation period. In practice, we conduct a rolling estimation of equation (2) to obtain time-varying thresholds for all industries, which will be presented in Section 2.4.

2.2.3 Structural Near-Vector Autoregressive Model

After obtaining the time-varying thresholds, we analyze the Japanese exporter's ERPT/PTM behavior; that is, the response of Japanese export prices on a yen basis to exchange rate disturbances. We employ a near-vector autoregressive (near-VAR) model, including the

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[7] For example, in the four-year window from January 2000 to December 2003, the estimated threshold is treated as the threshold value (exporter's predicted rate) for June 2003. The choice of a "four-year" window is somewhat arbitrary. We tried various windows with different lengths to obtain an appropriate number of trials. Using a graphical investigation such as in Figure 2.3 below, we finally chose the four-year window.

first-difference series of the natural log of industrial production index (Δipi), contract-NEER (Δe), input price index (Δp^{ip}), and a yen-based export price (Δp^{x}).

We establish the following near-VAR model with block exogeneity:[8]

$$\sum_{s=0}^{p} \begin{bmatrix} A_{11}(s) & A_{12}(s) \\ A_{21}(s) & A_{22}(s) \end{bmatrix} \begin{bmatrix} y_{1,t-s} \\ y_{2,t-s} \end{bmatrix} = \begin{bmatrix} \varepsilon_{1,t} \\ \varepsilon_{2,t} \end{bmatrix} \qquad (3)$$

where $A_{12}(s) = 0$ for each $s = 0, 1, \ldots, p$, $y_{1,t}$ denotes a vector of exogenous variables external to the domestic country, and $y_{2,t}$ denotes a vector of variables in the domestic country. A vector of structural shocks, $\varepsilon_t = \begin{bmatrix} \varepsilon_{1,t} & \varepsilon_{2,t} \end{bmatrix}'$, is uncorrelated with past y_{t-s} for $s > 0$ and satisfies $E[\varepsilon_t \varepsilon_t' \mid y_{t-s}, s > 0] = I$ and $E[\varepsilon_t \mid y_{t-s}, s > 0] = 0$, where $\varepsilon_{1,t}$ denotes a vector of structural shocks of external origin, and $\varepsilon_{2,t}$ denotes a vector of structural shocks of domestic origin. We impose the block exogeneity restriction, $A_{12}(s) = 0$ for each $s = 0, 1 \ldots p$, which indicates that domestic shocks, $\varepsilon_{2,t}$, have neither contemporaneous nor lagged effects on the external variables, $y_{1,t}$.

A foreign block, $y_{1,t}$, includes the world industrial production index (IPI), i.e., the first difference of the natural log of the IPI (Δipi). A domestic block, $y_{2,t}$, includes three variables: namely, the first difference of the natural log of contract-NEER (Δe), input price

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[8] See Cushman and Zha (1997), Zha (1999), and Maćkowiak (2007) for an analysis using a near-VAR model with block exogeneity.

index (Δp^{ip}), and yen-based export price (Δp^x). We impose the Cholesky decomposition in the domestic block. Since the domestic input price includes procurements of intermediate inputs from both domestic and foreign sectors, the domestic input price index is contemporaneously affected by the change in contract-NEER but not *vice versa*. The yen-based export price is also contemporaneously affected by the change in contract-NEER because more than 50 percent of Japanese exports are denominated or invoiced in US dollars, as will be discussed below. Thus, contract-NEER is most exogenous in the domestic block, and the order of variables is contract-NEER (Δe), input price index (Δp^{ip}), and yen-based export price (Δp^x). [9] The lag order of the near-VAR model is set to four to avoid a small number of observations in conducting threshold near-VAR estimation for sub-samples. The RATS 9.0 econometric software program is used for estimation.

2.3 Data

The data of all the variables above are monthly series, with the sample period from January 1980 to December 2014. Domestic input prices and yen-based export prices are obtained from the BOJ website, with base years of 2005 and 2010. We break down industry data for the domestic input price and the yen-based export price: (i) All Manufacturing, (ii) Textiles, (iii) Chemicals and related products (henceforth, Chemical), (iv) Metal and related products (Metal), (v) General purpose, production, and business-oriented machinery (General

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[9] As will be discussed below, we tried estimation with a different order of variables in the domestic block, and the result is very similar to the benchmark result.

Machinery), (vi) Electric and electronic products (Electric Machinery), (vii) Transportation Equipment, and (viii) Other Manufacturing.

Contract Currency-Based NEER

In contrast to previous studies, we employ the "contract currency-based NEER" (contract-NEER) that Ceglowski (2010) first used to measure the degree of an exporter's price responses to changes in the yen vis-à-vis invoice currencies. As shown in the study by Ito *et al.* (2012), Japan's exports are invoiced mainly in US dollars and yen. In the second-half of 2014, 53.5 percent of Japanese world exports were invoiced in US dollars and 35.7 percent were invoiced in yen. [10] Conventional NEERs provided by the Bank for International Settlements (BIS) are based on a trade weight, which cannot reflect a large role of the third currency (US dollar) in the invoicing of Japanese exports.

The contract-NEER can be constructed by using export price indices published by the BOJ. Specifically, the BOJ publishes two types of export price indices by industry/commodity: one in *yen* and the other on a *contract* (*invoice*) *currency* basis. [11] Suppose only three currencies are used in Japanese exports: the yen, US dollar, and Euro. [12] Export price indices on a contract currency basis (P_{con}^{EX}) and on a yen basis (P_{yen}^{EX}) can be expressed as follows: [13]

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[10] The data on Japan's trade invoice currency is published by the Ministry of Finance.

[11] The BOJ collects export price data when cargo is loaded in Japan at the customs clearance stage, and when free-on-board (FOB) prices at a Japanese port of exports are surveyed. As long as they are traded in foreign currencies, sample prices are recorded in the original contract currency and finally compiled as the "export price index on the contract currency basis." To compile the "export price index on the yen basis," sample prices in the contract currency are converted into yen equivalents by using the monthly average exchange rate of the yen vis-à-vis the contract currency. See the BOJ website (https://www.boj.or.jp/en/statistics/pi/cgpi_2010/index.htm/) for further details.

[12] This assumption is relaxed when constructing the contract-NEER in practice.

[13] By definition, the sum of the weights in equations (4) and (5) is assumed to be unity.

$$P_{con}^{EX} = \left(P_{yen}\right)^{\alpha} \left(P_{usd}\right)^{\beta} \left(P_{eur}\right)^{\gamma} \qquad\qquad (4)$$

$$P_{yen}^{EX} = \left(P_{yen}\right)^{\alpha} \left(E_{yen/usd}P_{usd}\right)^{\beta} \left(E_{yen/eur}P_{eur}\right)^{\gamma} \qquad\qquad (5)$$

The BOJ collects information on the choice of contract (invoice) currency when surveying Japanese exporters at a port level. Using a nominal exchange rate of the yen vis-à-vis the contract currency, the BOJ constructs export price indices on a contract currency basis and converts the indices into yen-based export price indices. Dividing equation (5) by equation (4), we obtain the following formula of the contract-NEER:

$$NEER_{yen}^{Contract} = \frac{P_{yen}^{EX}}{P_{con}^{EX}} = \left(E_{yen/usd}\right)^{\beta} \left(E_{yen/eur}\right)^{\gamma}. \qquad\qquad (6)$$

The above discussion, based on the three contract (invoice) currencies, can be generalized to a case of four or more contract currencies. As shown in Table 2.1, as of December 2014, 96.8 percent of Japan's total exports were invoiced in yen, US dollars, and the Euro, whereas 3.2 percent were invoiced in other currencies. Such a small share of invoices in other currencies is also captured by the contract-NEER used in the following analysis.

The contract-NEER has two notable advantages. First, we can calculate an *industry-specific* NEER on a contract currency basis. Since the BOJ publishes and breaks down industry and commodity data on export price indices, on both a yen and a contract currency basis, we can calculate industry-specific contract-NEERs. Second, and more importantly, the contract-NEER reflects the degree of exchange rate risk that exporters face in each industry. In equation

(6), the larger the weight of α, the smaller the exchange rate risk. The contract-NEER will be compared across industries in the next section.

Domestic Input Price Index

The literature on ERPT typically uses the domestic producer price index to allow for changes in production costs. In contrast, we use the domestic input price index published by the BOJ, which is constructed as a weighted average of the prices of intermediate input goods (i.e., raw materials, including fuel and energy, intermediate parts, and components) and services to produce products in these industries. The weights are based on input coefficients calculated from Japanese Input-Output (IO) Table.[14] Thus, the BOJ input price index reflects domestic production cost in each industry much better than the producer price index.

World Industrial Production Index

The world IPI is calculated by taking an average of IPIs (2010 base year data) of 20 major trading partner countries and areas.[15] The 20 partner countries and areas are selected by the criteria that the destination country or area's share is equal to one percent or larger of Japan's total exports. All series are finally standardized to 100 as of the 2010 base year. Census X-12 method is used for seasonal adjustment.

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[14] Weights are based on the input values of goods (i.e., raw and intermediate materials, fuel, and energy) and services for the manufacturing industry, using purchasers' prices in the IO Table during the 2005 base year, published by the Ministry of Internal Affairs and Communications.

[15] The 20 countries and areas are France, Germany, the Netherlands, Australia, Canada, Hong Kong, Korea, Singapore, the United States, the United Kingdom, mainland China, India, Indonesia, Malaysia, the Philippines, Thailand, Vietnam, Russia, Mexico, and Taiwan

2.4 Empirical Results

We employ a four-year window for rolling estimation to obtain time-varying thresholds from July 1983 to June 2014. We then conduct a near-VAR estimation for the entire sample from January 1985 to June 2014 to investigate the degree of ERPT/PTM by industry. We also divide the entire sample period into two sub-periods: one from January 1985 to December 1999, and the other from January 2000 to June 2014, in order to analyze whether the degree of ERPT/PTM has changed over the sample period.

Before proceeding to empirical investigation, we check time-series properties of variables using the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests, with the lag length determined by the Schwarz Information Criterion (SIC). Although not reported in this study, the results of both ADF and PP unit-root tests show that all variables are non-stationary in level but stationary in first differences. Thus, we use the first difference series for both threshold estimation (equation (2)) and the near-VAR estimation (equation (3)).

2.4.1 Differences in Exchange Risk and Predicted Exchange Rates across Industries

Figure 2.3 presents both contract-NEERs and time-varying thresholds. The level and changes in contract-NEERs differ to a large extent across industries. For instance, as shown in Table 2.2, the average of contract-NEERs is lowest and the corresponding standard deviation is smallest in General Machinery. Figure 2.3 also indicates that the contract-NEER of General Machinery fluctuates within a far narrower range over the sample period than that of other

industries. During a large appreciation from January 1985 to January 1995, the contract-NEER of All Manufacturing changed from 190.3 to 98.2, whereas that of General Machinery declined (appreciated) only from 148.0 to 99.4. Such small fluctuations in the contract-NEER suggest that Japanese exporters of General Machinery tend to face smaller foreign exchange risk, reflecting the choice of invoice currency. As shown in Table 2.1, 61.9 percent of General Machinery exports were invoiced in yen as of December 2014, which is consistent with the smallest fluctuations for the contract-NEER of General Machinery. Thus, the higher the share of yen-invoiced exports, the less exchange rate risk faced by exporters. This aspect is fully considered when investigating the predicted exchange rate based on the contract-NEER.

Figure 2.3 also shows the expected exchange rates (NEERs) obtained by the time-varying threshold estimation, which differ across industries. Given the strong yen appreciation trend from 1985 to 1995, Table 2.2 shows that just 15–20 percent of total months from 1985 to 1999 are periods of yen depreciation. Even in the second half of the sample period, from 2000 to 2014, about 20–40 percent of the months are considered to be yen depreciation periods. Among the industries, General Machinery has more observations during a yen depreciation period than other industries, reflecting the highest share of exports invoiced in yen. Our estimated result is consistent with Ito *et al*. (2016) that demonstrated that yen invoicing tends to reduce foreign exchange exposure of Japanese exporters. Since both contract-NEERs and time-varying thresholds are quite different across industries, the length and timing of yen appreciation and depreciation periods also differ across industries, which has not been considered in the previous studies.

2.4.2 Results of Structural Near-VAR Estimation with Time-varying Thresholds

2.4.2.1 Analysis of Entire Sample Period

The main purpose of this study is to demonstrate possible differences in the degree of ERPT/PTM in Japanese exports, by industry, between exchange rate appreciation and depreciation periods. We estimate impulse responses of yen-based export prices to the exchange rate shock that is measured by a one standard deviation shock to the contract-NEER. A larger impulse response of the export price to an exchange rate shock indicates that Japanese export price in terms of the yen is correlated more strongly with the exchange rate changes, which implies that exporters tend to stabilize the export price in the destination country. On the other hand, a smaller impulse response suggests that Japanese export price in the yen is less correlated with exchange rate changes, which suggests a stronger tendency for exporters to pass through exchange rate changes to importers.

The results of accumulated impulse responses in All Manufacturing and seven industries for the entire sample period are presented in Figure 2.4.[16] Impulse responses of yen-based export prices to the exchange rate shock are generally larger during a yen depreciation period than during a yen appreciation period, except for General Machinery. While it is argued that PTM is a typical pricing strategy for Japanese exporters, the degree of impulse responses differs in practice between yen appreciation and depreciation periods. Only in the case of General Machinery exports, the degree of impulse responses is not different between two periods. As shown in Figure 2.3 and Table 2.2, General Machinery exporters tend to choose yen-invoiced exports and, hence, to have smaller exposure of exchange rate risk. The results

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[16] Although not reported in this paper, the accumulated impulse responses are statistically significant for at least the first five periods (the results are available upon request). As shown below, we present the results of both impulse responses and error-confidence bands for a sub-sample analysis.

of impulse responses presented in Figure 2.4 fully reflect such different degree of exposure to exchange rate risk.

2.4.2.2 Analysis of Sub-Sample Periods

We also divide the entire sample period into two sub-sample periods and conduct near-VAR estimation. Results of accumulated impulse responses are presented in Figure 2.5.[17] First, during the first sub-sample period from 1985 to 1999, the degree of export price responses to the exchange rate shock is much higher during the yen depreciation period than during the yen appreciation period for all industries, even including General Machinery. This result is almost consistent with the findings obtained from the near-VAR estimation for the entire sample period (Figure 2.4).

Second, during the latter sub-sample from 2000 to 2014, the degree of differences in impulse responses become substantially small between the yen appreciation and depreciation periods. While the level of impulse responses decline in the yen depreciation period, the level of impulse responses does not change much during the yen appreciation. Thus, Japanese exporter's pricing behavior becomes more symmetric between the yen appreciation and depreciation periods after 2000s.

2.4.2.3 Short-run and Long-run ERPT and PTM

We have so far found a difference in the degree of impulse responses of export price to one standard deviation of exchange rate shock between the yen appreciation and depreciation

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[17] The results of both impulse responses and error-confidence bands for sub-sample periods are presented in Appendix Figure A.2.1. All impulse responses are statistically significant at least for the first five periods.

periods, especially in the first sub-sample from 1985 to 1999. But, in Section 2.4.1, we also revealed a clear difference in the degree of exchange risk that exporters face across industries, which indicates an industry difference of exchange rate volatility. To make rigorous examinations of ERPT, we estimate the impulse responses of contract-NEER to the exchange rate shock. Then, we divide the accumulated impulse responses of export price to the exchange rate shock by the corresponding accumulated impulse responses of contract-NEER to obtain the "PTM ratio". If the PTM ratio is unity (zero), it means a complete (no) PTM or a zero (complete) ERPT.

Table 2.3 shows a summary result of the PTM ratio from the first to twenty-fourth month. First, when looking at the PTM ratio at the first period, the ratio is found to be very close to unity, which indicates that short-run ERPT is almost zero and hence complete PTM. This result is not surprising, because short-run ERPT or PTM tends to reflect the choice of invoice currency (Gopinath *et al*., 2010). Since we use the contract-NEER as the exchange rate variable, the short-run ERPT (PTM) tends to be zero (complete) unless exporters change the export price itself.

Second, Table 2.3 clearly shows that ERPT or PTM is symmetric between yen appreciation and depreciation periods from the first through the twenty-fourth month. This symmetric pattern is observed in all sample periods: not only in the entire sample period but also in two sub-sample periods.

Third, the PTM ratio tends to fall from the first to twenty-fourth period, which indicates that the degree of PTM (ERPT) declines (increases) in the long-run. But, it must be noted that the PTM ratios reported in Table 2.3 are based on the accumulated impulse responses that are intrinsically short-run, because we perform the near-VAR estimation in first-

differences. Thus, we need to carefully interpret the PTM ratios in Table 2.3 as evidence of the long-run PTM or ERPT.

Fourth, the PTM ratios change differently across industries, and the differences become much larger if we look at the results of the second sub-sample period. On one hand, in the second sub-sample period, two major machinery industries, General Machinery and Transport Equipment, exhibit a small decline of the PTM ratio from around unity to 0.82 – 0.85 at the twenty-fourth month. Electric Machinery shows almost complete PTM from the first to twenty-fourth month. These findings suggest a strong PTM behavior. On the other hand, Chemical and Metal show a large decline of the PTM ratio from around unity to 0.59 and 0.37 – 0.44, respectively, at the twenty-fourth month, which indicates a greater ERPT.

Thus, even though PTM or ERPT behavior is found to be symmetric between the yen appreciation and depreciation periods, the degree of PTM or ERPT changed from the first sub-sample to the second sub-sample period. Specifically, the long-run PTM increased from the first to second sub-sample period in Electric Machinery and Transport Equipment, and such strong PTM behavior is observed in General Machinery as well. Since these three machinery industries account for around two-thirds of Japanese total exports, such strong PTM practices suggest that export prices of these industries became less responsive to the exchange rate changes, which is consistent with the slow recovery of real exports in response to the rapid and substantial depreciation of the yen from the end of 2012. In contrast, Metal and, to a lesser extent, Chemical show a greater decline of the PTM ratio, indicating that these industries tend to lower the export price itself in response to the large depreciation of the yen from the end of 2012.

Shimizu and Sato (2015) argued that the Japan's slow recovery of real exports and trade balance would be likely due to the PTM behavior of Japanese exporters.[18] Our empirical results support the above study especially in the case of Japanese major machinery exports that are generally considered highly differentiated products.[19] In contrast, Metal and Chemical that are typically considered less differentiated tend to increase the degree of ERPT to maintain the export price competitiveness. Japanese exporters pricing behavior can be at least partly related to the slow recovery of trade balance in recent years.

2.5 Concluding Remarks

In contrast to the previous ERPT research on Japanese exports, this study has evaluated the degree of ERPT/PTM by employing the NEER based on contract currency weight. The contract-NEER itself provides a useful information on the degree of exchange rate risk for each industry. Considering a different degree of exchange rate risk across industries, we estimate time-varying thresholds as a proxy for exporter's expected exchange rates, which is a novel approach to distinguish between yen appreciation and depreciation periods. Allowing for such industry-specific differences, we employ a near-VAR model with time-varying thresholds to examine whether the degree of ERPT/PTM is regime dependent.

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[18] By estimating the time-varying parameter model, Shimizu and Sato (2015) found that the coefficient of the contract NEER (i.e., the PTM elasticity) declined sharply, but only temporarily, during the yen appreciation period from 2011 to 2012. They also found that Japanese exporters returned to the strong PTM behavior after the rapid depreciation of the yen from the end of 2012.

[19] Ito *et al*. (2012) investigate a relationship between product differentiation and invoice currency choice using the firm-level information obtained from interviews with Japanese major machinery firms.

