Temporal Homogeneity of Japanese Yen, Euro and Chinese Yuan Exchange Rate Behavior

Part II: How Has the Behavior Been Affected by the U.S.-China Trade War and the Novel Coronavirus Outbreak/Pandemic?

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Abstract

How the U.S.-China trade war and the novel coronavirus outbreak have affected the Japanese yen, Euro and Chinese yuan exchange rate (denoted by JD, ED and CD) behavior is studied by making inferences on temporal homogeneity of the behavior. Applying usual descriptive statistics to three conjectures reveals first that exchange-rate variability is not temporally homogeneous (that is, a variance shift is inferred), over either of the subperiods before and during the U.S.-China trade war and the subperiods before and during the coronavirus outbreak. Second, a mixture of two cross-sectionally opposing inferences is drawn: Temporal homogeneity is inferred in cross correlations for two pairs, JD and CD, and ED and CD, but not for the pair of JD and ED. Also, negative cross correlations detected for the pair of JD and CD supports the Japanese yen's actual role as a safe haven currency. And third, contrasting the entirety of the former two subperiods and the trade war period, exchange rate time series models are not temporally homogeneous (possibly due to the variance shift).

1 Introduction

"Temporal homogeneity," "cross-sectional (cross-currency/exchange rate) homogeneity" and "temporal and cross-currency homogeneity" of the Japanese yen, Euro and Chinese yuan exchange rate behavior are meant

*Department of Commerce, Seinan Gakuin University, Fukuoka, Japan. E-mail: kojima@seinan-gu.ac.jp My motivation for the present time series research as Part II lies in expanding a sample period to include the first half of 2020, to newly provide evidence on the temporal homogeneity of the multiple exchange rate behavior, a topic studied previously by Kojima (2020) as Part I for days until December 2016.

to conjecture, respectively, that an exchange rate behaves similarly over two or more nonoverlapping periods, that a multiple exchange rates have one or more features in common in their behavior during a period and that a multiple exchange rates behave similarly for two or more nonoverlapping periods. Exploring and drawing inferences on homogeneity as such constitutes an important attempt that will enable us to identify common (business/economic/financial and statistical) factors essential to specifying an exchange rate behavior, temporally and/or cross-sectionally.

Such an initial attempt is Kojima (2019) studying the individual and joint behavior of three daily exchange rates, the Japanese yen (JPY), the Euro (EUR) and the Chinese yuan (CNY), all against a U.S. dollar (USD), during the period ("V through 2016") of Monday, June 21, 2010-Friday, December 30, 2016, the longest period of time when the CNY was continuously less managed/controlled by China's central bank under (managed) flexible exchange rate system. Similar time series econometric study remains, then, for the previous period ("III") of Thursday, July 21, 2005-Thursday, July 31, 2008, the third longest period of time when China employed (managed) flexible exchange rate system.

Contrasting the findings between two periods, III and V through 2016, is thus a topic studied previously in Kojima (2020, as Part I), which investigates possible temporal, as well as cross-currency, homogeneity of the exchange rate behavior over the two periods.

What then still remains is to study more recent Period VI (September 1, 2015-May 29, 2020) which encompasses both the pre-U.S.-China trade war period and the U.S.-China trade war period, with the latter in concurrence with a novel coronavirus (COVID-19) outbreak.[1]

With tremendous uncertainty during the COVID-19 pandemic as detected by Altig, et al. (2020) in mind,[2] the present paper thus aims to study how the behavior of the three daily exchange rates has been affected by the U.S.-China trade war and the novel coronavirus outbreak, based on inferences on possible temporal, as well as cross-currency, ho-

[1]The period is the second longest period of time when China employed (managed) flexible exchange rate system. For exchange rate systems employed by China over differing periods such as Periods III, V and VI, see Table 1.

[2]Most recently, Altig, et al. (2020) studies "several economic uncertainty indicators for the US and UK before and during the COVID-19 pandemic: implied stock market volatility, newspaper-based economic policy uncertainty, twitter chatter about economic uncertainty, subjective uncertainty about future business growth, and disagreement among professional forecasters about future GDP growth."

mogeneity of the behavior during Period VI and its subperiods.