It is found that the degree of export price responses to exchange rate shock declines and becomes more symmetric in the second sub-sample period from 2000 to 2014. The calculated PTM ratios reveal that the PTM or ERPT behavior is almost symmetric between yen appreciation and depreciation periods. In addition, the degree of PTM or ERPT differs across industries and such industry-differences become larger in the second sub-sample period. Specifically, Japanese three major machinery industries tend to exhibit a strong tendency of PTM in the long-run, while other industries including Chemical and Metal tend to show a greater degree of ERPT in the long-run. This difference is likely due to the product differentiation of export goods in respective industries.

Finally, this study can be extended by investigating time-varying responses of export price indices to exchange rate shock. Shimizu and Sato (2015) applied the Kalman filter technique to the single-equation model of ERPT in Japanese exports. Shioji (2014, 2015) employed a time-varying parameter VAR approach to analyze the ERPT in Japanese imports. Such time-varying techniques will be useful for further understanding possible changes in ERPT and PTM. In addition, the impulse responses obtained from the near-VAR model in first-differences are intrinsically short-run, and the results of long-run PTM or ERPT need to be carefully interpreted. More rigorous analysis of both short-run and long-run PTM or ERPT will be necessary for future study.

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Table 2.1. Percent Share of Invoice Currency in Japanese Export and Import Indices as of December 2014 (%)

Industry :	Export Price Index				Industry :	Import Price Index			
	JPY	USD	EUR	Others		JPY	USD	EUR	Others
					Foodstuffs (75.8)	30.3	62.6	3.8	3.3
Textiles (12.5)	9.5	79.8	10.7	0.0	Textiles (53.5)	57.5	40.9	0.7	0.9
Chemicals (95.4)	28.9	69.4	1.7	0.0	Chemicals (83.3)	51.5	36.2	9.8	2.5
Metals (118.2)	21.5	77.8	0.6	0.0	Metals (117.1)	11.0	87.0	0.0	2.0
					Wood & Lumber (16.5)	4.1	70.3	16.1	9.4
					Petroleum (305.4)	8.7	91.3	0.0	0.0
General Machinery (192.0)	61.9	26.0	9.0	2.9	General Machinery (53.9)	40.1	54.4	2.7	2.7
Electric Machinery (232.9)	37.3	53.5	8.3	1.1	Electric Machinery (184.3)	44.9	54.0	0.2	0.9
Transport Equipment (240.6)	29.8	50.3	10.3	9.7	Transport Equipment (34.1)	42.1	42.8	15.1	0.0
Other Products (108.4)	33.0	62.3	3.1	1.5	Other Products (76.1)	21.9	71.9	3.2	3.0
All Industries (1,000.0)	36.7	53.1	6.9	3.2	All Industries (1,000.0)	27.2	69.0	2.4	1.5

Note: A round number is presented as a share of invoice currency. Figures in parentheses under the name of each industry (commodity group) denote the weight of the corresponding industry. The weight of all industries is 1,000.0.

Source: Bank of Japan, Export and Import Price Indices (2010 base).

Table 2.2. Key Statistics of Contract NEER and a Time-varying Threshold

Contract Currency NEER:		All	Textile	Chemical	Metal	General	Electric	Transport	Others
1985-1999	Average	127.0	144.8	136.8	142.1	114.7	125.2	129.5	126.9
	Stdev	17.1	26.6	27.4	26.2	9.0	17.1	18.4	16.4
2000-2014	Average	111.5	116.7	114.2	116.2	107.8	110.4	111.6	112.4
	Stdev	9.6	14.0	12.4	13.9	6.5	8.9	9.8	10.5
Time-Varying Threshold:		All	Textile	Chemical	Metal	General	Electric	Transport	Others
1985-1999	Depreciation	61	46	60	58	73	59	62	45
	Appreciation	293	308	294	296	281	295	292	309
	Average	135.7	154.3	147.4	156.6	116.8	135.6	135.6	134.0
	Stdev	25.7	34.9	39.1	39.6	12.6	25.7	23.7	23.5
2000-2014	Depreciation	82	79	89	74	100	79	95	76
	Appreciation	272	275	265	280	254	275	259	278
	Average	112.0	116.9	112.6	118.2	106.3	111.9	110.9	113.2
	Stdev	8.2	12.7	9.4	12.8	5.6	7.4	6.8	9.3

Note: "Depreciation" and "Appreciation" show the number of observations that are categorized into the depreciation and appreciation periods, respectively.

Table 2.3. Pricing-to-Market Ratio of Japanese Exports

Time:	Entire Sample Period 1985M01-2014M12		1st Sub-Sample Period 1985M01-1999M12		2nd Sub-Sample Period 2000M01-2014M12	
	Appreciation	Depreciation	Appreciation	Depreciation	Appreciation	Depreciation
1. All Manufacturing						
1	0.98	0.98	0.97	0.97	1.00	1.01
6	0.77	0.77	0.74	0.75	0.85	0.86
12	0.73	0.73	0.65	0.66	0.88	0.88
24	0.71	0.71	0.61	0.62	0.87	0.87
2. Textile						
1	0.95	0.95	0.85	0.87	0.99	1.00
6	0.78	0.78	0.68	0.70	0.84	0.83
12	0.76	0.77	0.66	0.69	0.81	0.81
24	0.76	0.76	0.66	0.68	0.81	0.81
3. Chemical						
1	0.96	0.97	0.92	0.93	1.03	1.05
6	0.70	0.71	0.67	0.68	0.69	0.70
12	0.61	0.62	0.68	0.68	0.64	0.64
24	0.59	0.60	0.61	0.62	0.59	0.59
4. Metal						
1	0.98	0.98	0.92	0.93	1.02	0.98
6	0.68	0.67	0.75	0.75	0.59	0.54
12	0.48	0.48	0.59	0.60	0.47	0.43
24	0.48	0.47	0.58	0.58	0.44	0.37
5. General Machinery						
1	0.98	0.98	1.00	0.99	0.97	0.98
6	0.85	0.85	0.86	0.86	0.84	0.84
12	0.81	0.81	0.81	0.81	0.82	0.82
24	0.81	0.81	0.81	0.81	0.82	0.82
6. Electric Machinery						
1	0.96	0.97	0.94	0.96	0.98	0.98
6	0.84	0.84	0.76	0.78	1.02	1.02
12	0.80	0.80	0.71	0.75	1.00	1.01
24	0.79	0.79	0.71	0.74	1.00	1.00
7. Transport Equipment						
1	0.98	0.98	0.97	0.97	1.01	1.01
6	0.72	0.72	0.70	0.69	0.80	0.81
12	0.70	0.70	0.64	0.63	0.85	0.85
24	0.68	0.68	0.62	0.61	0.83	0.85
8. Other Manufacturings						
1	1.00	1.00	0.97	0.97	1.03	1.04
6	0.86	0.86	0.83	0.86	0.83	0.83
12	0.81	0.81	0.76	0.80	0.79	0.78
24	0.80	0.80	0.75	0.80	0.75	0.74

Note: The PTM ratio is calculated by dividing the accumulated impulse response of export price to exchange rate shock by the corresponding response of contract-NEER. The impulse responses at the first, sixth, twelfth, and twenty-fourth months are presented.

Figure 2.1. Japanese Export Price Indices (2005=100) and Nominal Exchange Rate
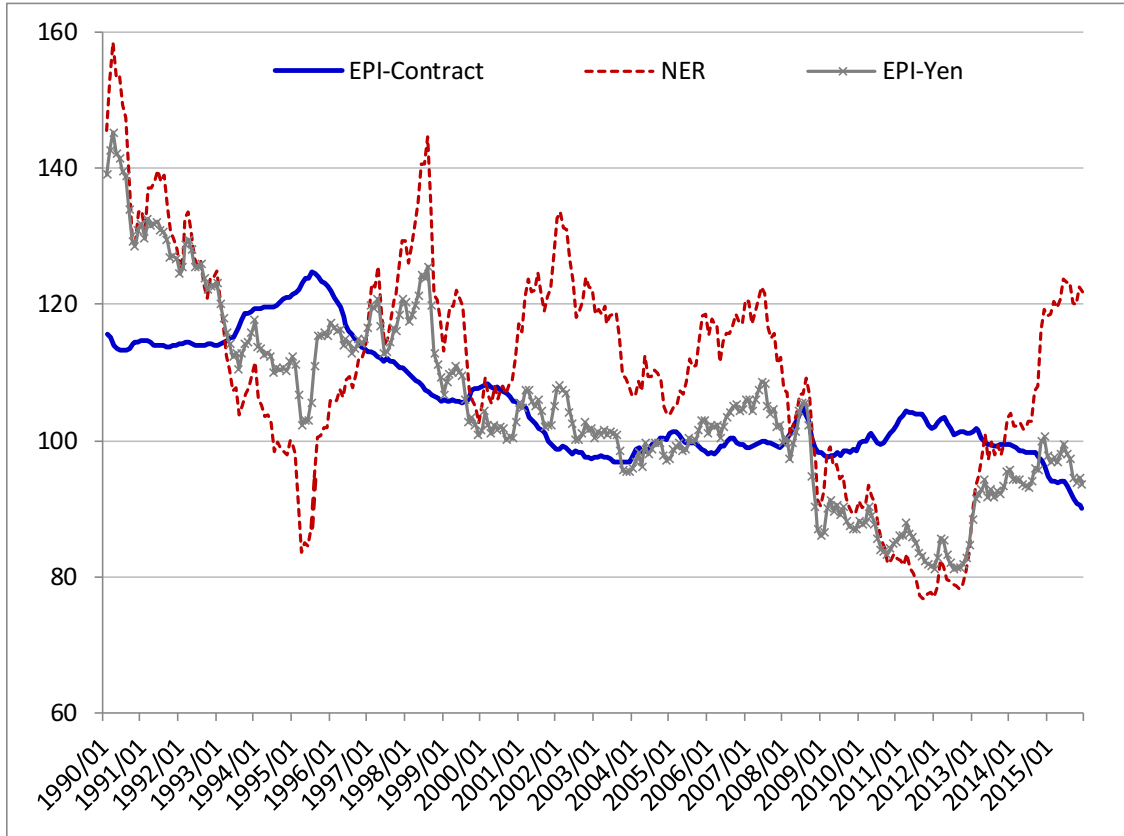
Note: Sample period ranges from January 1990 to December 2015. "EPI-Contract" denotes the Japanese manufacturing export price on a contract currency basis (2005=100); "EPI-Yen" denotes the corresponding export price on a yen basis (2005=100); "NER" denotes the nominal exchange rate of the yen vis-à-vis the US. dollar. An increase (decrease) in NER denotes depreciation (appreciation) of the yen.

Source: Bank of Japan and CEIC Database.

Figure 2.2. Japanese Trade Balance, Real Exports, and Nominal Exchange Rate
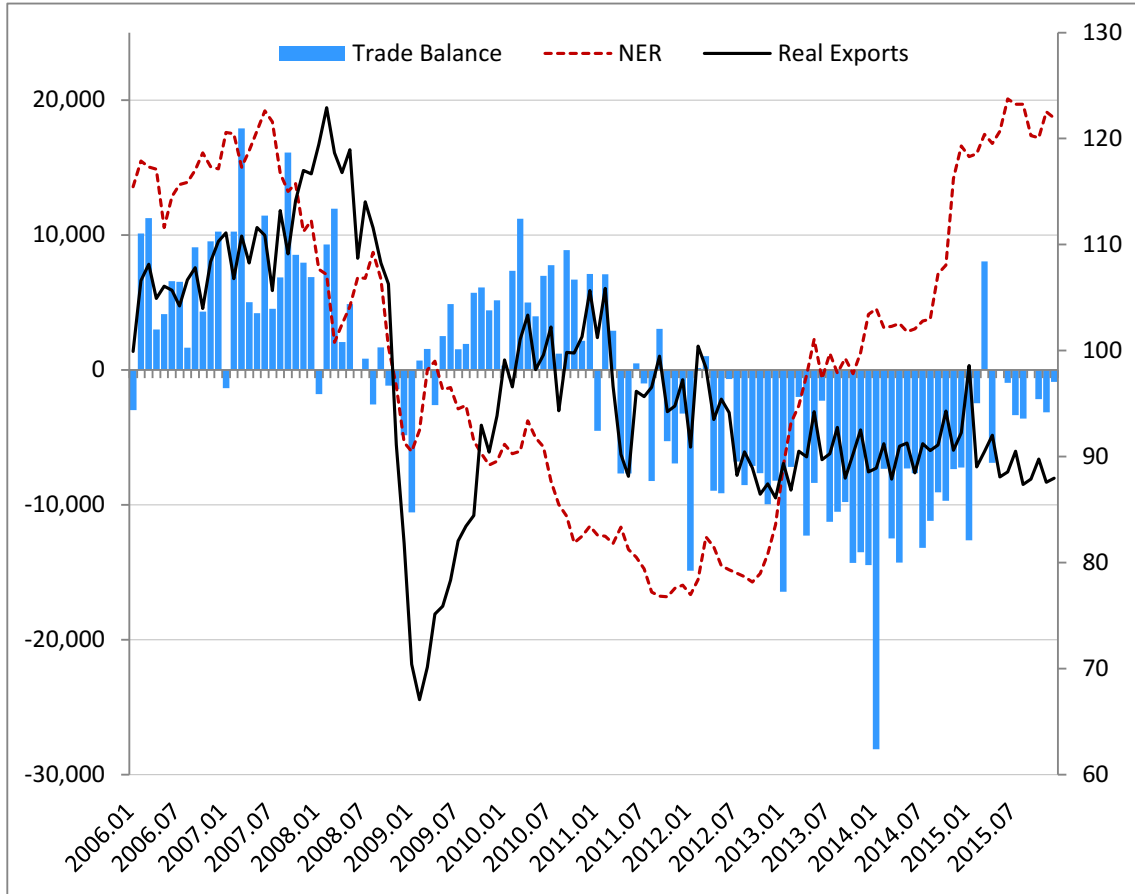
Note: Sample period ranges from January 2006 to December 2015. "Trade Balance" denotes the Japanese trade balance (left axis: 100 million yen); "Real Exports" denotes Japanese real export index (right axis: 2010=100); "NER" denotes the nominal exchange rate of the yen vis-à-vis the US dollar (right axis). An increase (decrease) in NER denotes depreciation (appreciation) of the yen.

Source: Ministry of Finance and CEIC Database.

Figure 2.3. Contract Currency-Based NEER and Time-varying Thresholds
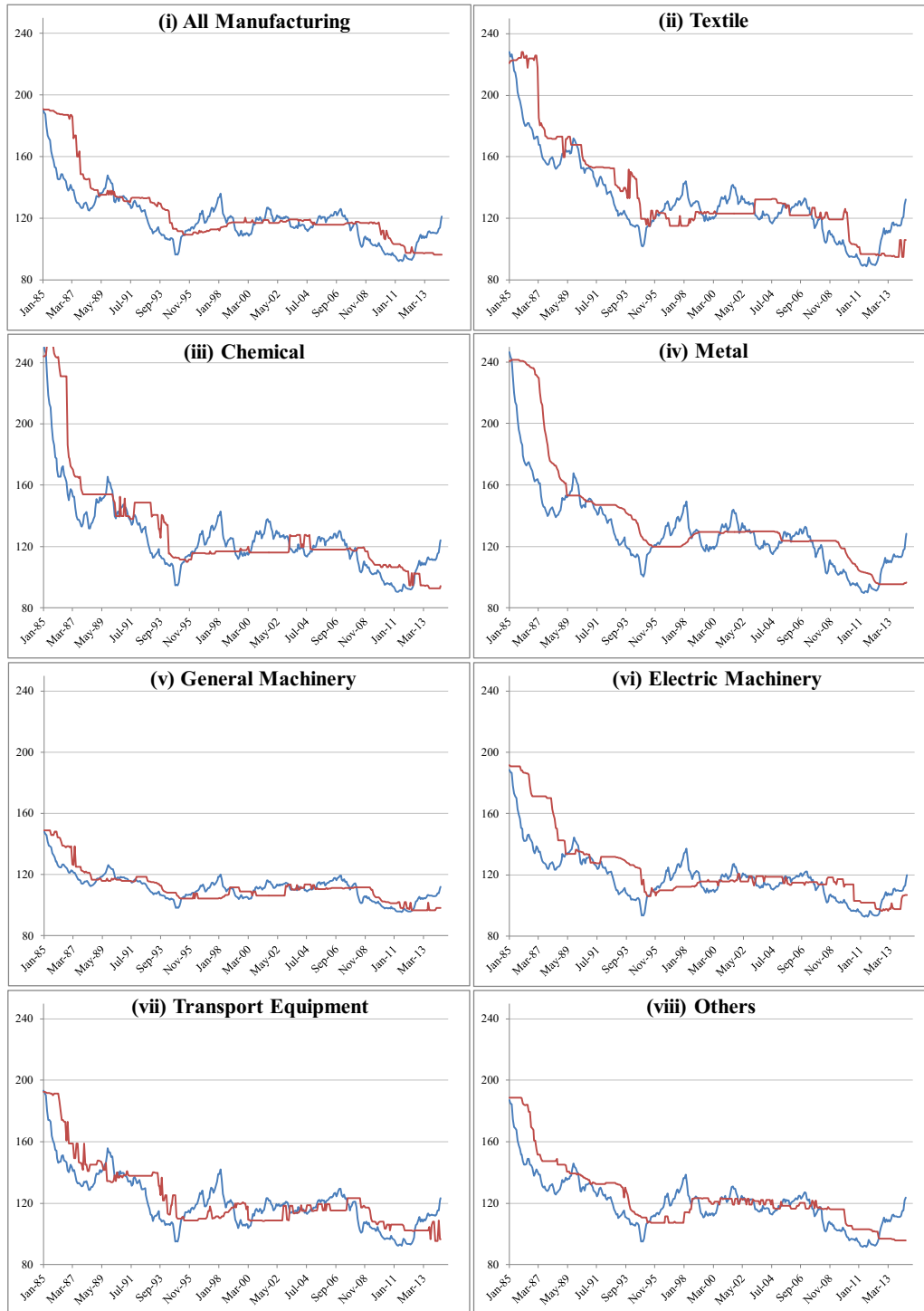
Note: A blue line shows the contract currency-based NEER (January 2010 = 100). A red line indicates the time-varying threshold that is considered the expected exchange rate at an industry level.