Inferences will be made on temporal homogeneity, three conjectures about which are explained as follows:

1.1 Temporal homogeneity [1]

Markets will be more volatile due to trade war, intuitively, than in the pre-trade war period. And fear(s) characterizes financial market behavior during the COVID-19 outbreak period[3] and will, too, intuitively make the markets more volatile than in the pre-COVID-19 period without such fears. We will thus ask: Is there observed such common variability among the three exchange rates, over two such consecutive periods? We will explore the difference between the two periods in exchange rate variability, based on coefficient of variability and sample variance (both constituting a first descriptive analysis). What we mean to conjecture by "temporal homogeneity [1]" is thus no significant differences in exchange rate variability between two consecutive periods.

1.2 Temporal homogeneity [2]

Fear(s) and/or troubled times (such as a trade war and COVID-19 outbreak) will likely lead to natural reliance or dependence on a safe haven currency; the degree of safety may be related to that of risk appetite as depicted in the following table.

Contracts/Decreases ←	Risk Appetite	→ Grows/Increases
Safer ←	Currencies Demanded	→ Riskier
⊂ JPY	[USD ⊃	EUR Australian $]

There have been observed two types of demand for a currency. One is safe-haven demand for a currency:[4] "The JPY, a safe haven in troubled times" and "the safe-haven yen" are indicated by ⊂ ··· ⊃ in the table. There are, however, weeks (in February and March 2020) when 'Japan's yen may lose its long-standing status as a "safe-haven asset"' (as indicated by [· · ·] in the table).[5]

[3] A "fear trade" appears first time in Appendix B.1.4 for "F24," the week of 2/24 to 2/28/2020.

[4] Another is real demand-backed buying: There is, for example, real demand-backed USD-buying, for Japanese importers' settlement purposes. The evidence is provided in: The footnote for Appendix A-**k**-*(ii)*-Thursday; and Appendix B.2.10-*19,20 & 22* (Wed.,Thu. & Fri. 5/20,21 & 22).

[5] The evidence is provided in the second footnote in Subsection 4.3.1.

Meanwhile, the USD plays a role as a safe haven (as indicated by $[\cdots]$ in the table) and as a risk asset (as indicated by $\subset \cdots \supset$ in the table).[6]

The safe-haven demand for a currency may be statistically measured by negative cross correlations for a pair of exchange rates. We will thus ask: Does a pair of exchange rates comove in the same direction or move in the opposing direction? We will study the difference between two successive periods in joint exchange rate behavior (comovement in the same direction or movement in the opposing direction), based on the cross correlations (constituting a second descriptive analysis). What "temporal homogeneity [2]" is meant to conjecture is no significant differences in sign of cross correlations between two successive periods.

1.3 Temporal homogeneity [3]

Further, we will study and ask a statistical question, based on univariate time series analysis (constituting a third descriptive analysis): Are exchange rate time series models homogeneously specified and estimated, for both the entire (Period VI) and the trade war periods?[7] The answer "Yes" is what we mean to conjecture by "temporal homogeneity [3]."[8]

The paper proceeds as follows: Data and the sample (sub)period(s) are described, tabulated and plotted in Section 2. As a descriptive analysis for drawing inferences on temporal homogeneity [1] (exchange rate variability, over two successive periods), Section 3 attempts to compute and graph some descriptive statistics (coefficient of variability and sample variance), together with F-tests, for two subperiods of Period VI. For temporal homogeneity [2] (moving in the same direction or the opposing direction, over two successive periods), Section 4 attempts to compute and graph descriptive statistics (cross correlations). For temporal homogeneity [3] (time series models, over two differing periods), Section 3 attempts to contrast estimated time series models between the entire and the trade war periods. Based on a summary table constructed at the end of Section 4, several concluding inferences are drawn in Section 5. Three appendices follow, which are, however, too long to include in the paper and provided as a pdf file available from the author upon request.

[6] The evidence is provided in a footnote in Subsection 4.5.1.

[7] The question will not be asked for "before and during the coronavirus (COVID-19) outbreak/pandemic" (due to small sample size in the latter period).

[8] "Temporal homogeneity [3]" here is the same as "temporal homogeneity" studied by Kojima (2020, as Part I).

Table 1 Exchange Rate Systems in China since 1994, together with Variability of Daily Rate of Change in CD (grCD):[a] Panel 1

I. Monday, January 3, 1994-Tuesday, December 31, 1996 ($T = 767$ for Raw, Undifferenced Data):[b] *Flexible (Essentially, Pegged-to-U.S. Dollar) Exchange Rate System.*			
Statistics on Series grCD			
Observations 745[c] Skipped/Missing 21[d]			
Sample Mean	-0.000060	Variance	0.000002[e]
Minimum	-0.021362[f]	Maximum	0.020855[g]
Median	-0.000048		
II. 1997-Wednesday, July 20, 2005: *Fixed Exchange Rate System.*			
III. Thursday, July 21, 2005-Thursday, July 31, 2008 ($T = 761$ for Raw, Undifferenced Data):[h] *Managed Flexible Exchange Rate System.*			
Statistics on Series grCD			
Observations 760[i]			
Sample Mean	-0.000225	Variance	0.000001[j]
Minimum	-0.004599	Maximum	0.003163[k]
Median	-0.000169		
IV. August 2008-Friday, June 18, 2010: *Fixed Exchange Rate System.*			

(Continued to Panel 2 of the table)

[a]See Fig. 1 for a monthly data plot. CD denotes CNYUSD, the CNY exchange rate against a USD. Source: BJidentify_fxdata.prg.

[b]This is the shaded period without vertical grid lines in Fig. 1. See Fig. 2-[Right] for dlogCD$_t$ (= logged CD$_t$−logged CD$_{t-1}$) that closely approximates grCD$_t$ [= (CD$_t$-CD$_{t-1}$)/CD$_{t-1}$]. See Kojima (2019, Subsection 3.1) for the economic interpretation of logged series in first differences as a rate of change.

[c]This equals $T' - Missing = T - d - Missing = 767 - 1 - 21$ where T' denotes the effective sample size (the number of differenced data) and d the order of (consecutive) differencing required to compute the rate of change grCD; see Table 4 in Subsection 3.1.2 for the notation. Tuesday, January 4, 1994-Tuesday, December 31, 1996.

[d]This is due to the dates when (raw) JD (denoting JPYUSD, the JPY exchange rate against a USD) is available but neither CD nor ED (denoting EURUSD, the EUR exchange rate against a USD): They are 11th, 36th, 65th, 66th, 106th, 131st, 231st, 266th, 291st, 361st and 387th dates; and thus daily rates of change are not available at twenty one dates (11th, 12th, 36th, 37th, 65th, 66th, 67th, 106th, 107th, 131st, 132nd, 231st, 232nd, 266th, 267th, 291st, 292nd, 361st, 362nd, 387th and 388th dates). For such details as exact dates see the corresponding footnote in Kojima (2020, Table 1-Panel 1).

[e]An unbiased sample variance (Doan 2007a, p.441). The (unbiased) sample standard deviation = 0.001382.

[f]Huge appreciation on Tuesday, December 20, 1994 (249th day).

[g]Huge devaluation on Monday, December 19, 1994 (248th day).

[h]This is the shaded period without vertical grid lines in Fig. 1.

[i]Friday, July 22, 2005-Thursday, July 31, 2008.

[j]The (unbiased) sample standard deviation = 0.000956.

[k]Range (=Maximum-Minimum)=0.007762.

Panel 2

V. Monday, June 21, 2010-Monday, August 10, 2015
($T = 1286$ for Raw, Undifferenced Data):[a] *(Managed) Flixible Exchange Rate System.*

Statistics on Series grCD			
Observations 1285[b] Skipped/Missing 1[c]			
Sample Mean	-0.000070	Variance	0.000001[d]
Minimum	-0.005912	Maximum	0.006042[e]
Median	-0.000075		

VI. Tuesday, September 1, 2015-Friday, May 29, 2020
($T = 1186$):[f] *(Managed) Flixible Exchange Rate System.*[g]

Statistics on Series grCD			
Observations 1185[h] Skipped/Missing 1[i]			
Sample Mean	0.000099	Variance	0.000006[j]
Minimum	-0.012204	Maximum	0.012207[k]
Median	0.000063		

Two Subperiods:[l]
–Pre-U.S.-China trade war period (September 1, 2015-June 14, 2018);
–U.S.-China trade war period (June 15, 2018-May 29, 2020).
Two Further Subperiods of the Trade War Period:[m]
–Pre-COVID-19 outbreak period (June 15, 2015-January 16, 2020);
–COVID-19 outbreak period (January 17, 2020-May 29, 2020).

[a]This is the shaded period without vertical grid lines in Fig. 1.

[b]Tuesday, June 22, 2010-Monday, August 10, 2015.

[c]For why one missing see the corresponding footnote in Kojima (2020, Table 1-Panel 2).

[d]The (unbiased) sample standard deviation = 0.001139, which is larger than that for the period of Friday, July 22, 2005-Thursday, July 31, 2008 above (see footnote *j* to Panel 1 of the table).