Figure 2.4. Result of an Impulse Response Function Analysis: Entire Sample Period
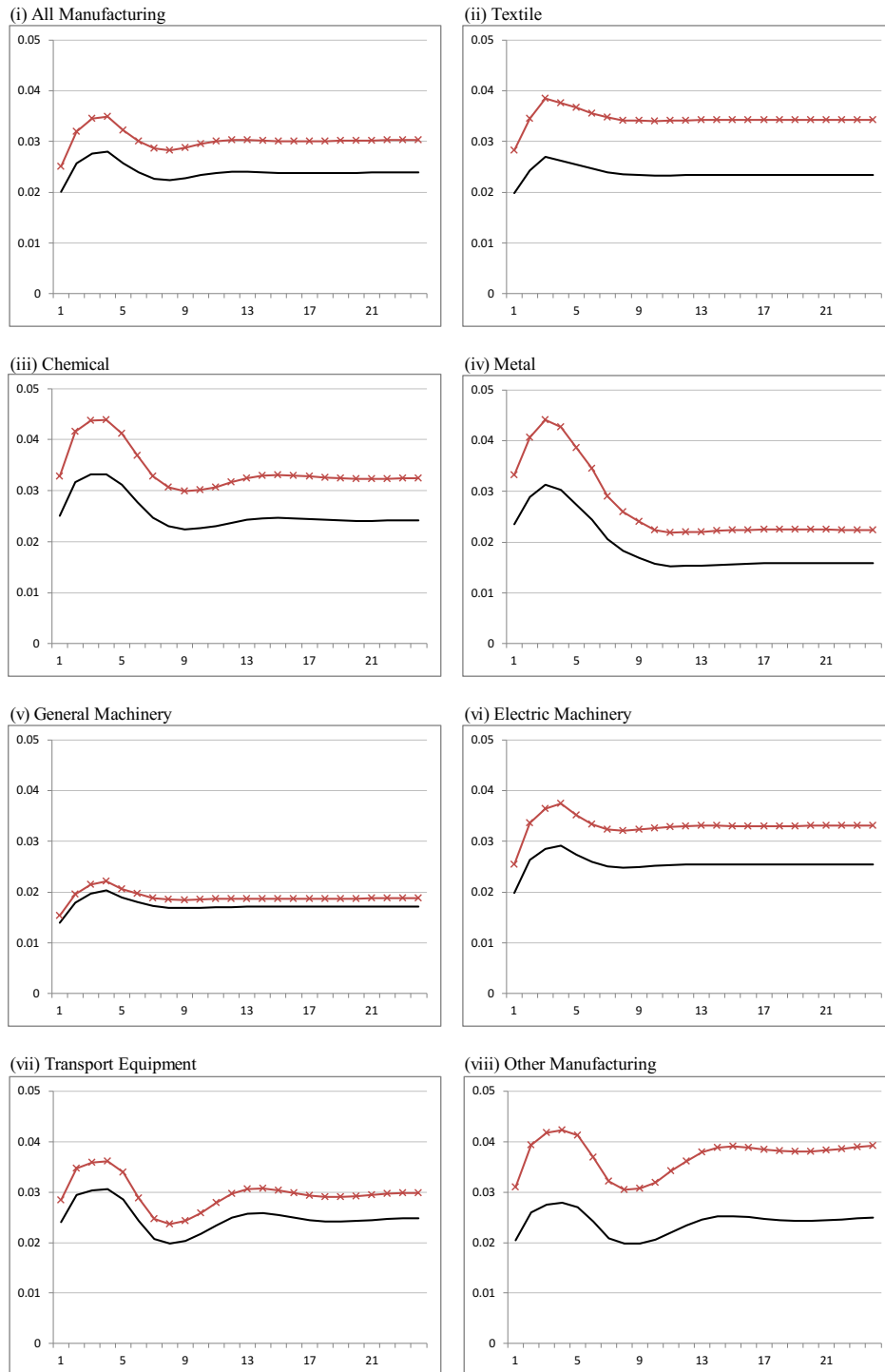
Note: The red and black lines show the accumulated impulse responses of the export price index to a one standard deviation shock to the contract NEER during yen depreciation and appreciation periods, respectively.

Figure 2.5. The Impulse Response Function: A Comparison between Two Periods

(i) All Manufactureing (1985-1999)

(i) All Manufactureing (2000-2014)

(ii) Textile (1985-1999)

(ii) Textile (2000-2014)

(iii) Chemical (1985-1999)

(iii) Chemical (2000-2014)

(iv) Metal (1985-1999)

(iv) Metal (2000-2014)

41
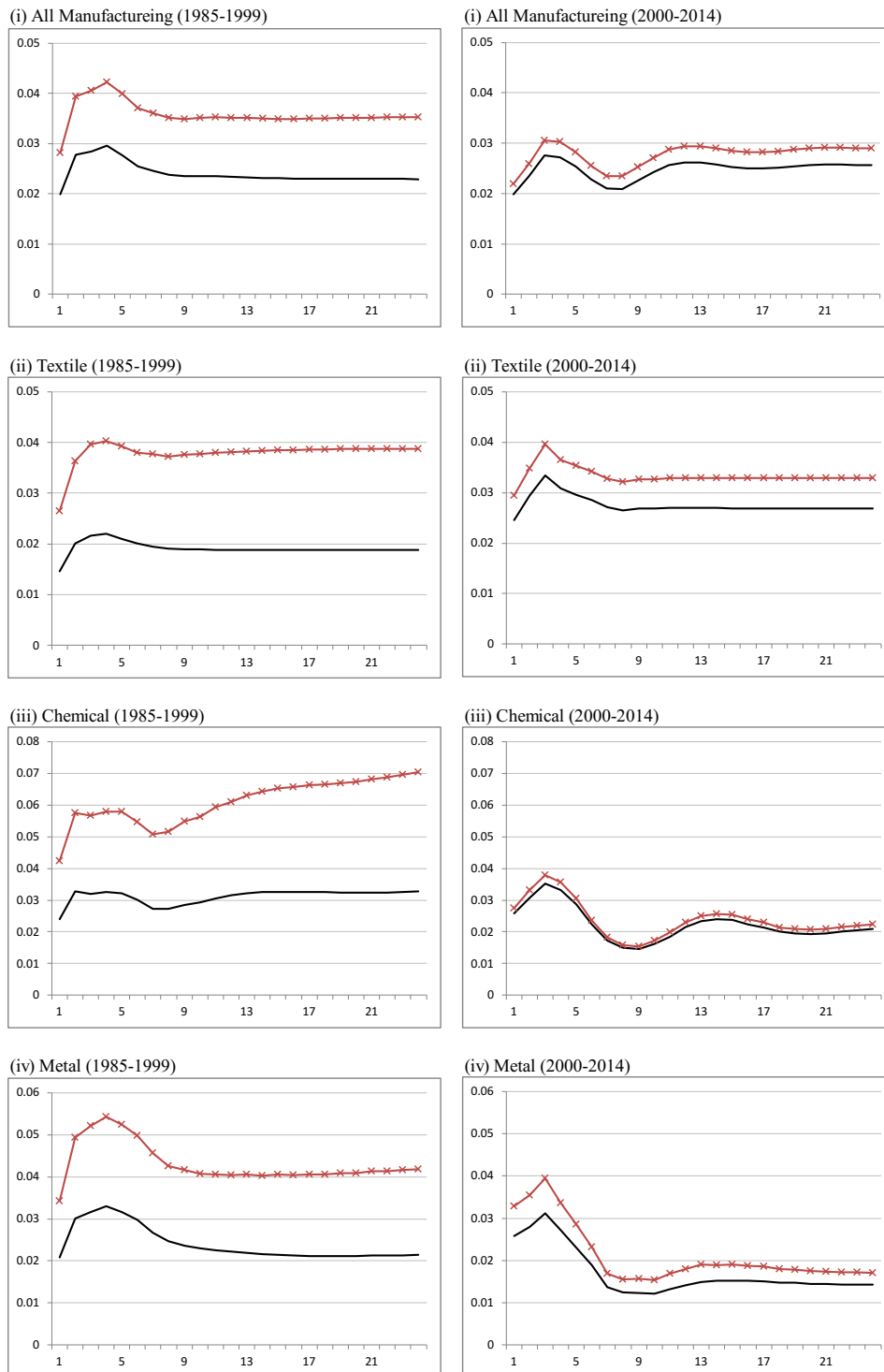
Figure 2.5 (cont.) The Impulse Response Function: A Comparison between Two Periods

(v) General Machinery (1985-1999)

(v) General Machinery (2000-2014)

(vi) Electric Machinery (1985-1999)

(vi) Electric Machinery (2000-2014)

(vii) Transport Equipment (1985-1999)

(vii) Transport Equipment (2000-2014)

(viii) Other Manufacturing (1985-1999)

(viii) Other Manufacturing (2000-2014)
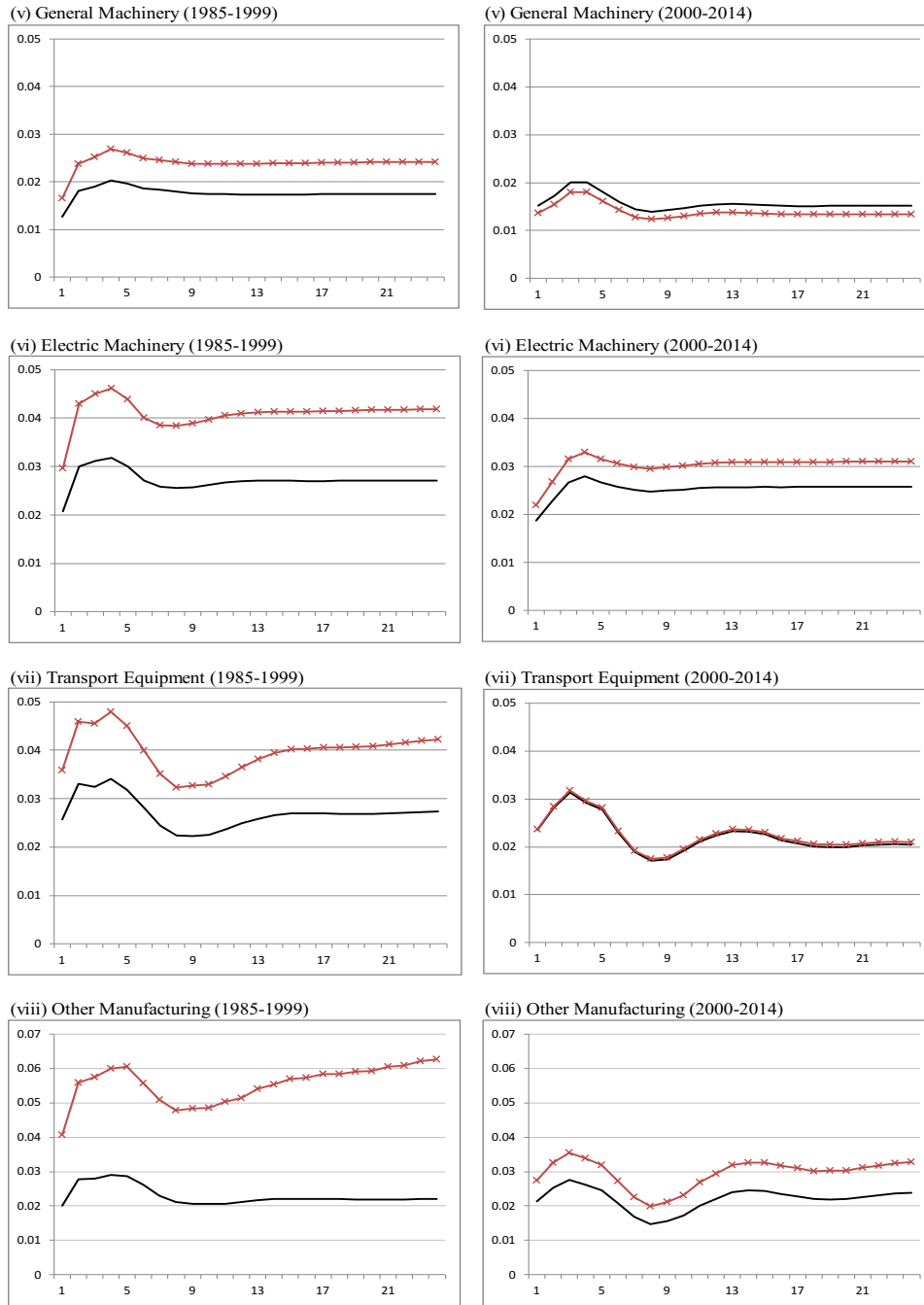
Note: The red (x mark) and black (no mark) lines show the accumulated impulse responses of the export price index to a one standard deviation shock to the contract NEER in yen depreciation and appreciation periods, respectively.

Appendix Figure A2.1. Impulse Response Function Results with an Error Confidence Band

(i) All Manufacturing
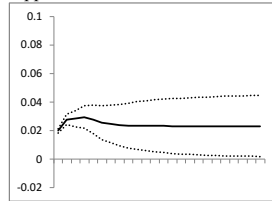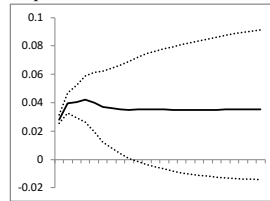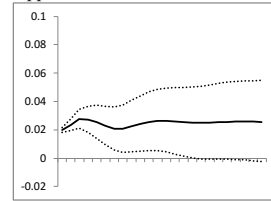
Appreciation: 1985-1999 · Depreciation: 1985-1999 · Appreciation: 2000-2014 · Depreciation: 2000-2014
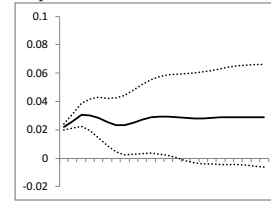
(ii) Textile
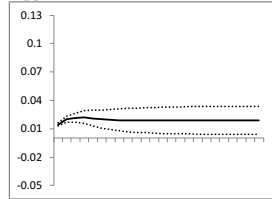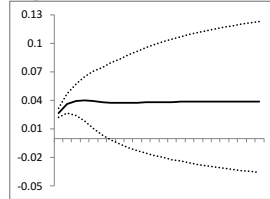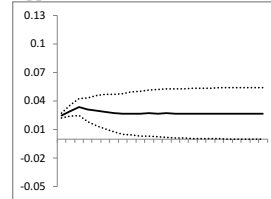
Appreciation: 1985-1999 · Depreciation: 1985-1999 · Appreciation: 2000-2014 · Depreciation: 2000-2014
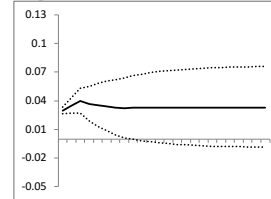
(iii) Chemical
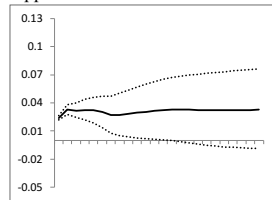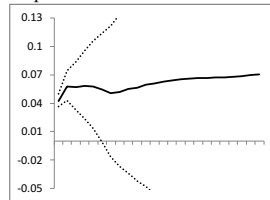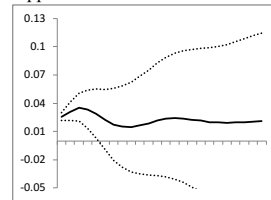
Appreciation: 1985-1999 · Depreciation: 1985-1999 · Appreciation: 2000-2014 · Depreciation: 2000-2014
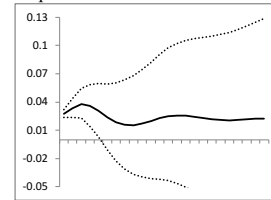
(iv) Metal
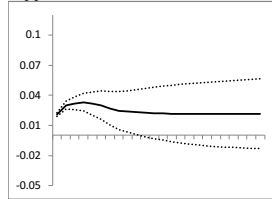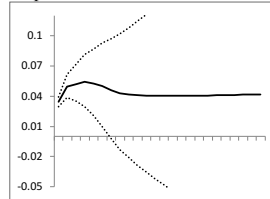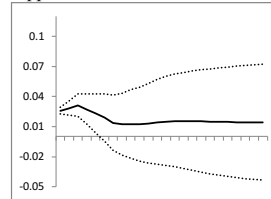
Appreciation: 1985-1999 · Depreciation: 1985-1999 · Appreciation: 2000-2014 · Depreciation: 2000-2014
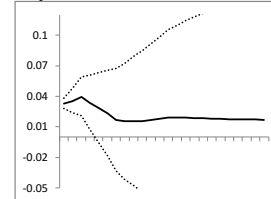
(v) General Machinery
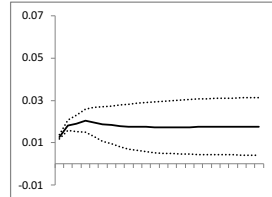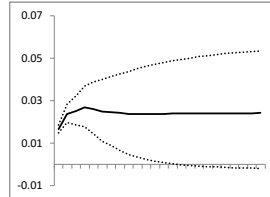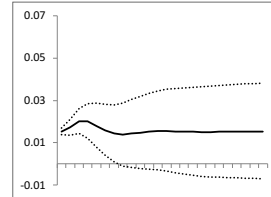
Appreciation: 1985-1999 · Depreciation: 1985-1999 · Appreciation: 2000-2014 · Depreciation: 2000-2014
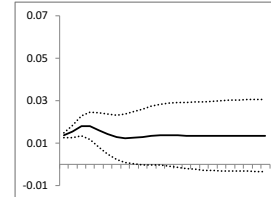
Appendix Figure A2.1 (cont.) Impulse Response Function Results with an Error Confidence

Band

(vi) Electric Machinery

| Appreciation: 1985-1999 | Depreciation: 1985-1999 | Appreciation: 2000-2014 | Depreciation: 2000-2014 |

(vii) Transport Equipment

| Appreciation: 1985-1999 | Depreciation: 1985-1999 | Appreciation: 2000-2014 | Depreciation: 2000-2014 |

(viii) Other Manufacturing

| Appreciation: 1985-1999 | Depreciation: 1985-1999 | Appreciation: 2000-2014 | Depreciation: 2000-2014 |
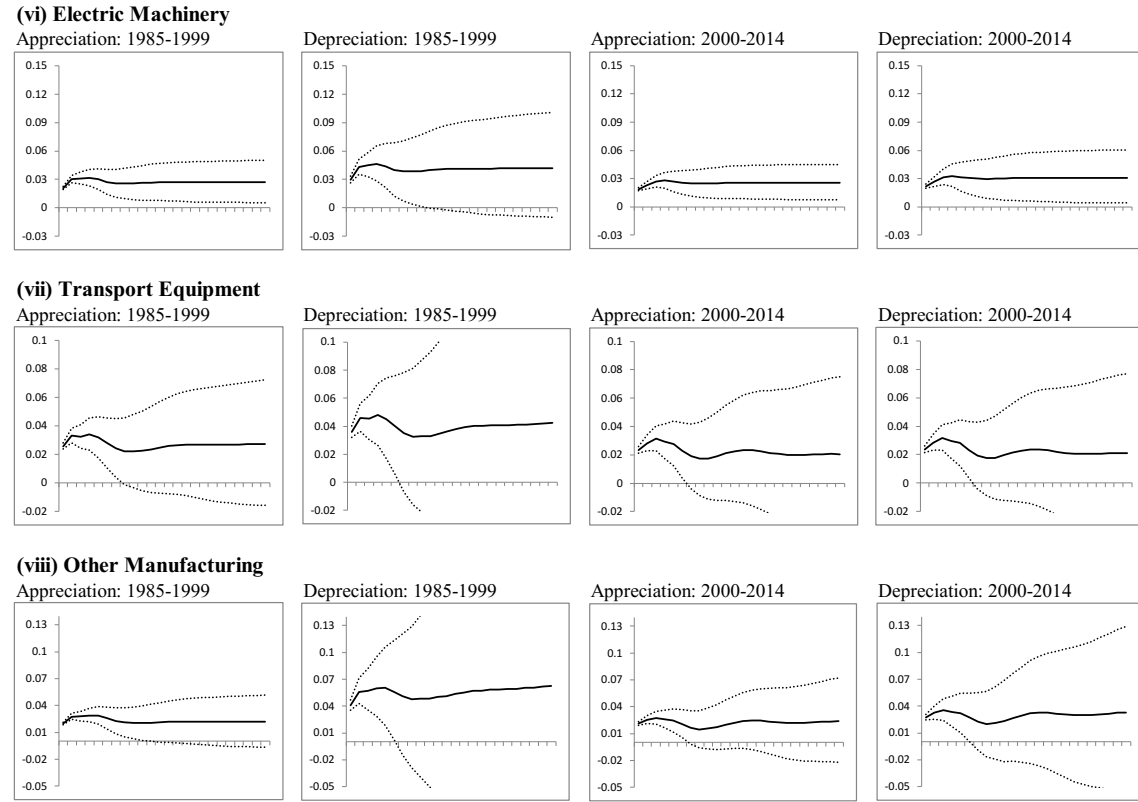
Note: The solid line shows the accumulated impulse responses of the export price index to a one standard deviation shock to the contract-NEER. The dotted lines show error confidence bands.