[e]Range =0.011954, which is larger than that for the period of Friday, July 22, 2005-Thursday, July 31, 2008 in Period III (see footnote *k* to Panel 1 of the table).

[f]This is the shaded period *with* vertical grid lines in Fig. 1, which includes both the U.S.-China trade war period from June 15, 2018 (for which a vertical grid line is drawn) through May 29, 2020 and the outbreak of (deadly) novel coronavirus in the central Chinese city of Wuhan, a major business and transportation hub, on January 17, 2020. (The period is summarized for daily economic and public-health incidences in Ssection 2.1.)

[g]The same system as for Period V.

[h]Tuesday, June 22, 2010-Monday, August 10, 2015.

[i]For why one missing see the corresponding footnote in Kojima (2020, Table 1-Panel 2).

[j]The (unbiased) sample standard deviation = 0.001139, which is larger than that for the period of Friday, July 22, 2005-Thursday, July 31, 2008 above (see footnote *j* to Panel 1 of the table).

[k]Range =0.011954, which is larger than that for the period of Friday, July 22, 2005-Thursday, July 31, 2008 in Period III (see footnote *k* to Panel 1 of the table).

[l]See A and B in Table 2 in Section 2.

[m]See B1 and B2 in Table 2 in Section 2.

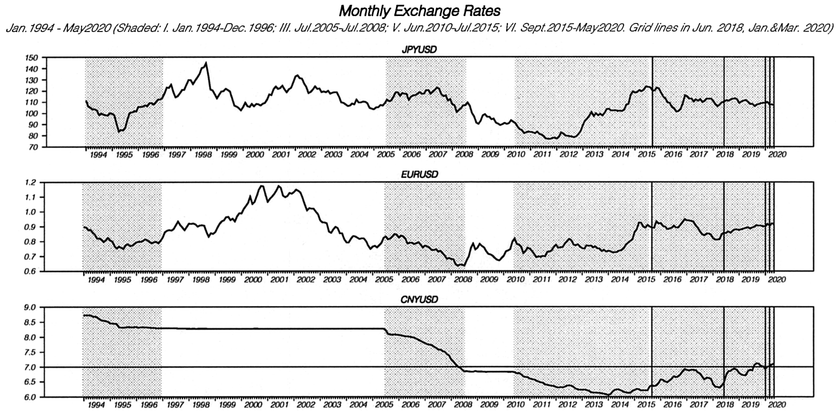

Figure 1 Monthly Exchange Rates, January 1994-May 2020 (Shaded: I. January 1994-December 1996; III. July 2005-July 2008; V. June 2010-July 2015; VI. September 2015-May 2020 with vertical grid lines at both two ends, together with grid lines in June 2018, January 2020 and March 2020). Note 1: Period VI is the second longest period of time when CD was continuously less managed/controlled by the central bank in China under (managed) flexible exchange rate system; this period corresponds to Period VI as in Panel 2 of Table 1. Note 2: The grid line in June 2018 is the essential beginning month of the (ongoing) U.S.-China trade war; another grid line in January 2020 is the month when on January 17, 2020 the outbreak of (deadly) novel coronavirus in the central Chinese city of Wuhan was announced by the city offcials and on January 30, 2020 the W.H.O. declared the global health emergency; still another grid line in March 2020 is the month when on March 11, 2020 the W.H.O. declared the coronavirus pandemic; see Fig. 2-[Left] for daily descriptions of the grid lines.

2 Data and the Sample (Sub)Period(s)

Three daily and monthly exchange rate data are all extracted from the Database Retrieval System (v2.11), available at the University of British Columbia's Sauder School of Business (http://fx.sauder.ubc.ca/ data.html). Daily data are daily average rates and monthly data monthly averages to which the daily data are converted.[9] The (entire) sample period is Period VI (September 1, 2015-Friday, May 29, 2020 [$T = 1186$ observations]. For the sample period see Note 1, a note on the shaded period with vertical grid lines added, in Fig. 1; the daily data for Period VI are plotted in Fig. 2.