Firms' Predicted Exchange Rates and Nonlinearities in Pricing-to-Market

3.1. Introduction

Since Japan adopted a floating exchange rate in 1971, the Japanese economy has faced a large yen appreciation period three times. The latest period corresponds to the subprime mortgage crisis in 2007, witnessing a sharp fall in the yen vis-à-vis the US dollar from around 120 in 2007 to the post-WWII record high of 75.32 yen/USD in 2011. In late 2012, however, Prime Minister Shinzo Abe initiated his economic stimulus package, known as "Abenomics," targeting steady currency depreciation. This put an end to the yen appreciation trend and dramatically turned the yen toward large depreciation.

The question of how Japanese export firms reacted to such large fluctuations in the yen from 2007 warrants investigation. Existing studies have typically found strong evidence of pricing-to-market (PTM) or weak evidence of exchange rate pass-through (ERPT) in Japanese exports, implying that Japanese exporters tend to stabilize their export prices in response to exchange rate changes. [20] For instance, using rolling regression, Ceglowski (2010) demonstrated that Japanese exporters increased the degree of PTM from the late 1990s to 2007. However, Japanese firms are likely to have changed their export pricing behavior from 2007 in response to the rapid, large exchange rate fluctuations.

Figure 3.1 plots the contract currency-based and yen-based export prices of all manufacturing and the yen vis-à-vis the US dollar bilateral exchange rate. During the 2007–

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[20] See Marton (1990), Knetter (1994), Parsons and Sato (2008), and Yoshida (2010).

2015 period, exchange rate changes have been correlated more with the yen-based export price rather than the contract currency-based export price, which indicates that Japanese firms on average tend to utilize a PTM strategy in terms of their exports. When observing export prices at an industry level, however, two major Japanese machinery industries, Transport Equipment and General Machinery, exhibit different pricing behaviors in their exports (Figure 3.2). The contract currency-based export prices appear to increase to some extent in response to yen appreciation, while they have stayed at the same level despite the sharp, large depreciation of the yen from 2012 to the present. This visual inspection suggests that Japanese exporters' pricing behaviors are likely to differ across industries and between yen appreciation and depreciation periods.

The main purpose of this study is to empirically investigate possible differences in Japanese exporters' pricing behaviors between yen appreciation and depreciation periods. Recent studies, such as Delatte and Lopez-Villacencio (2012) and Fedoseeva and Werner (2016), employed the nonlinear autoregressive distributed lag (NARDL) model proposed by Shin et al. (2014) to investigate the possible nonlinearity of the exporter's pricing behavior. The NARDL model has an advantage in testing the hypothesis of nonlinear PTM or ERPT not only in the short run but also in the long run, an effect that cannot be captured via conventional first-differenced models.

However, the current NARDL studies have two drawbacks. First, they rely on the conventional appreciation/depreciation threshold specification in which exchange rate changes are simply divided into positive and negative changes.[21] However, even in the medium- and

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[21] The conventional threshold specification approach is widely used in the literature, see for example Knetter (1994), Madavi (2002) and Delatte and Lopez-Villacencio (2012). We discuss this further in Section 3.2.

long-run currency appreciation period, for instance, a small, short-lived depreciation often occurs, which is included in the yen depreciation period by the conventional approach.[22] In employing the conventional threshold approach, it is difficult to distinguish correctly between yen appreciation and depreciation periods.

Second, exporters' pricing behaviors may be revised when the degree of changes in the realized exchange rate exceeds that of exporters' expectations. The conventional threshold approach, which uses the realized exchange rate changes, fails to capture the exporters' expectations of the future exchange rate. This study proposes a new empirical method of threshold specification using firms' predicted exchange rates published by the Bank of Japan (BOJ), "Short-Term Economic Survey of Enterprises in Japan (Tankan)."[23] The BOJ administers an extensive survey on exporting firms' predicted exchange rate that is used for building their business plans. Another advantage of the BOJ's predicted exchange rate is that industry-level data are available, which enables us to capture differences in exporters' predictions reflecting their export competitiveness.

Utilizing the BOJ's predicted exchange rates and the new threshold approach for the estimation of the NARLD model, we present new empirical evidence of Japanese PTM or ERPT behavior. Specifically, we find evidence of long-run asymmetry in PTM in four of seven exporting industries and in all manufacturing industries. While most industries exhibit incomplete but relatively strong PTM during the yen appreciation period, the transport equipment and general machinery industries, which are known to have strong export

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[22] In Figure 3.1, the yen appreciated substantially from 2007 to 2012. During this appreciation period, we observe a number of short-run depreciations.

[23] The details of our new method are explained in Section 3.3.

competitiveness, tend to conduct full PTM during the yen depreciation period. In contrast, other industries with less-differentiated products significantly lower (increase) the degree of PTM (ERPT) during the yen depreciation period. In the short run, however, almost full and symmetric PTM is found across all industries for all sample periods, which is consistent with the findings of previous studies that firms' short-run PTM or ERPT behaviors are strongly affected by the invoice currency choice.

Understanding Japanese exporters' PTM or ERPT behaviors is crucially important in considering the impact of exchange rate volatility on the Japanese economy. We reveal differential pricing behavior not only across industries but also between yen appreciation and depreciation periods. Given that at least two of the three main manufacturing industries in Japan do not pass through yen depreciation to their export prices, it is hard to reasonably expect a decline in export prices in response to currency depreciation. Although trade balance is not solely determined by such a price factor, our empirical results at least partly answer the question as to why the Japanese trade balance has been unresponsive to yen depreciation since the end of 2012.

The remainder of this paper is organized as follows. We provide a brief overview of the literature on asymmetric ERPT/PTM in Section 3.2. Section 3.3 explains the empirical model, followed by a description of our data in Section 3.4. Empirical results are presented and discussed in Section 3.5. Section 3.6 concludes this study.

3. 2. Literature review

3.2.1. Asymmetric ERPT

The possibility of asymmetric ERPT has been addressed in the literature. There are three principal theoretical arguments for asymmetric pass-through: imperfect competition, low-inflation environment, and quantity rigidities.

The market power of exporting firms allows them to consider consumer demand when setting their price. Krugman (1987), Dixit and Stiglitz (1977), and Knetter (1993) addressed imperfect competition, in which firms can adjust their mark-ups to absorb exchange rate changes. To this end, if producers decide to conduct PTM when their currency appreciates, they are willing to squeeze their profits to keep the importers' demands unchanged. In a currency depreciation period, it is easier to decide whether to absorb all the exchange rate changes into a mark-up increase (while keeping demand unchanged) or to pass through exchange rate changes to importers by lowering the export price in the importer's currency to stimulate the importer's demand. Therefore, the magnitude of ERPT and PTM is ambiguous. Even though most exporters have more incentive to increase the degree of ERPT when their currency appreciates, less-competitive exporters are likely to choose PTM to avoid declines in their export sales due to a hike in their selling prices.

Meanwhile, a low-inflation environment is often discussed to explain ERPT to import prices. Quantity rigidities are also considered in relation to firm characteristics. However, this study does not initiate a further discussion in these two domains.[24]

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[24] See Delatte and Lopez-Villacencio (2012) for further discussion on low inflation environments and quantity rigidities.

3.2.2. Nonlinear approach to asymmetric ERPT

While theoretical literature has explored possible nonlinearity, only a few studies have empirically investigated asymmetric ERPT or PTM between currency appreciation and depreciation periods. Knetter (1994), Mahdavi (2002), and Pollard and Coughlin (2004) were among the first to analyze differences in the short-run ERPT between appreciation and depreciation periods. Even though they found some evidence of asymmetric ERPT, these empirical methods are arguably limited because their models only estimate a short-run relationship by using log-differenced data and they use the "zero threshold" of exchange rate changes to specify currency regimes, i.e., positive and negative exchange rate changes are regarded as currency depreciation and appreciation, respectively. Thus, the conventional identification approach fails to distinguish precisely between appreciation and depreciation periods. To overcome this drawback of conventional threshold identification, Balke and Fomby (1997) proposed a "band of inaction," in which two thresholds are used to distinguish between large and minor exchange rate changes. Similarly, Nguyen and Sato (2015) proposed using an exchange rate level instead of its changes and endeavored to calculate the firm's reference exchange rate in levels as a threshold.

The NARDL model developed by Shin et al. (2014) has stimulated empirical studies on asymmetric ERPT and PTM. First, the NARDL model enables us to test both short-run and long-run asymmetry. When using first-differenced variables as in most previous studies, long-run asymmetry cannot be tested rigorously. Moreover, the NARDL model can be combined with flexible threshold specification. For instance, Delatte and Lopez-Villacencio (2012) investigated the asymmetric effect of exchange rate variations on consumer price indices (CPIs) using a mark-up model with zero threshold. They found evidence that exchange rate changes

are passed through to prices more in the depreciation period than in the appreciation period, which suggests a weak competition structure. Fedoseeva and Werner (2016) used destination-specific German beer exports to test for nonlinear PTM. Specifically, they used the exchange rate standard deviation as a threshold to distinguish between large appreciation, small change, and large depreciation. Although Verheyen (2013) did not directly examine the ERPT, this study also used two threshold regimes to distinguish between large appreciation and depreciation with inaction bands and analyzed the exchange rate impact on EMU export quantities to the United States.

In contrast to previous studies, we develop a new method of distinguishing between appreciation and depreciation periods by using the firm's predicted exchange rate, data that has not previously been considered in the literature.[25]

3.3. Empirical methods

3.3.1 ARDL model

The ARDL modeling approach (Pesaran and Shin, 1999) is similar to the error correction model (ECM), which tests long-run cointegration relationships among variables. While the model can be easily derived from the ECM, the ARDL model has several advantages over the ECM: (1) the ARDL model does not require all variables to be integrated of the same order,

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[25] There are a few exceptions such as Morikawa (2016) that uses the BOJ predicted exchange rate, but his paper examines not ERPT but the effect of exchange rate volatility on export quantities.

and (2) the level coefficients can be bounds tested to detect the existence of long-run relationships among variables.[26]

We first employ a conventional ERPT approach proposed by Goldberg and Knetter (1997), in which the export price is explained by the primary "control" variable, the exchange rate, and other control variables. In our model, the (log) yen-based export price index, *ex*, is explained by the (log) input price, *dp*, as the production cost, the (log) nominal effective exchange rate, *e*, and the (log) world industrial production index, *ipi*, as a proxy for world demand.

The ECM has two steps, with Step 1 estimating a long-run cointegration relationship:

$$ex_t = \alpha + \beta_1 e_t + \beta_2 dp_t + \beta_3 ipi_t + \varepsilon_t \quad (3.1)$$

β_1 denotes the effect of exchange rate on yen-based export price, i.e., PTM (or ERPT) level in the long run.

If the residuals $\hat{\varepsilon}_t$ obtained from Equation (3.1) are found to be stationary, we can conclude that the variables are cointegrated and proceed to Step 2 estimating an ECM:[27]

$$\Delta ex_t = \alpha + \rho\hat{\varepsilon}_{t-1} + \sum_{i=1}^{k-1} \gamma_1 \Delta ex_{t-i} + \sum_{i=0}^{k} \left(\gamma_2 \Delta e_{t-i} + \gamma_3 \Delta dp_{t-i} + \gamma_4 \Delta ipi_{t-i} \right) + \upsilon_t \quad (3.2)$$

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[26] See Pesaran *et al*. (2001).

[27] These estimated residuals show the estimated values of the deviations from the long-run disequilibrium.

where k is the lag order of a four-variable VAR model in first differences and υ_t is an *iid* process. The coefficient ρ that explains the speed of adjustment from long-run disequilibrium should have a negative, statistically significant sign.

For variables that are not integrated of the same order, the ECM cannot be estimated. Instead, we can use the ARDL model that is easily obtained from the ECM:

$$\Delta ex_t = \alpha + \rho_1 ex_{t-1} + \rho_2 e_{t-1} + \rho_3 dp_{t-1} + \rho_4 ipi_{t-1} +$$
$$\sum_{i=1}^{k}\gamma_{1i}\Delta ex_{t-i} + \sum_{i=0}^{l}\gamma_{2i}\Delta e_{t-i} + \sum_{i=0}^{m}\gamma_{3i}\Delta dp_{t-i} + \sum_{i=0}^{n}\gamma_{4i}\Delta ipi_{t-i} + \upsilon_t \quad (3.3)$$

Note that another advantage of the ARDL model is that the lag orders can differ among variables. Our interest is in the long-run PTM coefficient that can be calculated as $\beta_1 = -\dfrac{\rho_2}{\rho_1}$.

The null hypothesis $H_1 : \rho_1 = \rho_2 = \rho_3 = \rho_4 = 0$ and $H_1 : \rho_1 = 0$ can be tested with the bounds *F*-test and bounds *t*-test, respectively. The conclusion of long-run cointegration is derived if the null is rejected.

3.3.2 NARDL model

Shin et al. (2014) developed the NARDL model to allow for asymmetry of the variables in question. The main feature of this framework is the decomposition of possible asymmetric variables (i.e., exchange rates in this study) into partial sums using thresholds. The conventional approach of dividing exchange rate changes into positive and negative changes corresponds to:

$$e_t^+ = \sum_{j=1}^{t} e_j^+ = \sum_{j=1}^{t} \max(\Delta e_j, 0), \quad e_t^- = \sum_{j=1}^{t} e_j^- = \sum_{j=1}^{t} \min(\Delta e_j, 0) \quad (3.4)$$

However, as discussed above, this conventional threshold specification has a drawback. Since the exchange rate tends to be volatile, we can observe short-lived periods of depreciation, e.g., even during unambiguous appreciation periods. However, if we follow the conventional threshold approach, such short-run depreciation will be ultimately included in the yen depreciation period, which might cause misspecification problems.

To overcome the drawback of this approach, certain studies have used two or more thresholds to capture large positive/negative changes with small changes confined to an inaction band. [28] However, the criteria for defining critical values for thresholds remain ambiguous. We contribute to the literature by developing a new threshold approach using firms' predicted exchange rates.

Firms typically set their assumed or predicted exchange rates for the purposes of planning and management, which suggests that the predicted exchange rate itself contains important information on a firm's trade and pricing strategy. For instance, if the actual bilateral exchange rate turns out to be higher (lower) than the firm's predicted exchange rate, it would be considered a home currency depreciation (appreciation). Figure 3.3 shows the actual bilateral nominal exchange rate of the yen vis-à-vis the US dollar and the corresponding predicted exchange rate of all manufacturing exporters from 1997 to 2015. On one hand, firms might be conservative in revising their predicted exchange rates given that such revisions could impact their business plans. On the other hand, firms are willing to revise their predicted

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[28] The method has been widely used, see for example Belke *et al.* (2009), Belke *et al.* (2012) and Verheyen (2013).

exchange rates quickly in response to exchange rate changes, especially during currency depreciation periods. Hence, the adjustment speed of a firm's predicted exchange rate in response to actual exchange rate movements provides us with useful information on whether the current exchange rate level is regarded as overvalued (appreciated) or undervalued (depreciated) from the firm's point of view.

We use a mean of prediction errors as a threshold,[29] and the partial sum takes the following form:

$$e_t^+ = \sum_{j=1}^{t} e_j^+ = \sum_{j=1}^{t} \Delta e_j I\{er_t > mean(er)\}, \quad e_t^- = \sum_{j=1}^{t} e_j^- = \sum_{j=1}^{t} \Delta e_j I\{er_t < mean(er)\} \quad (3.5)$$

where er and mean(er) denote the prediction error (actual minus predicted exchange rate) and the mean of prediction error, respectively. $I\{Z\}$ is an indicator function that takes a value of one if condition Z is satisfied and zero otherwise.

From Shin et al. (2014), we can modify the ARDL model in Equation (3.3) into the NARDL model to allow asymmetry:

$$\Delta ex_t = \alpha + \rho_1 ex_{t-1} + \rho_2 e_{t-1}^+ + \rho_3 e_{t-1}^- + \rho_4 dp_{t-1} + \rho_5 ipi_{t-1} +$$
$$\sum_{i=1}^{k} \gamma_{1i} \Delta ex_{t-i} + \sum_{i=0}^{l} \left(\gamma_{2i}^+ \Delta e_{t-i}^+ + \gamma_{2i}^- \Delta e_{t-i}^- \right) + \sum_{i=0}^{m} \gamma_{3i} \Delta dp_{t-i} + \sum_{i=0}^{n} \gamma_{4i} \Delta ipi_{t-i} + \upsilon_t \quad (3.6)$$

<hr>

[29] Prediction error is the difference between the actual exchange rate and the firm's predicted exchange rate. As a robustness exercise, we also apply the zero value instead of the mean of prediction errors as a threshold value for regression. The results are found to be very similar.

We estimate Equation (3.6) with maximum lag 12 to choose the preliminary optimal lag length using Schwartz's information criteria (SC). Adjustment to lag length is carried out if serial correlation is detected.

To check for long-run relationships, a test can be performed by either the t_{BDM} statistic under the null hypothesis, $H_1 : \rho_1 = 0$, or the F_{PSS} statistic testing the joint null hypothesis, $H_1 : \rho_1 = \rho_2 = \rho_3 = \rho_4 = \rho_5 = 0$. Due to dependence between the series e_t^+ and e_t^-, the true value of k, i.e., the number of regressors entering the long-run relationship, is not clear, but it lies between three and four because we have three explanatory variables and four regressors. Shin et al. (2014) suggested that rejecting the null of no long-run relationship using lower k provides strong evidence for the existence of a long-run relationship. The mis-sizing could be resolved by bootstrapping, but this is beyond the scope of our current inquiry.

Finally, we can test for nonlinearity of PTM in the short and long runs by performing Wald tests. The null hypothesis of symmetry in the long run is $H_1 : -\dfrac{\rho_2}{\rho_1} = -\dfrac{\rho_3}{\rho_1}$, testing the equality of long-run exchange rate coefficients. As for symmetry of PTM in the short run, two standard Wald tests can be performed based on the following nulls: (1) $H_1 : \gamma_{2i}^+ = \gamma_{2i}^-$ for $i=0,..., l$ or (2) $H_1 : \sum_{i=0}^{l} \gamma_{2i}^+ = \sum_{i=0}^{l} \gamma_{2i}^-$.

3.4. Data description

3.4.1 Predicted exchange rate

The BOJ conducts a large-scale firm-level survey entitled "Short-Term Economic Survey of Enterprises in Japan (Tankan)" in March, June, September, and December each year. In the March 2015 survey, for instance, questionnaires were distributed to 11,126 firms. The survey, which commenced in March 1997, poses a question about the predicted exchange rate of the yen vis-à-vis the US dollar that sample firms use for export planning in each half of the fiscal year. Figure 3.4 simplifies the structure of the data. For example, the survey carried out in March 2015 asks for the firm's forecast of the exchange rate for the first half of fiscal year 2015 (from April to October 2015) and the second half of fiscal year 2015 (from October 2015 to March 2016). These predictions are updated in the subsequent survey. Therefore, even though the survey elicits exchange rate predictions semi-annually, sample firms update their predictions every quarter. If we assume that the sample firms' answers are most reliable for the first three post-survey months, we can construct quarterly data using the results obtained from each survey as predictions for the next three months. Moreover, the predicted exchange rates that sample firms provided in March 2015 can be used to construct monthly series of predicted exchange rates for April, May, and June 2015 under the non-trivial assumption that once the predictions were made, firms would not change them for three months. The BOJ reports Tankan data by firm size and by industry. All firms are categorized by size in terms of capital stock: large, medium, and small. In this paper, we do not use the firm size information but use the industry breakdown data to construct monthly series of predicted exchange rates.[30]

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[30] We use the predicted exchange rate for all firms in each industry. Most industry categories in *Tankan* data correspond well with the categories of the BOJ export price data except for Metal and Other products which does not appear in the *Tankan* data. Thus, instead we have to defer to its sub-sectors: Iron and Steel, Nonferrous Metal and Processed Metal. We calculate the prediction exchange rate for the Metal industry using sub-sector data weighted by the export price.

We can obtain the series of prediction errors by simply subtracting the (log) actual bilateral exchange rate of the yen vis-à-vis the US dollar from the (log) corresponding predicted exchange rate. Normally, the error fluctuates around zero, and if the error is positive, it suggests yen depreciation as the yen depreciates toward what firms predicted. We choose to utilize this prediction error to obtain thresholds. Since we use the nominal effective exchange rate (NEER) as an independent variable, it could be advisable to use the prediction error for NEER and not for the bilateral exchange rate of the yen vis-à-vis the US dollar. However, we do not use the prediction error for NEER for two reasons. First and foremost, since it is an index number, the level of NEER is conditional on the choice of the base year. Hence, it is unclear whether the prediction error computed from NEER is informative. Second, we do not use the prediction error directly to estimate the NARDL model but only to distinguish between yen appreciation and depreciation periods, which provides us with a reasonable distinction that will be discussed below.

The superiority of our method can be visualized in Figure 3.5. It is a common understanding that Japanese firms experienced an unprecedented yen appreciation period from the subprime loan crisis in 2007 to the end of 2012. A yen depreciation period followed; the yen started to depreciate rapidly and substantially from the end of 2012 concomitant with the onset of Abenomics. However, the conventional zero threshold approach in (3.4) fails to distinguish clearly between yen appreciation and depreciation periods, as plotted in Figure 3.5(a). To gauge robustness, we also use not only the yen vis-à-vis the US dollar but also the NEER obtained from the Bank for International Settlements (BIS). The results presented in Figures 3.5(b) and 3.5(c) are similar to 3.3(a). In contrast, our new method in (3.5) distinguishes correctly between yen appreciation and depreciation periods, as shown in Figure

3.5(d). Thus, the appreciation and depreciation periods are distinguished more precisely by our new method, especially when focusing on the 2007–2012 appreciation period and the 2013–2015 depreciation period, which is superior to other threshold specifications in the literature.

3.4.2 Other data

We use the monthly series of variables for a sample period from April 1997 to December 2015.

Domestic input prices and yen-based export prices are obtained from the BOJ website, with base years of 2005 and 2010 at an industry-specific level for aggregated and seven specific industries: (i) all manufacturing; (ii) textiles; (iii) chemicals and related products (henceforth, chemical); (iv) metal and related products (henceforth, metal); (v) general purpose, production, and business-oriented machinery (henceforth, general machinery); (vi) electric and electronic products (henceforth, electric machinery); (vii) transport equipment; and (viii) other manufacturing. Although the domestic producer price index is generally used in previous empirical studies on ERPT, the BOJ domestic input price index is constructed using input coefficients calculated from Japanese input-output data; hence, it better reflects the actual production costs of each industry.[31]

In contrast to previous studies, we use the contract currency-based NEER (henceforth, contract NEER) that Ceglowski (2010) first used to measure the degree of exporters' price responses to changes in the yen vis-à-vis invoice currencies. As shown in the study by Ito et

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[31] Input price index is constructed as a weighted average of the prices of intermediate input goods, (i.e., raw materials, including fuel and energy, intermediate parts, and components) and services to produce products in these industries. Thus, the BOJ input price index reflects the domestic production cost in each industry better than the producer price index.

al. (2012), Japan's exports are invoiced mainly in US dollars and yen.[32] Conventional NEERs provided by the BIS are based on a trade weight, which cannot reflect a large role of the third currency (US dollar) in invoicing of Japanese exports. As shown in Appendix A, the contract NEER can be calculated using both the yen-based and contract currency-based export prices. The contract NEER has two notable advantages. First, we can calculate an industry-specific NEER on a contract currency basis because the BOJ publishes industry- and commodity-specific data on export price indices on both a yen basis and contract currency basis. Second, and more importantly, the contract NEER reflects the degree of exchange rate risk that exporters face, which is likely to be different across industries.

The world industrial production index is calculated by taking an average of the industrial production index (2010 base year) of 20 major trading partner countries for Japan.[33] The 20 partner countries are selected based on the criterion that the destination country's share is equal to one percent or larger in Japan's total exports. All series are standardized to 100 as of the 2010 base year. Seasonality is adjusted using the Census X12 method.

The monthly bilateral nominal exchange rate of the yen vis-à-vis the US dollar published by the International Monetary Fund is used to calculate the exchange rate prediction error. The prediction error is the (log) actual exchange rate subtracted from the (log) predicted exchange rate. Therefore, when using a mean of prediction error as a threshold, an error larger than the

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[32] According to data on Japan's trade invoice currency published by the Ministry of Finance, in the second-half of 2014, 53% of Japanese world exports were invoiced in US dollars compared to 35.7% in yen.

[33] The 20 countries and areas are France, Germany, the Netherlands, Australia, Canada, Hong Kong, Korea, Singapore, the United States, the United Kingdom, mainland China, India, Indonesia, Malaysia, the Philippines, Thailand, Vietnam, Russia, Mexico, and Taiwan.

mean error (i.e., e_t^+) is considered the depreciation regime and the appreciation regime (i.e.,

e_t^-) otherwise.

We explore time-series properties of variables using the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests. Although not reported in this paper, the results of both ADF and PP unit-root tests suggest that all variables are non-stationary in levels but stationary in first differences. To analyze whether the degree of ERPT/PTM has changed over time, we divide the entire sample period into two sub-periods: one from April 1997 to December 2006 and the other from January 2007 to December 2015. The breakpoint of 2007 is chosen by considering empirical yen fluctuations: from the subprime loan crisis in 2007 to 2015, the yen has substantially fluctuated up and down. We focus particularly on this period to investigate whether Japanese exporters changed their pricing behavior in response to large exchange rate fluctuations.

3.5. Empirical results

We first briefly explain the sign and the meaning of coefficients in Equation (3.6). As ρ_1 represents the adjustment speed from long-run disequilibrium, it should have a negative and significant sign. The long-run exchange rate coefficients in the depreciation and appreciation periods are $\beta_1^+ = -\dfrac{\rho_2}{\rho_1}$ and $\beta_1^- = -\dfrac{\rho_3}{\rho_1}$, respectively. Those long-run coefficients represent the level of PTM, which can be interpreted as a percentage change in the yen-based export price corresponding to a one-percent change in the exchange rate in the long run. Since the contract NEER increases when the yen depreciates, the sign of either β_1^+ or β_1^- should be

positive; hence, ρ_2 and ρ_3 should be positive. ρ_2 and ρ_3 need to be statistically significant, but they are not sufficient to conclude that the exchange range responses differ by regime. To reveal possible nonlinearities, we need to test for not only a long-run relationship to confirm the long-run coefficients are meaningful but also the hypothesis of $\beta_1^+ = \beta_1^-$. As for the domestic input price, an increase in the input price should lead to an increase in the export price, which indicates that ρ_4 should be significantly positive. Since an increase in world demand can result in either an increase in price or a fall in price, the sign of ρ_5 is ambiguous. The same sign is expected for all variables in the short run. We hereafter focus on the relationship between the exchange rate and export price.

3.5.1. Short-run ERPT

Tables 3.1–3.3 show the results of PTM levels in both the short and long runs in all industries for the entire sample (1997–2015), first sub-sample (1997–2006), and second sub-sample (2007–2015), respectively.[34] ERPT of Japanese exports in the short run is found to be almost zero among all seven industries and all manufacturing in all sample periods. This finding is consistent with the literature on Japanese export ERPT (Marston, 1990; Knetter, 1994; and Parson and Sato, 2008), in which PTM strategies are strongly confirmed. However, even though the results are highly significant, we cannot find any evidence of asymmetric ERPT in the short run.

Gopinath et al. (2010) discussed the relationship between ERPT and currency choice, implying that the invoice currency choice is related more to the short-run ERPT than to the

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[34] Detailed results of NARDL model estimations in each sample with the mean threshold approach are shown in Appendix Tables A.3.2, A.3.3, and A.3.4.

long-run alternative and that the local currency pricing or invoicing results in the low ERPT in the short run. This is consistent with the empirical pattern of invoice currency choice in Japanese exports presented in Appendix Table A.3.1, in which foreign currencies account for a larger share in most industries. Given such a large share, complete PTM is typically observed in the short run.

For comparative purposes, the standard ARDL model is also estimated for the entire sample and sub-samples.[35] Appendix Table A.3.5 presents the summary results of PTM coefficient estimates for each sample period. The short-run coefficients in the NARDL model present the same pattern as in the ARDL model, suggesting the robustness of symmetric and full PTM in the short run for Japanese exports.

3.5.2. Long-run ERPT

Let us first look at the results for the entire sample (1997–2015) in Table 3.1. Although the t_{BDM} and F_{PSS} bounds tests for all manufacturing and textiles show strong evidence for cointegration, we cannot find a long-run relationship for other industries.[36] Among them, only all manufacturing shows evidence of asymmetric PTM in the long run, with a higher PTM level in the appreciation period. Table 3.2 presents the results for the first sub-sample (1997–2006), where a cointegrating relationship is found only in other manufacturing in terms of both t_{BDM} and F_{PSS} bounds tests. Long-run symmetry of PTM is also rejected strongly in other

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[35] Detailed results from ARDL modeling are available upon request.

[36] The number of observations for the entire sample, first sub-sample, and second sub-sample is 225, 117, and 108, respectively. Narayan (2005) posits a small-sample bound F-test (up to 80 observations). However, conclusions do not change even when we use Narayan's critical value (for n=80).

manufacturing, implying that this industry employs different price-setting strategies with higher ERPT in the yen depreciation period.

Our main findings emanate from the second sub-sample results (2007–2015) in Table 3.3. First, we found a significant cointegrating relationship in not only all manufacturing but also four of seven industries: textiles, metal, general machinery, and transport equipment. In addition, although chemical does not show a significant cointegrating relationship when assuming $k = 3$, a significant cointegrating relationship for chemical does exists if assuming $k = 4$. Second, test for nonlinearities of PTM in all manufacturing, metal, general machinery, transport equipment, and chemical if we accept its significance at $k = 4$, reject the null hypothesis of symmetric PTM in the long run. Thus, we can conclude that Japanese exporters in the above four industries and all manufacturing conduct different pricing strategies between yen appreciation and depreciation periods. It must also be noted that we found symmetric PTM behavior in the short run for the second sub-sample from 2007 to 2015 in all industries except other manufacturing.

Let us next focus more on the asymmetric PTM in the long run. First, in the yen appreciation period, all manufacturing and five industries (textiles, chemical, metal, general machinery, and transport equipment) exhibit an incomplete long-run PTM, the coefficient of which ranges from 0.57 to 0.86. This finding suggests a low degree of ERPT, i.e., just 14–43% of exchange rate changes are passed through to importers. This pricing strategy, i.e., incomplete but relatively strong PTM in the long run, is common in the above five industries. Second, in the yen depreciation period, however, exporters pricing strategies become divergent across the above five industries. The long-run PTM coefficients for chemical and metal are 0.29 and 0.14, respectively, implying that these industries tend to raise the degree of ERPT in

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the yen depreciation period. In contrast, the long-run PTM coefficients for general machinery and transport equipment are 1.14 and 0.92, respectively, which suggests that exporters in these industries choose complete PTM to fully exploit exchange gains when the yen depreciates.

3.5.3. Interpretation

The above results can be interpreted as follows. First, Japanese firms are likely to change their long-run pricing strategies in response to rapid and substantial changes in exchange rates, whereas almost complete PTM is generally observed in the short run, reflecting the choice of invoice currency. As shown in Figures 3.1 and 3.3, the extent of exchange rate changes is much larger in the second sub-sample period than in the first sub-sample period. Figure 3.5 also reveals that our threshold approach with prediction errors can correctly distinguish between the yen appreciation and depreciation periods.

Second, in the latter sub-sample from 2007 to 2015, the long-run PTM coefficient becomes smaller or statistically insignificant in chemical and metal during the yen depreciation period, suggesting greater ERPT by lowering the export price in the destination currency to gain export price competitiveness. In contrast, the long-run PTM coefficient converges toward unity in general machinery and transport equipment, which implies that almost complete PTM is conducted by stabilizing the local currency export price to reap large exchange gains.

Third, the difference between the above two industry groups can be explained in terms of market power as discussed in Section 3.2. Export products of general machinery and transport equipment are well known to be differentiated and to have strong export competitiveness, whereas the automobile markets are highly competitive, especially in the

United States.[37] Their strong competitiveness enables them to fully exploit the exchange gains from yen depreciation while passing through some exchange losses to importers during the period of yen appreciation.[38] In contrast, less-competitive firms in chemical and metal tend to raise the degree of ERPT during the yen depreciation period by lowering the export price in the local market to stimulate local demand.

Fourth, previous studies that employ the conventional ARDL model typically assume symmetric PTM, but we have demonstrated that the symmetric PTM assumption is too restrictive. When using the conventional ARDL model, we could find a long-run cointegrating relationship only for textiles and transport equipment in the second sub-sample period (Appendix Table A.3.5). In addition, when using the conventional ARDL model, we cannot confirm asymmetric PTM in the long run, especially during the second sub-sample from 2007 to 2015 (Appendix Table A.3.5 and Table A.3.3).

Our empirical findings provide us with insight into why the Japanese trade balance has not improved even though the yen started to depreciate substantially from the end of 2012. General machinery and transport equipment account for 43% of all Japanese exports.[39] Given such a large export share and complete PTM behavior in these two industries when the yen depreciates, that depreciation is less likely to boost real Japanese exports.

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[37] Indicators of trade balance (METI, 2014) and unit labor cost (Ito and Shimizu, 2015) as well as a firm-level interview analysis (Ito *et al.*, 2012) support the strong competitiveness of these two industries compared with others.

[38] This finding is in the same vein as Berman *et al*. (2012) who find that high-performance firms react to a depreciation by increasing their markup significantly more than their export volume.

[39] BOJ price data provides information on Japanese export shares by industry as of 2010.

3.6. Conclusion

The aim of this paper is to test for possible nonlinearities in the PTM behavior of Japanese exports between yen appreciation and depreciation periods. We propose a new threshold approach for distinguishing between yen appreciation and depreciation periods using large-scale firm-level survey data on Japanese firms' exchange rate predictions published by the BOJ. Our new threshold method considers both the change and the level of exchange rates by calculating the difference between the actual exchange rate and firms' predicted exchange rates. Using the NARDL modeling approach, possible asymmetric PTM behavior is investigated in both the long- and short-run.

In the short run, we found complete and symmetric PTM in all industries for both the first and second sub-sample periods. This result is consistent with the previous studies that found strong PTM in Japanese exports, reflecting their tendency to choose foreign currency invoicing. In the long run, we revealed evidence of cointegrating relationships and asymmetric PTM in several industries, especially in the 2007–2015 period when the yen fluctuated substantially. At least four of seven industries and all manufacturing show evidence of long-run relationships, and most of them exhibit nonlinearities in long-run PTM coefficients. On one hand, these industries specifically seem to follow the same pricing strategy in the appreciation regime. That is, incomplete but relatively stronger PTM is conducted, and around 60–80% of exchange rate changes are taken by Japanese exporters. On the other hand, less-competitive industries, like chemical and metal, choose to increase the degree of ERPT when the yen depreciates, which implies that exporters in those industries tend to stabilize the local currency export price to stimulate importers' demand, even though they must squeeze their

profit margins. In contrast, relatively competitive industries, like general machinery and transport equipment, raise the level of PTM to almost 100% so they can fully exploit foreign exchange gains during the yen depreciation period.

Understanding Japanese exporters' PTM or ERPT behavior will be crucially important in considering the impact of exchange rate volatility on the Japanese economy. We revealed different pricing behaviors not only across industries but also between yen appreciation and depreciation periods. Given that at least two of the three main manufacturing industries in Japan, i.e., general machinery and transport equipment, do not pass through yen depreciation to their export prices, it may be unreasonable to expect a decline in export prices in response to currency depreciation. Although trade balance is not solely determined by such a price factor, our empirical results at least partly answer the question as to the unresponsiveness of the Japanese trade balance to the yen depreciation witnessed since the end of 2012.

Appendix A: Calculation of Contract NEER

The contract NEER can be constructed using export price indices published by the BOJ. Specifically, the BOJ publishes two types of export price indices by industry/commodity: one in yen and the other on a contract (invoice) currency basis.[40] For simplicity, suppose only three currencies are used in Japanese exports: the yen, US dollar, and euro. Export price indices on a contract currency basis (P_{con}^{EX}) and on a yen basis (P_{yen}^{EX}) can be expressed as follows:[41]

$$P_{con}^{EX} = \left(P_{yen}\right)^{\alpha} \left(P_{usd}\right)^{\beta} \left(P_{eur}\right)^{\gamma} \qquad (A.1)$$

$$P_{yen}^{EX} = \left(P_{yen}\right)^{\alpha} \left(E_{yen/usd} P_{usd}\right)^{\beta} \left(E_{yen/eur} P_{eur}\right)^{\gamma} \qquad (A.2)$$

The BOJ collects information on the choice of contract currency when surveying Japanese exporters at the port level. Using a nominal exchange rate for the yen versus the contract currency, the BOJ constructs export price indices on a contract currency basis and converts the indices into yen-based export price indices. Dividing Equation (A.2) by Equation (A.1), we obtain the following formula of the contract NEER:

$$NEER_{yen}^{Contract} = \frac{P_{yen}^{EX}}{P_{con}^{EX}} = \left(E_{yen/usd}\right)^{\beta} \left(E_{yen/eur}\right)^{\gamma}. \qquad (A.3)$$

The above discussion, based on the three contract (invoice) currencies, can be generalized to a case of four or more contract currencies. As shown in Appendix Table A.3.1, as of December 2014, 96.8% of Japan's total exports were invoiced in yen, US dollars, and the euro,

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[40] The BOJ collects export price data when cargo is loaded in Japan at the customs clearance stage, and when free-on-board (FOB) prices at a Japanese port of exports are surveyed. Provided they are traded in foreign currencies, sample prices are recorded in the original contract currency and finally compiled as the "export price index on the contract currency basis." To compile the "export price index on the yen basis," sample prices in the contract currency are converted into yen equivalents by using the monthly average exchange rate of the yen vis-à-vis the contract currency. See the BOJ website (https://www.boj.or.jp/en/statistics/pi/cgpi_2010/index.htm/) for further details.

[41] By definition, the sum of the weights in equations (A.1) and (A.2) is assumed to be unity.

whereas only 3.2% were invoiced in other currencies. Such a small share of invoices in other

currencies is also captured by the contract NEER used in the following analysis.