The date June 15, 2018 here is chosen as the beginning of the U.S.-China trade war period, for "President Donald Trump has approved a plan to impose punishing tariffs on tens of billions of dollars of Chinese goods as early as Friday [June 15, 2018.]"[10] and "China's government responded quickly to U.S. President Donald Trump's tariff hike on Chinese goods by announcing Friday it will immediately impose penalties of 'equal strength' on U.S. products."[11]

As shown in Panel 2 of Table 1, two subperiods to be studied are pre-U.S.-China trade war period (September 1, 2015-June 14, 2018) and U.S.-China trade war period (June 15, 2018-May 29, 2020), with the latter in concurrence with a novel coronavirus outbreak.

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[9]For daily data: http://fx.sauder.ubc.ca/today.html, at which "Rates quoted are daily average rates as determined by trades in the Toronto interbank market, ..." For monthly data: http://fx.sauder.ubc.ca/data.html, at which "Data Frequency" provides Pacific Exchange Rate Service Help on Specific Topics "Frequency" where "monthly: If you wish to obtain longer time series, the daily data are converted to monthly averages."

[10]See *The Mainichi, Japan* (June 15, 2018a). (Note: All the newspaper articles referenced throughout the paper are free-to-read, electronic versions and listed at the end of the pdf file, newly created by the author of the present paper, for three appendices A, B and C: See Appendices for further.) The bracketed phrase is being added, by the author of the present paper, to the original sentence in the article; the same applies to such remaining phrases throughout the paper including appendices.

[11]See *The Mainichi, Japan* (June 15, 2018b).

Also note that "[As of August 18, 2019, the CNY] has depreciated 8% since June 2018, when the U.S. formally announced its first round of punitive tariffs on Chinese goods." See *Nikkei Asian Review, Japan* (August 18, 2019).

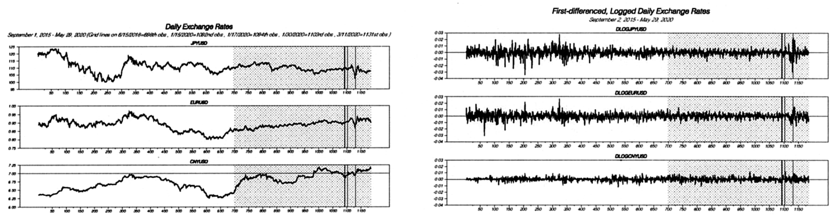

Figure 2 [**Left**] Daily Exchange Rates, Period VI [$T = 1186$ Observations]. Note 1: The dates are numbered in such a way that Tuesday, September 1, 2015 is the 1st day of the whole sample period "Period VI"; see Table 2 as well as Panel 2 of Table 1. Note 2: The shaded region is a period of the ongoing U.S.-China trade war, centering on which is Fig. 3. Note 3: The grid lines are drawn on: June 15, 2018 (the 698th observation in Period VI)), when the trade war esentially started between the U.S. and China; January 15, 2020 (the 1092nd observation in Period VI)), when the U.S. signed an initial trade deal with China; January 17, 2020 (the 1094th observation in Period VI), when the outbreak of (deadly) novel coronavirus in the central Chinese city of Wuhan was announced by the city officials; January 30, 2020 (the 1103rd observation in Period VI), when the W.H.O. declared a global health emergency; and March 11, 2020 (the 1131st observation in Period VI), when the W.H.O. declared the novel coronavirus outbreak a pandemic. [**Right**] Logged Daily Exchange Rates in First Differences (Daily Rate of Change in Exchange Rates), From Wednesday, September 2, 2015 (in Period VI) [$1 + d$ to T: 2 to 1186, with $T' = T - d = 1186 - 1$ where T' and d are as defined in Table 4.

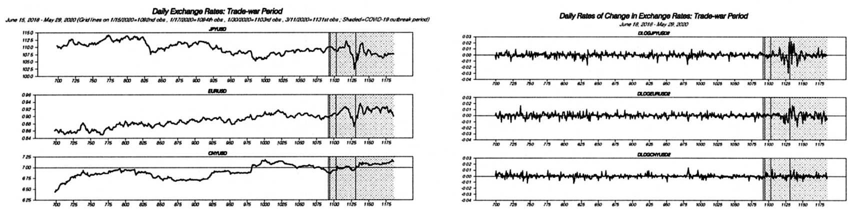

Figure 3 [**Left**] Daily Exchange Rates, Trade War Period (Shaded in Fig. 2-[Left]). Note 1: See Notes in Fig. 2. Note 2: The shaded region here corresponds to the COVID-19 outbreak period. Note 3: The figure will be further studied in (Sub)Sections 2.1, 3 and 4. [**Right**] Daily Rates of Change in Exchange Rates, Trade War Period (Shaded in Fig. 2-[Right]).