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Figure 3.1: Yen-based and contract currency-based Japanese export prices (2005 = 100)
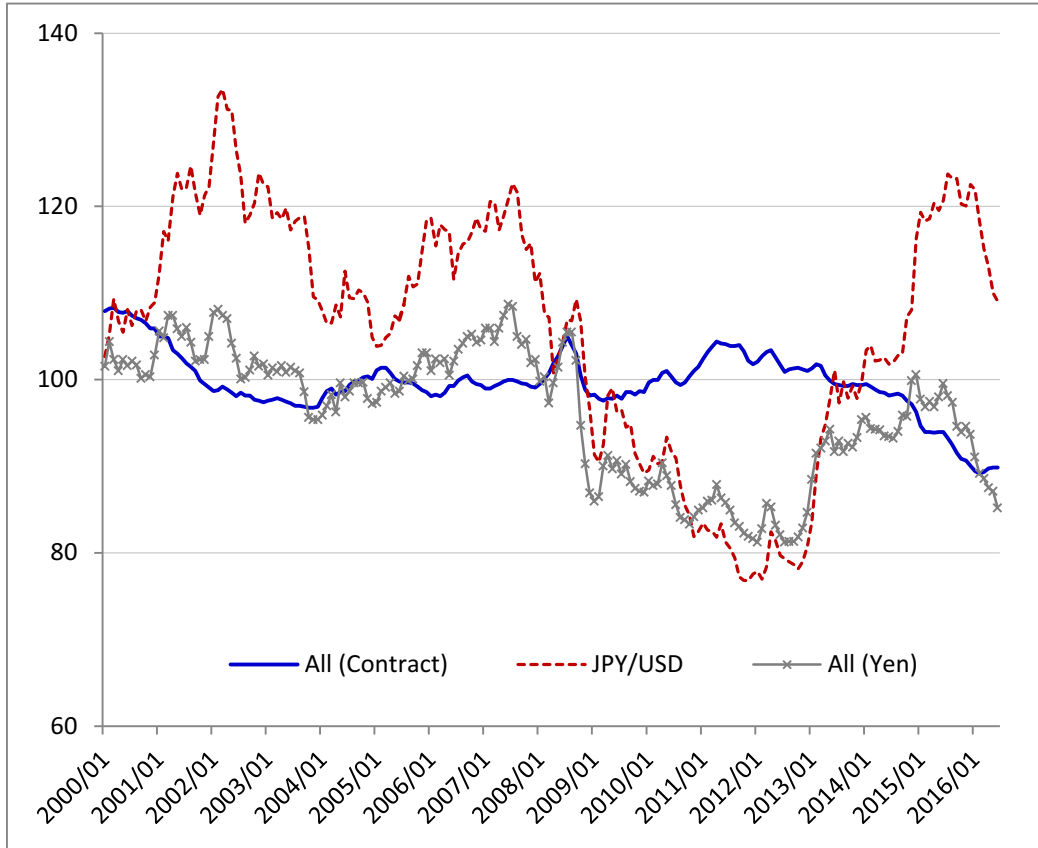
Note: Sample period ranges from January 2000 to June 2016. All (Contract) and All (Yen) denote the contract currency-based and yen-based export price indices (2005 = 100) of all manufacturing, respectively. JPY/USD is the bilateral nominal exchange rate of the yen vis-à-vis the US dollar.

Figure 3.2: Yen-based and contract currency-based Japanese export price (2005 = 100)
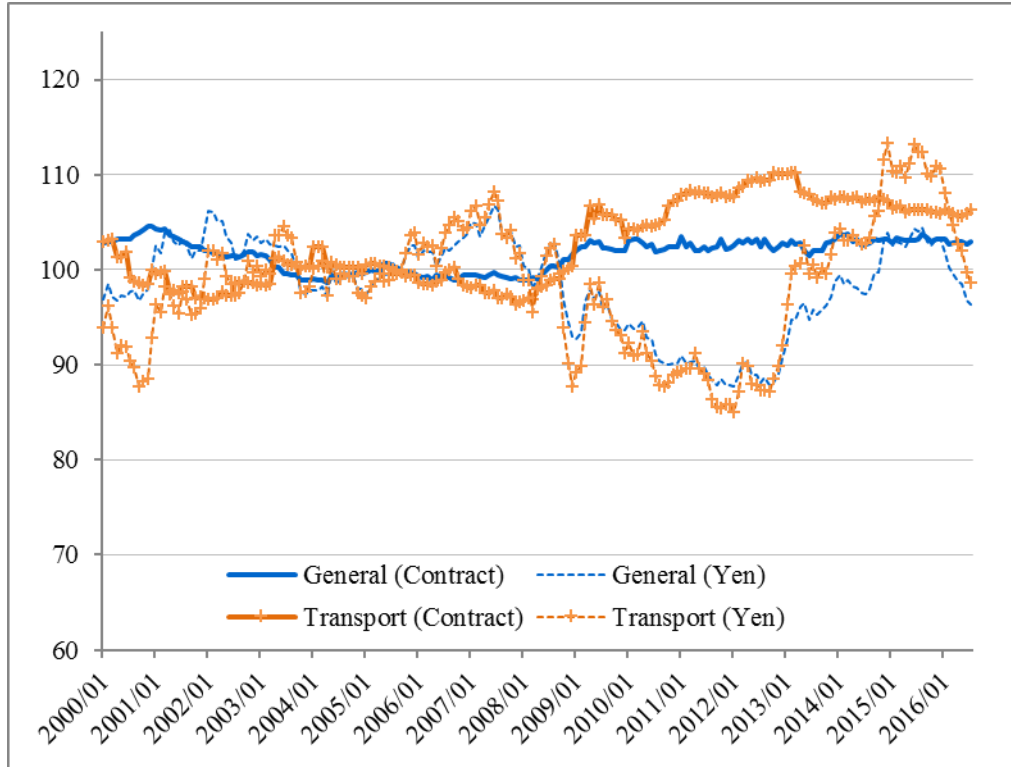
Note: Sample period ranges from January 2000 to June 2016. General (contract), General (yen), Transport (Contract), and Transport (yen) denote the contract currency-based and yen-based export price indices (2005 = 100) of general machinery and transportation equipment industries.

Figure 3.3: Actual and predicted exchange rates of the yen vis-à-vis the US dollar
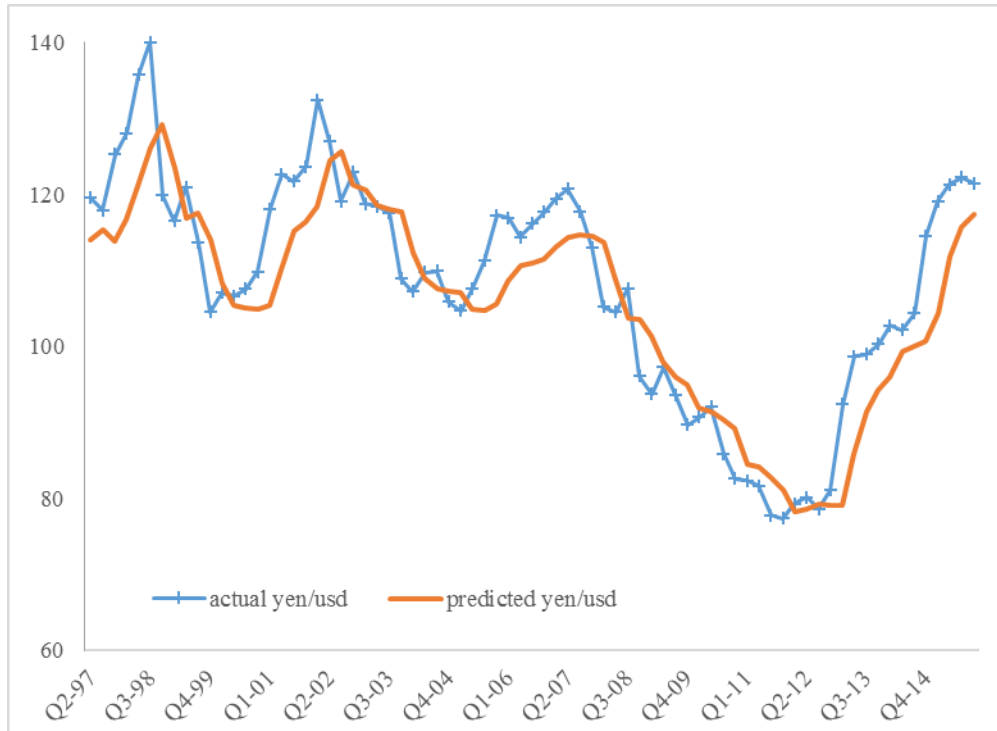
Note: Sample period ranges from the second quarter of 1997 to the fourth quarter of 2015. The solid orange line shows the predicted exchange rate of the yen vis-à-vis the US dollar. The solid blue line with + markers shows the actual nominal exchange rate of the yen vis-à-vis the US dollar.

Figure 3.4: Illustration of BOJ predicted exchange rates for the 2015 fiscal year
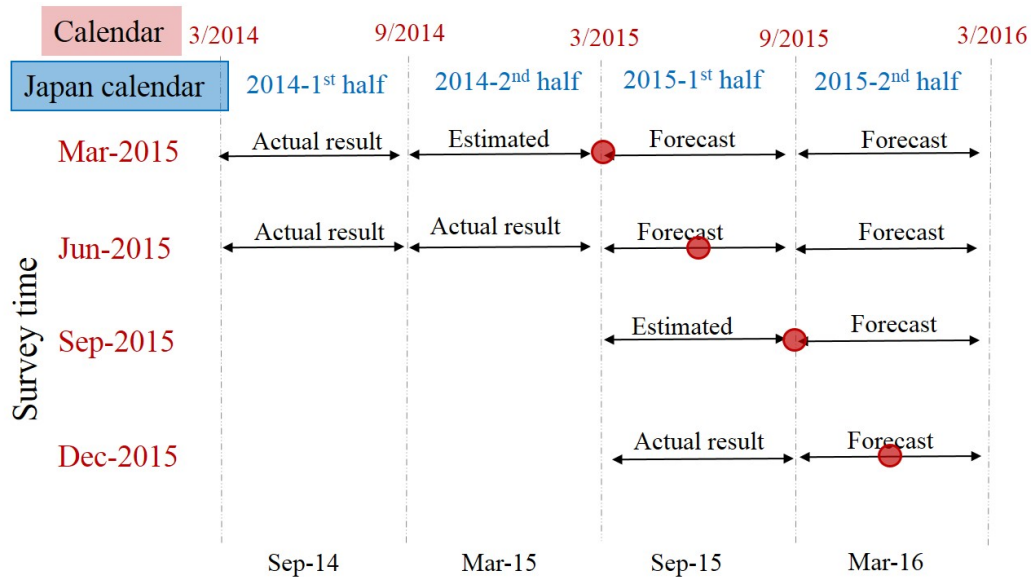
Note: The BOJ Tankan survey is conducted four times a year: in March, June, September, and December. Red circles denote the survey periods. "Japan calendar" indicates the Japanese fiscal year. "Actual result," "Estimated," and "Forecast" denote the data of the realized expected exchange rate, the estimated expected exchange rate based on the recent realized exchange rates, and the predicted exchange rate, respectively. When the survey is conducted in March 2015, for example, "Estimated" predicted exchange rates for the second half of the 2014 fiscal year are estimated based on information from July 2014 to March 2015. Similar estimation is conducted in the September survey. When the survey is conducted in June 2015, the "Forecast" predicted exchange rates for the first half of the 2015 fiscal year ranging from April 2015 to September 2015 are reported. In this case, sample firms update their "Forecast" predicted exchange rates using the available information for April – June 2015. Similar forecasting is conducted in the December survey.

Figure 3.5: Changes in contract NEERs in the yen appreciation and depreciation periods with different thresholds

(a) Contract NEER with 0 threshold
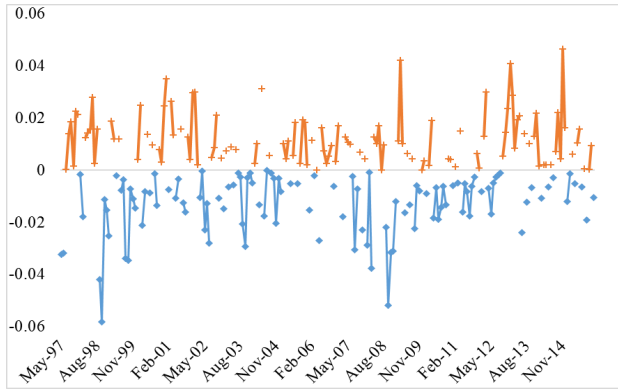
(b) JPY/USD with 0 threshold
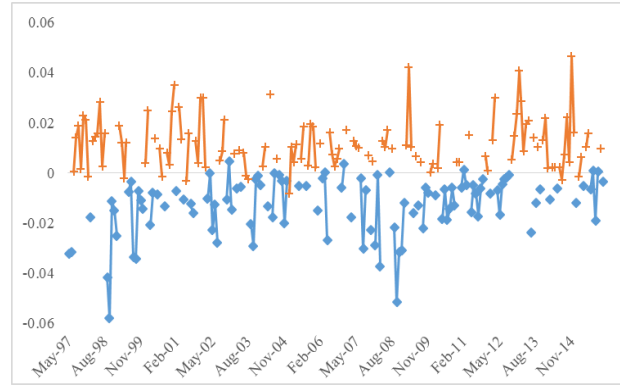
(c) NEER with 0 threshold
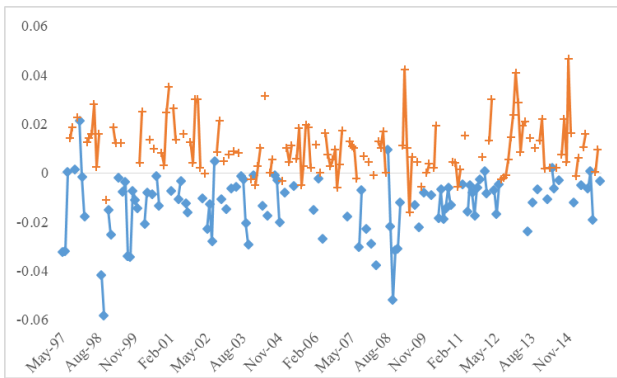
(d) Prediction error with mean threshold
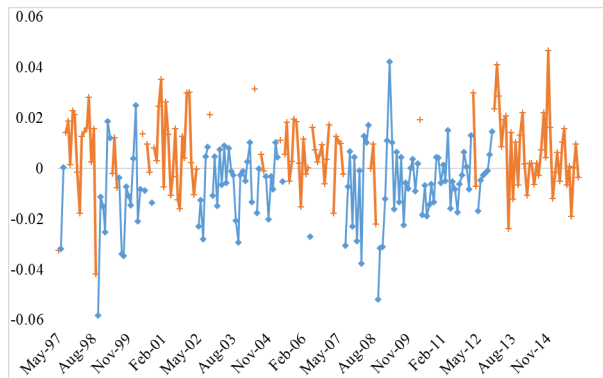
Note: The solid orange line with + markers and the solid blue line with rhombus markers denote depreciation and appreciation periods of the yen, respectively. (a) Contract NEER is applied. (b) The bilateral nominal exchange rate of the yen vis-à-vis the US dollar is applied. (c) NEER published by BIS is applied. (d) Contract NEER is applied.

Table 3.1: NARDL estimation results using the mean threshold approach for the whole sample

Industry	Whole Sample (1997-2015)							
	Cointegration Test		Short-run PTM			Long-run PTM		
	t_{BDM}	F_{PPS}	SR$^+$ Coefficient	SR$^-$ Coefficient	SR Symmetry	LR$^+$ Coefficient	LR$^-$ Coefficient	LR Symmetry
All	-4.620 ***	6.683 ***	0.897 ***	0.946 ***	0.590	0.497 ***	0.900 ***	0.000 ***
Textile	-5.116 ***	7.726 ***	0.991 ***	0.879 ***	0.658	0.534 ***	0.456 ***	0.171
Chemical	-2.309	3.144	0.824 ***	0.829 ***	0.303	0.504 **	0.135	0.198
Metal	-3.057	2.599	0.755 ***	0.743 ***	0.248	0.465 **	0.238	0.069 ***
Machinery	-2.853	4.039 *	1.052 ***	0.996 ***	0.948	0.725 **	0.825 **	0.282
Electric	-1.631	2.671	0.964 ***	0.894 ***	0.004 ***	2.175	-1.611	0.211
Transport	-2.655	3.868 *	0.982 ***	1.033 ***	0.344	0.828 **	0.617 *	0.139
Others	-1.866	3.193	0.915 ***	1.051 ***	0.008 ***	-0.448	0.127	0.053 ***

(1997–2015)

Note: (a) */**/*** denote significance at 10%, 5%, and 1%, respectively. For cointegration testing, the significance is based on both t_{BDM} and F_{PPS} bounds tests for $k = 3$. (b) The LR$^+$ and LR$^-$ coefficients represent the PTM behavior in the exchange rate depreciation and appreciation periods, respectively. (c) *p*-values are reported for symmetry tests for both long-run (LR) and short-run (SR) coefficients.

Table 3.2: NARDL estimation results using the mean threshold approach for the first sub-sample (1997–2006)

| | First Sub-Sample (1997-2006) | | | | | | | |
| | Cointegration Test | | Short-run PTM | | | Long-run PTM | | |
Industry	t_{BDM}	F_{PPS}	SR$^+$ Coefficient	SR$^-$ Coefficient	SR Symmetry	LR$^+$ Coefficient	LR$^-$ Coefficient	LR Symmetry
All	-2.772	2.129	0.886 ***	0.926 ***	0.579	0.466 **	0.856 **	0.000 ***
Textile	-3.862 **	3.763	0.924 ***	0.808 ***	0.625	0.536 **	0.331 *	0.002 ***
Chemical	-2.294	2.355	0.734 ***	0.766 ***	0.330	0.010	-0.023	0.873
Metal	-3.024	3.149	0.838 ***	0.705 ***	0.138	0.358	-0.038	0.003 ***
Machinery	-1.769	4.518 **	0.986 ***	0.962 ***	0.712	0.222	0.146	0.810
Electric	-2.197	2.268	0.929 ***	0.858 ***	0.047 **	0.737	-0.605	0.234
Transport	-3.066	3.503	0.949 ***	1.015 ***	0.388	0.909 ***	0.852 **	0.789
Others	-5.203 ***	7.000 ***	0.924 ***	0.991 ***	0.646	0.597 ***	0.328 ***	0.000 ***

Note: (a) */**/*** denote significance at 10%, 5%, and 1%, respectively. For cointegration testing, the significance is based on both t_{BDM} and F_{PPS} bounds tests for $k = 3$. (b) The LR$^+$ and LR$^-$ coefficients represent the PTM behavior in the exchange rate depreciation and appreciation periods, respectively. (c) *p*-values are reported for symmetry tests for both long-run (LR) and short-run (SR) coefficients.

Table 3.3: NARDL estimation results using the mean threshold approach for the second sub-sample (2007–2015)

| | Second Sub-Sample (2007-2015) | | | | | | | |
| | Cointegration Test | | Short-run PTM | | | Long-run PTM | | |
Industry	t_{BDM}	F_{PPS}	SR$^+$ Coefficient	SR$^-$ Coefficient	SR Symmetry	LR$^+$ Coefficient	LR$^-$ Coefficient	LR Symmetry
All	-3.917 **	6.472 ***	0.888 ***	0.936 ***	0.329	0.584 ***	0.858 ***	0.000 ***
Textile	-4.107 **	6.139 ***	1.063 ***	1.005 ***	0.824	0.412 **	0.574 ***	0.166
Chemical	-3.059	3.591	0.806 ***	0.883 ***	0.688	0.291 *	0.670 **	0.058 *
Metal	-4.667 ***	6.684 ***	0.635 ***	0.747 ***	0.604	0.142	0.635 ***	0.001 ***
Machinery	-4.184 **	5.254 **	1.144 ***	0.970 ***	0.579	1.137 ***	0.726 ***	0.000 ***
Electric	-1.619	1.305	0.985 ***	1.000 ***	0.105	0.875	1.584	0.199
Transport	-5.627 ***	11.643 ***	1.030 ***	1.002 ***	0.840	0.923 ***	0.601 ***	0.000 ***
Others	0.424	3.175	0.926 ***	1.174 ***	0.011 ***	3.720	-0.865	0.677

Note: (a) */**/*** denote significance at 10%, 5%, and 1%, respectively. For cointegration testing, the significance is based on both t_{BDM} and F_{PPS} bounds tests for $k = 3$. (b) The LR$^+$ and LR$^-$ coefficients represent the PTM behavior in the exchange rate depreciation and appreciation periods, respectively. (c) *p*-values are reported for symmetry tests for both long-run (LR) and short-run (SR) coefficients.

Appendix Table A.3.1. Share of invoice currency in Japanese export and import indices as of December 2014 (%)

Industry :	Export Price Index				*Industry* :	Import Price Index			
	JPY	USD	EUR	Others		JPY	USD	EUR	Others
					Foodstuffs (75.8)	30.3	62.6	3.8	3.3
Textiles (12.5)	9.5	79.8	10.7	0.0	Textiles (53.5)	57.5	40.9	0.7	0.9
Chemicals (95.4)	28.9	69.4	1.7	0.0	Chemicals (83.3)	51.5	36.2	9.8	2.5
Metals (118.2)	21.5	77.8	0.6	0.0	Metals (117.1)	11.0	87.0	0.0	2.0
					Wood & Lumber (16.5)	4.1	70.3	16.1	9.4
					Petroleum (305.4)	8.7	91.3	0.0	0.0
General Machinery (192.0)	61.9	26.0	9.0	2.9	General Machinery (53.9)	40.1	54.4	2.7	2.7
Electric Machinery (232.9)	37.3	53.5	8.3	1.1	Electric Machinery (184.3)	44.9	54.0	0.2	0.9
Transport Equipment (240.6)	29.8	50.3	10.3	9.7	Transport Equipment (34.1)	42.1	42.8	15.1	0.0
Other Products (108.4)	33.0	62.3	3.1	1.5	Other Products (76.1)	21.9	71.9	3.2	3.0
All Industries (1,000.0)	36.7	53.1	6.9	3.2	All Industries (1,000.0)	27.2	69.0	2.4	1.5

Note: A round number is presented as a share of invoice currency. Figures in parentheses under the name of each industry (commodity group) denote the weight of the corresponding industry. The weight of all industries is 1,000.0.

Source: Bank of Japan, Export and Import Price Indices (2010 base).

Appendix Table A.3.2: NARDL estimation results for the entire sample (1997–2015)

	All manufacturing	Textile	Chemical	Metal	Machinery	Electric	Transport	Other
Constant	0.384***	0.327***	0.209**	0.098	0.182*	-0.146***	0.140	0.021
ex_{t-1}	-0.131***	-0.198***	-0.063**	-0.071***	-0.065**	-0.011	-0.065***	-0.025*
$neer^+_{t-1}$	0.065***	0.106***	0.032*	0.033**	0.047**	0.024**	0.054**	-0.012
$neer^-_{t-1}$	0.118***	0.091***	0.008	0.017	0.054**	-0.017	0.040*	0.002
dp_{t-1}	0.037***	0.054**	0.041	0.077***	0.026***	0.067***	0.046**	0.029*
ipi_{t-1}	0.022**	0.080***	-0.025	-0.029**	0.002	-0.028*	-0.010	-0.006
Δex_{t-1}	0.164***	-0.098	0.492***	0.221***	-0.185***	0.005	-0.024	0.475***
Δex_{t-2}			-0.368***					-0.080***
$\Delta neer^+_t$	0.897***	0.991***	0.824***	0.755***	1.052***	0.964***	0.982***	0.915***
$\Delta neer^+_{t-1}$	-0.117*	0.119	-0.546***	-0.233***	0.015**	0.073		-0.509***
$\Delta neer^+_{t-2}$			0.469***					
$\Delta neer^-_t$	0.946***	0.879***	0.829***	0.743***	0.996***	0.894***	1.033***	1.051***
$\Delta neer^-_{t-1}$	-0.191***	0.173*	-0.522***	-0.343***	0.203***	-0.033		-0.416***
$\Delta neer^-_{t-2}$			0.256***					
Δdp_t	0.325***	0.335**	0.682***	0.829***	-0.278***	0.404***	0.093	0.387***
Δdp_{t-1}					0.215**			
Δipi_t	0.010	-0.010	-0.002	0.043	0.011	-0.068***	0.037	-0.045
LR^+ coefficent	0.497	0.534	0.504	0.465	0.725	2.175	0.828	-0.448
LR^- coefficent	0.900	0.456	0.135	0.238	0.825	-1.611	0.617	0.127
$Adj.R^2$	0.962	0.743	0.832	0.881	0.929	0.926	0.894	0.894
t_{BDM}	-4.620***	-5.116***	-2.309	-3.057	-2.853	-1.631	-2.655	-1.866
F_{PSS}	6.683***	7.726***	3.144	2.599	4.039*	2.671	3.868*	3.193
SR symmetry	0.590	0.658	0.303	0.248	0.948	0.004***	0.344	0.008***
LR symmetry	0.000***	0.171	0.198	0.069*	0.282	0.211	0.139	0.053*

Note: (a) */**/*** denote significance at 10%, 5%, and 1%, respectively. (b) The LR^+ and LR^- coefficients represent the long-run PTM coefficients in the exchange rate depreciation and appreciation periods, respectively. (c) t_{BDM} and F_{PPS} are the bounds t- and F-statistics, respectively, for long-run cointegrating relationships, where critical values for $k = 3$ are invoked. (d) p-values are reported for the SR symmetry tests for the hypothesis that additive short-run PTM coefficients are different between yen depreciation and appreciation periods. (e) p-values are reported for the LR symmetry tests for the hypothesis that long-run PTM coefficients are different between yen depreciation and appreciation periods.

Appendix Table A.3.3: NARDL estimation results for the first sub-sample (1997–2006)

	All manufacturing	Textile	Chemical	Metal	Machinery	Electric	Transport	Other
Constant	0.376***	0.281*	0.332*	0.332***	0.107	-0.068	0.846*	0.591***
ex_{t-1}	-0.119***	-0.208***	-0.107**	-0.082***	-0.054*	-0.034**	-0.1665***	-0.229***
$neer_{t-1}^{+}$	0.056**	0.111**	0.001	0.029	0.012	0.025	0.1514***	0.137***
$neer_{t-1}^{-}$	0.102**	0.069*	-0.002	-0.003	0.008	-0.021	0.142**	0.230***
dp_{t-1}	0.049***	0.099***	0.153**	0.107***	0.039	0.108**	0.031	0.075***
ipi_{t-1}	-0.003	0.052	-0.119*	-0.100***	-0.007	-0.063*	-0.044	0.040**
Δex_{t-1}	0.170*	0.020	0.391***	0.329***	-0.146	0.055	-0.040	0.111
Δex_{t-2}			-0.371***					0.033*
$\Delta neer_{t}^{+}$	0.886***	0.924***	0.734***	0.838***	0.986***	0.929***	0.949***	0.924***
$\Delta neer_{t-1}^{+}$	-0.133	-0.028	-0.468***	-0.295***	0.145	0.020		-0.074
$\Delta neer_{t-2}^{+}$			0.554***					
$\Delta neer_{t}^{-}$	0.926***	0.808***	0.766***	0.705***	0.962***	0.858***	1.015***	0.991***
$\Delta neer_{t-1}^{-}$	-0.209**	0.003	-0.440***	-0.346***	0.192*	-0.091		-0.115
$\Delta neer_{t-2}^{-}$			0.250**					
Δdp_{t}	0.349***	0.118	0.861***	0.885***	0.023	0.405***	1.034***	0.183*
Δdp_{t-1}				-0.329***				-0.065
Δipi_{t}	0.012	-0.070	-0.019	0.025	0.007	-0.080*	0.069	-0.042
Δipi_{t-1}								-0.044*
LR^{+} coefficent	0.466	0.536	0.010	0.358	0.222	0.737	0.909	0.597
LR^{-} coefficent	0.856	0.331	-0.023	-0.038	0.146	-0.605	0.852	0.328
$Adj.R^{2}$	0.961	0.754	0.781	0.905	0.961	0.925	0.905	0.973
t_{BDM}	-2.772	-3.862**	-2.294	-3.024	-1.769	-2.197	-3.066	-5.203***
F_{PSS}	2.129	3.763	2.355	3.149	4.518**	2.268	3.503	7.000***
SR symmetry	0.579	0.625	0.330	0.138	0.712	0.047**	0.388	0.646
LR symmetry	0.000***	0.002***	0.873	0.003***	0.810	0.234	0.789	0.000***

Note: (a) */**/*** denote significance at 10%, 5%, and 1%, respectively. (b) The LR^{+} and LR^{-} coefficients represent the long-run PTM coefficients in the exchange rate depreciation and appreciation periods, respectively. (c) t_{BDM} and F_{PPS} are the bounds *t*- and *F*-statistics, respectively, for long-run cointegrating relationships, where critical values for *k = 3* are invoked. (d) *p*-values are reported for the SR symmetry tests for the hypothesis that additive short-run PTM coefficients are different between yen depreciation and appreciation periods. (e) *p*-values are reported for the LR symmetry tests for the hypothesis that long-run PTM coefficients are different between yen depreciation and appreciation periods.

Appendix Table A.3.4: NARDL estimation results for the second sub-sample (2007 – 2015)

	All manufacturing	Textile	Chemical	Metal	Machinery	Electric	Transport	Other
Constant	0.614***	-0.017	0.013	-0.287**	1.336***	0.379*	0.839*	0.135
ex_{t-1}	-0.200***	-0.246***	-0.192***	-0.225***	-0.301***	-0.056	-0.261***	0.013
$neer_{t-1}^{+}$	0.111***	0.101**	0.056*	0.032	0.342***	0.049*	0.241***	-0.049**
$neer_{t-1}^{-}$	0.163***	0.141***	0.129**	0.143***	0.218***	0.089	0.157***	0.011
dp_{t-1}	0.058***	0.118	0.081*	0.185***	0.053	0.002	0.095	-0.070
ipi_{t-1}	0.012	0.146**	0.125*	0.125***	-0.044***	-0.023	-0.016	0.034
Δex_{t-1}	0.051**	-0.213**	0.477***	0.133**	-0.147	-0.141	-0.274***	0.484***
Δex_{t-2}			-0.321***	0.110***				-0.196***
$\Delta neer_{t}^{+}$	0.888***	1.063***	0.806***	0.635***	1.144***	0.985***	1.030***	0.926***
$\Delta neer_{t-1}^{+}$		0.338**	-0.467***	-0.056	0.082	0.278**	0.353***	-0.537***
$\Delta neer_{t-2}^{+}$			0.381***					
$\Delta neer_{t}^{-}$	0.936***	1.005***	0.883***	0.747***	0.970***	1.000***	1.002***	1.174***
$\Delta neer_{t-1}^{-}$		0.351**	-0.486***	-0.250**	0.204**	0.133	0.397***	-0.410***
$\Delta neer_{t-2}^{-}$			0.219					
Δdp_{t}	0.384***	0.172	0.595***	0.797***	-0.323**	0.238*	-0.192	0.323
Δdp_{t-1}			0.141*		0.273**			-0.016
Δipi_{t}	-0.018	0.041	0.012	0.034	-0.003	-0.086***	0.019	-0.059
LR^{+} coefficent	0.584	0.412	0.291	0.142	1.137	0.875	0.923	3.720
LR^{-} coefficent	0.858	0.574	0.670	0.635	0.726	1.584	0.601	-0.865
$Adj.R^{2}$	0.967	0.773	0.889	0.909	0.923	0.944	0.932	0.882
t$_{BDM}$	-3.917**	-4.107**	-3.059	-4.667***	-4.184**	-1.619	-5.627***	0.424
F$_{PSS}$	6.472***	6.139***	3.591	6.684***	5.254**	1.305	11.643***	3.175
SR symmetry	0.329	0.824	0.688	0.604	0.579	0.105	0.840	0.011***
LR symmetry	0.000***	0.166	0.058*	0.001***	0.000***	0.199	0.000***	0.677

Note: (a) */**/*** denote significance at 10%, 5%, and 1%, respectively. (b) The LR^{+} and LR^{-} coefficients represent the long-run PTM coefficients in the exchange rate depreciation and appreciation periods, respectively. (c) t_{BDM} and F_{PPS} are the bounds *t*- and *F*-statistics, respectively, for long-run cointegrating relationships, where critical values for $k = 3$ are invoked. (d) *p*-values are reported for the SR symmetry tests for the hypothesis that additive short-run PTM coefficients are different between yen depreciation and appreciation periods. (e) *p*-values are reported for the LR symmetry tests for the hypothesis that long-run PTM coefficients are different between yen depreciation and appreciation periods.

Appendix Table A.3.5: PTM coefficient estimates in the ARDL model

Industry	Whole Sample (1997-2015)				First Sub-sample (1997-2006)				Second Sub-sample (2007-2015)			
	SR Coefficient	LR Coefficient	Contegration Test		SR Coefficient	LR Coefficient	Cointegration Test		SR Coefficient	LR Coefficient	Cointegration Test	
			t_{BDM}	F_{PSS}			t_{BDM}	F_{PSS}			t_{BDM}	F_{PSS}
All	0.922 ***	0.326			0.913 ***	-0.002			0.911 ***	0.703 **		**
Textile	0.923 ***	0.473 ***	***	***	0.819 ***	0.320			1.014 ***	0.500 ***	**	***
Chemical	0.814 ***	0.307			0.727 ***	0.028	*		0.846 ***	0.480 **		*
Metal	0.746 ***	0.296			0.769 ***	0.078			0.701 ***	0.393 **		
Machinery	1.020 ***	0.744 **		**	0.970 ***	-0.034		**	1.070 ***	0.848 *		
Electric	0.937 ***	0.505			0.899 ***	-0.098			0.990 ***	1.163		
Transport	1.003 ***	0.682 **			0.984 ***	0.885* ***	*	*	1.035 ***	0.692 ***	*	***
Others	0.986 ***	-0.373			0.947 ***	-0.446			1.028 ***	-5.035		

Note: (a) SR and LR denote the short-run and long-run PTM coefficients, respectively. (b) */**/*** denote significance at 10%, 5%, and 1%, respectively. For cointegration testing, the significance is based on both t_{BDM} and F_{PPS} bounds tests for $k = 3$.

Determinants of firm exchange rate predictions: Empirical evidence from survey data of Japanese firms

4.1 Introduction

Exchange rate expectations have long been an important research topic in international macroeconomics; yet, the question of how market participants predict future exchange rate levels remains unresolved. A few studies only, such as those by Ito (1989) and Takagi (1991), have used survey data to analyze this question empirically. Accordingly, the limited data availability on expected future exchange rates has prevented further rigorous examination of this unresolved research question.

The Bank of Japan (BOJ) regularly publishes firm predictions of the yen/ US dollar bilateral normal exchange rate when export by firm size and by industry, which they obtain by conducting large-scale surveys of Japanese firms.[42] Figure 4.1 presents the exchange rate prediction error for both large-size and small-size firms as well as the actual (quarterly averaged) yen/ US dollar bilateral nominal exchange rate, where the prediction error is defined as the differences between the actual and predicted exchange rate. It can be observed that the magnitude of the prediction error is larger with a longer duration in shaded yen depreciation periods than in non-shaded yen appreciation periods.[43] In addition, in most periods, the graph

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[42] BOJ's *Short-Term Economic Survey of Enterprises in Japan* (*TANKAN*) is published in every quarter. As of March 2018, for example, the BOJ sent out questionnaires to 10,020 firms and presents the averaged results by three types of firm size (large, medium-sized, and small firms) and by industry (17 manufacturing and 14 non-manufacturing industries).

[43] In this letter, the criteria of dividing currency regimes are based on prediction errors of exchange rates, i.e., the period is counted as yen depreciation period if the yen depreciates more than firms' expectation (prediction error

of large-size firms (black x marked line) is above that of small-size firms (red dotted line) implying that prediction errors by large-size firms are larger (smaller) than those of small-size firms during yen depreciation (appreciation) periods. Thus, questions are raised about why the degree of prediction errors differs (1) between yen appreciation and depreciation periods, and (2) depending on firm size.

This letter aims to use the BOJ's *Tankan* survey data to reveal the characteristic as well as the determinants of firm-level exchange rate predictions. The analysis revealed that, first, Japanese firms adjust their exchange rate prediction errors more quickly (slowly) in yen appreciation (depreciation) period. Second, the adjustment speed of exchange rate prediction is positively correlated with a firm's degree of export dependency in the yen depreciation period. Third, in contrast, the adjustment speed is found to have negative relationship with a firm's profitability performance in the yen depreciation period, with small-size firms tending to increase the adjustment speed in response to an unanticipated depreciation of the yen.

The letter is organized as follows. Section 4.2 investigates the characteristics of exchange rate prediction and adjustment speed. The relationship between the adjustment speed and firm characteristics is analyzed empirically in Section 4.3. Section 4.4 concludes.

4.2 Adjustment speed of exchange rate prediction

The adjustment speed (α_t) of exchange rate prediction is calculated by dividing the change in firm's predicted exchange rate by the exchange rate prediction error in the previous period:

>0) and yen appreciation otherwise. In fact, this currency regime specification is reasonable when comparing with the movement of actual yen/ US dollar exchange rate (blue solid line) in Figure 4.1.

$\alpha_t = (E_t s_{t+1} - E_{t-1} s_t)/(s_t - E_{t-1} s_t)$, where s_t is the natural log of bilateral nominal exchange rate at

t period, and E_t is an expectation operator conditional on all available information at t period.

Although firms use all the available information to predict the future exchange rate, it is

impossible to establish perfect expectations. Thus, the hypothesis proposed here is that firms

tend to determine the predicted exchange rate conservatively when making an export plan. The

additional hypothesis is that the magnitude of prediction errors depends on firm characteristics

such as export dependency and profitability.

To test the above hypothesis, the adjustment speed, α_t, which measures how quickly firms

update their predicted exchange rate by observing current (realized) exchange rate, is estimated.

To allow for possible asymmetric prediction of future exchange rates, the following threshold

regression model is established:

$$E_t s_{t+1} - E_{t-1} s_t = I \times \alpha_1 (s_t - E_{t-1} s_t) + (1 - I) \times \alpha_2 (s_t - E_{t-1} s_t) + v_{t+1} \quad (1)$$

where the dummy I takes the value of 1 (yen depreciation regime) if the prediction error is

positive, and takes 0 (yen appreciation regime) otherwise.

Quarterly data from 1997Q2 to 2016Q1 for three firm sizes in 10 manufacturing industries

are used for the above estimation.[44] Table 4.1 presents the results of α_1 and α_2 as well as the

results for the Wald-test for the null hypothesis $\alpha_1 = \alpha_2$. An asymmetric pattern of adjustment

speeds can be observed among almost all large and medium enterprises and in four out of 10

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[44] Following Nguyen and Sato (2017), this letter constructs the dataset from BOJ's *Tankan* data. Although data on 17 manufacturing sectors are available, as footnote 1 shows, we finally chose "all manufacturing" and nine manufacturing industries. See the footnote of Table 4.1 for industry information. Actual yen/ US dollar bilateral nominal exchange rate (quarterly average) s_t is taken from the IFS.

industries for small enterprises, where the adjustment speed is higher in the yen appreciation regime than in the yen depreciation regime.

One explanation for regime-dependent adjustment speed could be that exporting firms might need to revise their export plan quickly in response to an unexpected appreciation of the yen, especially when they use foreign currency invoicing in their exports.[45] In contrast, during the yen depreciation regime, Japanese firms could enjoy unexpected exchange gains, which provides less incentive to change their export plan and, hence, to revise their predicted exchange rate.

4.3 Determinants of adjustment speed

Next, we investigate what factors determine the adjustment speed. The BOJ provides notable data of forecasted (planned) export amounts, total sales, and ordinary profits as obtained from their *Tankan* surveys. These data are used to calculate the "forecasted export ratio" as well as the "forecasted profit ratio".[46] To investigate the effect of firm size on adjustment speed, firm-size dummies and their interactions with explanatory variables are included in the following fixed-effect model estimation:

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[45] As shown by Ito et al. (2018), Japanese firms tend to invoice exports in the destination currency (mainly in US dollars) when exporting products to advanced countries. Even for exports to Asian countries, the share of US-dollar-invoiced exports is higher than the share of yen-invoiced exports. Given such a large share of foreign currency invoicing in exports, Japanese firms shoulder foreign exchange loss when the yen appreciates unexpectedly.

[46] Export (profit) ratio is calculated as the ratio of firm's export (ordinary profit) amount compared with total sales amount. The two ratios' correlation coefficient is 0.33.

$$spd_{ijt} = c + \sum_i S_i + \alpha \cdot \exp\_ratio_{ijt-1} + \sum_i \alpha_i \cdot S_i \times \exp\_ratio_{ijt-1} +$$
$$+ \beta \cdot profit\_ratio_{ijt-1} + \sum_i \beta_i \cdot S_i \times profit\_ratio_{ijt-1} + \gamma_{ij} + \eta_t + \varepsilon_{ijt} \qquad (2)$$

where spd_{ijt}, $\exp\_ratio_{ijt}$, and $profit\_ratio_{ijt}$ denote the adjustment speed, export ratio, and

profit ratio of i firm-size-level in industry j at time t, respectively. S_i denotes dummies for large

or small enterprises. Fixed effects of industry-firm-size and time are captured by γ_{ij} and η_t,

respectively. Prediction error, er_t, is used to distinguish currency regimes. The sample period

ranges from 1999Q2 to 2016Q1.

A firm's export ratio has two conflicting effects on its adjustment speed. One effect is an

"exposure effect" that occurs when the export ratio is treated as a proxy for firms' exchange

rate exposure. Given the assumption of a positive relationship between the adjustment speed

and ERPT, the sign on α is expected to be positive.[47] The other effect is a "market share effect"

that arises when the export ratio is considered as a proxy for firms' sales dependency on the

international market. The fact that firms depend heavily on overseas sales might give them an

incentive to maintain (boost) their market share by decreasing (increasing) the level of ERPT

and hence to slowly (quickly) revise exchange rate predictions when the yen appreciates

(depreciates).[48] Therefore, taken together, α is expected to be positive when the yen

depreciates, but remains ambiguous when the yen appreciates.

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[47] Floden et al. (2008) shows that higher exchange rate exposure leads to a higher ERPT level.

[48] Krugman (1987) and Knetter (1993) discuss possible ERPT asymmetry due to market power.

The profit ratio is used to proxy for firms' business performance and is highly related to a firm's mark-up level. Depending on that firm's export competitiveness, the relationship between firm profitability and adjustment speed can be either positive or negative.[49]

Columns (4)–(6) in Table 4.2 reports the results of regression (2).[50] The coefficients of both the export and profit ratios are found to be significant in the regime-free as well as yen depreciation regime, but not in the yen appreciation regime.

In the yen depreciation regime, the coefficient of the export ratio is significantly positive as expected, with 1% increase in the export ratio leading to a 11% higher adjustment speed. However, firm size itself does not have a significant effect on adjustment speed, indicating a linear effect of the export ratio on adjustment speed among all types of enterprises. Meanwhile, the profit ratio shows a strongly significant nonlinear relationship with the adjustment speed in the yen depreciation regime. For benchmark medium-size enterprises, profitability negatively affects adjustment speed, whereas the interaction between firm size and profitability is significantly positive for small-size enterprises, making the point estimate 34.004. Thus, the smaller the firm size, the more likely it is that firms with high profitability will increase their adjustment speed in the yen depreciation regime.

As discussed earlier, firms with high profits tend not to revise their predictions of future exchange rates quickly in response to an unexpected depreciation of the yen. However, the small-size firms, often regarded as "less competitive," are likely to have a stronger incentive

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[49] Berman et al. (2012), Nguyen and Sato (2017) suggest a nonlinear relationship between firm performance (or industry competitiveness) and ERPT.

[50] For reference, the results of the model without firm-size dummies (model (3)) are reported in column (1)–(3) of Table 4.2. Only the export ratio coefficients are found to be significant in regime-free and yen depreciation regime. $spd_{ijt} = c + \alpha \cdot \exp\_ratio_{ijt-1} + \beta \cdot profit\_ratio_{ijt-1} + \gamma_{ij} + \eta_t + \varepsilon_{ijt}$ (3)

to update their predicted exchange rate to decrease their export price, thereby improving their export price competitiveness during the yen depreciation regime. This finding is consistent with the empirical results of Berman et al. (2012) and Nguyen and Sato (2017), which demonstrated an asymmetric relationship between firm business performance and ERPT.

4.5 Concluding remarks

Using the BOJ's *Tankan* data, we have investigated empirically the characteristic and determinants of firm exchange rate predictions. The novel findings are three-fold. First, Japanese exporting firms are more likely to update their exchange rate predictions in response to unexpected yen appreciation than in response to unexpected yen depreciation. Second, the performed panel estimation demonstrated that a firm's export dependency, as well as its profitability, has significant effect on the speed of updating predicted exchange rates in response to an unexpected yen depreciation. Finally, unlike the negative effect of profitability on prediction updating found among large- and medium-size firms, small-size firms tend to update their prediction of future exchange rates in response to unexpected yen depreciation, which suggests that firm size, often associated with firm export competitiveness, does matter in the prediction of future exchange rates. These empirical findings will motivate further research on firm-level predictions of future exchange rates.

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Figure 4.1: Prediction error of large and small Japanese manufacturing exporters
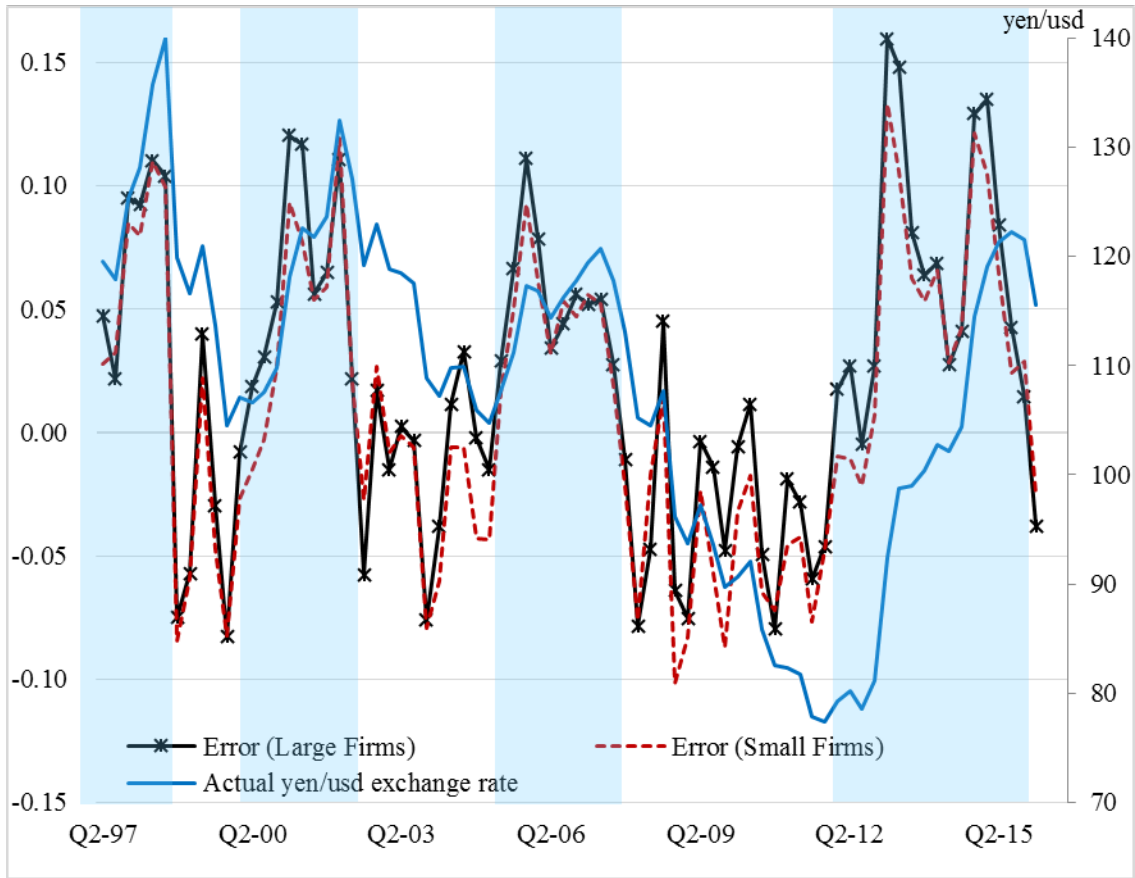
Note: Prediction error is calculated as the difference between natural log of the actual exchange rate and natural log of the predicted exchange rate, $er_t = \ln s_t - \ln E_{t-1} s_t$, indicating the deviation rate of the realized exchange rate from the expected one. "Error (Large Firms)," "Error (Small Firms)" are calculated using the expected exchange rate for large- and small-size firms, respectively. The shaded (non-shaded) yen depreciation (appreciation) periods are periods in which the prediction errors are larger (smaller) than 0.

Source: Bank of Japan, *Short-Term Economic Survey of Enterprises in Japan* (*TANKAN*); IMF, *International Financial Statistics*.

Table 4.1: Adjustment speed of exchange rate predictions to an error in the previous period

Firm-size level / Industry	Large enterprise			Medium enterprise			Small enterprise		
	Depre.	Appre.	Symmetry	Depre.	Appre.	Symmetry	Depre.	Appre.	Symmetry
Manufacturing	0.351*** (0.026)	0.632*** (0.052)	0.000***	0.357*** (0.023)	0.542*** (0.037)	0.000***	0.397*** (0.030)	0.480*** (0.041)	0.104
Textile	0.431*** (0.038)	0.573*** (0.527)	0.031**	0.442*** (0.031)	0.578*** (0.042)	0.011**	0.509*** (0.046)	0.611*** (0.062)	0.187
Chemical	0.381*** (0.030)	0.573*** (0.049)	0.001***	0.386*** (0.034)	0.565*** (0.053)	0.006***	0.345*** (0.032)	0.510*** (0.058)	0.015**
Iron and steel	0.478*** (0.045)	0.621*** (0.063)	0.014**	0.354*** (0.040)	0.543*** (0.066)	0.017**	0.480*** (0.053)	0.532*** (0.065)	0.539
Non-ferrous metal	0.377*** (0.041)	0.590*** (0.071)	0.011**	0.419*** (0.032)	0.613*** (0.049)	0.001***	0.500*** (0.047)	0.586*** (0.056)	0.241
Processed metal	0.370*** (0.039)	0.523*** (0.060)	0.036**	0.278*** (0.031)	0.673*** (0.077)	0.000***	0.256*** (0.047)	0.771*** (0.109)	0.000***
General	0.335*** (0.032)	0.656*** (0.069)	0.000***	0.345*** (0.025)	0.573*** (0.046)	0.000***	0.380*** (0.034)	0.628*** (0.063)	0.001***
Electric	0.251*** (0.049)	0.651*** (0.137)	0.007***	0.312*** (0.027)	0.623*** (0.054)	0.000***	0.396*** (0.031)	0.513*** (0.047)	0.041**
Transport	0.326*** (0.034)	0.699*** (0.076)	0.000***	0.256*** (0.025)	0.536*** (0.051)	0.000***	0.373*** (0.054)	0.352*** (0.052)	0.784
Other	0.367*** (0.034)	0.534*** (0.057)	0.014**	0.410*** (0.041)	0.370*** (0.045)	0.518	0.328*** (0.058)	0.275*** (0.060)	0.527

Note: (a) "Manufacturing," "General," "Electric," "Transport," and "Other" denotes "All manufacturing industries," "General machinery" (including the three sectors of "General-purpose machinery," "Production machinery," and "Business oriented machinery"), "Electrical machinery," "Transportation machinery," and "Other manufacturing," respectively.

(b) "Depre." and "Appre." denote the yen depreciation and appreciation regimes, respectively.

(c) "Symmetry" indicates *p*-values of the Wald test for the hypothesis of equality in adjustment speed ($\alpha_1 = \alpha_2$) in the two regimes.

Table 4.2: Relationship of adjustment speed with other firm characteristics.

dependent var: adjustment speed	no regime (1)	depreciation (2)	appreciation (3)	no regime (4)	depreciation (5)	appreciation (6)
exp_ratio	5.462**	9.532***	-2.788	6.955**	11.152***	-1.590
	(2.543)	(2.982)	(4.187)	(3.472)	(4.145)	(5.657)
profit_ratio	-8.624	-7.355	-1.378	-17.628**	-25.715**	-6.280
	(5.589)	(6.503)	(9.297)	(8.252)	(10.183)	(12.942)
large*exp_ratio				-1.592	-1.325	-3.406
				(5.098)	(5.937)	(8.463)
small*exp_ratio				-2.079	0.390	1.427
				(6.858)	(9.024)	(10.011)
large*profit_ratio				10.383	19.538	7.562
				(9.694)	(12.063)	(15.004)
small*profit_ratio				25.820**	59.719***	8.647
				(12.122)	(16.058)	(17.962)
Constant	-0.590	-1.482*	2.378	0.073	-0.504	4.025
	(0.841)	(0.899)	(3.378)	(0.840)	(0.878)	(3.417)
large enterprise				-0.681	-0.889	-1.430
				(1.066)	(1.211)	(1.823)
small enterprise				-1.099	-1.440	-3.061*
				(1.031)	(1.294)	(1.585)
time-fixed effect	YES	YES	YES	YES	YES	YES
cross-section fixed effect	YES	YES	YES	YES	YES	YES
degree of freedoms	1908	1074	771	1904	1070	767
R-squared	0.067	0.232	0.128	0.069	0.242	0.129
No. of obs	2006	1159	847	2006	1159	847

Note: */**/*** denotes significance at 10%, 5% and 1%, respectively.

5 Conclusion

This Ph.D. dissertation was conducted to investigate throughout the possibility of asymmetric exchange rate pass-through in Japanese export, which has not been fully considered in the literature, especially when taking into account the large yen fluctuation from 2007 to 2015. In particular, we propose a new threshold specification approach using firms' predicted exchange rates, taking exporters' expectations into consideration, to overcome the disadvantage of a conventional threshold.

For that purpose, this Ph.D. dissertation consists of three independent research papers. The first research paper estimates a proxy for firm predicted exchange rate and uses it to test the nonlinearities of ERPT by applying the Threshold Structural Near-Vector Autoregressive Model (Threshold SVAR). The second research paper utilizes actual data of firm predicted exchange rate published in the Bank of Japan's Tankan data and investigates the ERPT asymmetry to the Nonlinear Autoregressive Distributed Lag (NARDL) Model. The third paper further explores our variable of interest – firms' predicted exchange rates, by investigating its characteristics and determinants. All these three research papers examine the nonlinearities in Japanese export pricing behavior as well as exchange rate prediction mechanism when exports. This enables us to understand further the pattern of pricing behavior and exchange rate prediction formation of Japanese exporters regarding to exchange rate fluctuation, giving an insight of appropriate policies.

The main findings of the three research papers are as follows:

(1) In the first paper, it is found that the degree of export price responses to exchange rate shock declines and becomes more symmetric in the second sub-sample period from 2000 to 2014. The calculated PTM ratios reveal that the PTM or ERPT behavior is almost symmetric between yen appreciation and depreciation periods. In addition, the degree of PTM or ERPT differs across industries and such industry-differences become larger in the second sub-sample period. Specifically, Japanese three major machinery industries tend to exhibit a strong tendency of PTM in the long-run, while other industries including Chemical and Metal tend to show a greater degree of ERPT in the long-run. This difference is likely due to the product differentiation of export goods in respective industries.

(2) The findings of the second paper are consistent with the first one in short-run PTM. We found complete and symmetric PTM in all industries for both the first and second sub-sample periods, reflecting their tendency to choose foreign currency invoicing. In the long run, we revealed evidence of cointegrating relationships and asymmetric PTM in several industries, especially in the 2007–2015 period when the yen fluctuated substantially. At least four of seven industries and all manufacturing show evidence of long-run relationships, and most of them exhibit nonlinearities in long-run PTM coefficients. On one hand, these industries specifically seem to follow the same pricing strategy in the appreciation regime. That is, incomplete but relatively stronger PTM behavior is observed, and around 60–80% of exchange rate changes are absorbed by Japanese exporters. On the other hand, less-competitive industries, like Chemical and Metal, choose to increase the degree of ERPT when the yen

depreciates, which implies that exporters in those industries tend to stabilize the local currency export price to stimulate importers' demand, even though they must squeeze their profit margins. In contrast, relatively competitive industries, like General Machinery and Transport Equipment, raise the level of PTM to almost 100% so they can fully exploit foreign exchange gains during the yen depreciation period.

(3) The third paper found that, first, Japanese exporting firms are more likely to update their exchange rate predictions in response to unexpected yen appreciation than in response to unexpected yen depreciation. Second, the performed panel estimation demonstrated that a firm's export dependency, as well as its profitability, has significant effect on the speed of updating predicted exchange rates in response to an unexpected yen depreciation. Finally, unlike the negative effect of profitability on prediction updating found among large- and medium-size firms, small-size firms tend to update their prediction of future exchange rates in response to unexpected yen depreciation, which suggests that firm size, often associated with firm export competitiveness, does matter in the prediction of future exchange rates.

In summary, the first and second papers confirmed that the PTM in the short-run is indeed to be symmetric, while the PTM in long run is asymmetric across industries and between currency regimes. While the first paper could not confirm the PTM asymmetry between currency regimes, the second paper found a possibility of nonlinear PTM behavior between yen depreciation and appreciation regime in 2007-2015 period. However, they both suggest that industries with strong competitiveness due to product differentiation adopts higher PTM

behavior than less competitive ones. This result gives an insight to explain the unresponsiveness of the Japanese trade balance to the yen depreciation from late 2012. Unless Japanese prominent export industries such as General Machinery and Transport Equipment do not pass on exchange rate gains of the yen depreciation into their export price, yen depreciation can hardly be expected to improve trade balance.

We also get some information of nonlinearities on the way firms adjust their exchange rate prediction. Specially, large- and medium-enterprises with high profits tend not to revise their predictions of future exchange rates quickly in response to an unexpected depreciation of the yen. However, the small-size firms, often regarded as "less competitive," are likely to have a stronger incentive to update their predicted exchange rate to decrease their export price, thereby improving their export price competitiveness during the yen depreciation regime. In this logic, the third paper is consistent with the empirical results the first two papers. However, to make final conclusion, many more studies that are outside the scope of this study need to be done to examine especially the link between firms' predicted exchange rates revision and exchange rate pass-through level.

From a policy analysis perspective, understanding Japanese exporters' PTM or ERPT behavior will be crucial in considering the impact of exchange rate volatility on the Japanese economy. Although trade balance is not solely determined by such a price factor, our empirical results at least partly answer the question as to the unresponsiveness of the Japanese trade balance to the yen depreciation witnessed since the end of 2012.