Table 2 Date Numbering for Period VI ($T = 1186$)[a]
Entire Sample Period: Period VI (Divided into A and B in the table): Panel 1

	Date Number	Date	Day
A. Pre-trade War Period ($T = 697$)			
	1	2015/9/1	Tue
	...	...	...
	697	2018/6/14	Thu
B. Trade War Period [b] ($T = 489$)			
B1. Pre-coronavirus Outbreak Period	698	2018/6/15	Fri
($T = 396$)	699	2018/6/18	Mon
	...	...	...
DJF. 1063 to 1109[c]	1063	2019/12/2	Mon
[Shaded in Fig. 4]	...	...	...
	1092	2020/1/15	Wed
	1093	2020/1/16	Thu
B2. Coronavirus Outbreak Period	1094	2020/1/17	Fri
($T = 93$)	...	...	...
	1103	2020/1/30	Thu
	1104	2020/1/31	Fri
	1105	2020/2/3	Mon
	...	...	...
	1109	2020/2/7	Fri
F10. 1110 to 1114[d]	1110	2020/2/10	Mon
	...	...	...
	1114	2020/2/14	Fri
F18. 1115 to 1118[e]	1115	2020/2/18	Tue
[Shaded in Fig. 4]	...	...	...
	1118	2020/2/21	Fri
F24. 1119 to 1123[f]	1119	2020/2/24	Mon
	...	...	...
	1123	2020/2/28	Fri
M2. 1124 to 1128[g]	1124	2020/3/2	Mon
[Shaded in Fig. 4]	...	...	...
	1128	2020/3/6	Fri

(Continued to Panel 2 of the table)

[a]See Panel 2 of Table 1 and Fig. 2.

[b]The period is shaded in Fig. 2 and divided here into two subperiods: B1 and B2 immdiately below. See also Fig. 3 concentrating on the trade war period.

[c]More recent trade war period whose exchange rate behavior is drawn in Fig. 4 is divided into DJF, F10, etc.: "DJF" here will be studied in Subsections 4.4 and 4.5.1-**b**, Appendices A-**b** and B.1.1.

[d]"F10" here will be studied in Subsection 4.5.1-**b**, Appendices A-**b** and B.1.2.

[e]"F18" here will be studied in Subsection 4.5.1-**a**, Appendices A-**a** and B.1.3.

[f]"F24" here will be studied in Subsection 4.5.1-**a**, Appendices A-**a** and B.1.4.

[g]"M2" here will be studied in Subsection 4.5.1-**c**, Appendices A-**c** and B.2.1.

Panel 2

	Date Number	Date	Day
M9. 1129 to 1133[a]	1129	2020/3/9	Mon
	...	...	...
	1133	2020/3/13	Fri
M16. 1134 to 1138[b] [Shaded in Fig. 4]	1134	2020/3/16	Mon
	...	...	...
	1138	2020/3/20	Fri
M23. 1139 to 1143[c]	1139	2020/3/23	Mon
	...	...	...
	1143	2020/3/27	Fri
M30. 1144 to 1148[d] [Shaded in Fig. 4]	1144	2020/3/30	Mon
	...	...	...
	1148	2020/4/3	Fri
A6. 1149 to 1152[e]	1149	2020/4/6	Mon
	...	...	...
	1152	2020/4/9	Thu
A13. 1153 to 1157[f] [Shaded in Fig. 4]	1153	2020/4/13	Mon
	...	...	...
	1157	2020/4/17	Fri
A20. 1158 to 1162[g]	1158	2020/4/20	Mon
	...	...	...
	1162	2020/4/24	Fri
A27. 1163 to 1167[h] [Shaded in Fig. 4]	1163	2020/4/27	Mon
	...	...	...
	1167	2020/5/1	Fri
My. 1168 to 1186[i]	1168	2020/5/4	Mon
	...	...	...
	1186	2020/5/29	Fri

[a] "M9" here will be studied in Subsection 4.5.1-**d**, Appendices A-**d** and B.2.2.

[b] "M16" here will be studied in Subsection 4.5.1-**e**, Appendices A-**e** and B.2.3.

[c] "M23" here will be studied in Subsection 4.5.1-**f**, Appendices A-**f** and B.2.4

[d] "M30" here will be studied in Subsection 4.5.1-**g**, Appendices A-**g** and B.2.5.

[e] "A6" here will be studied in Subsection 4.5.1-**h**, Appendices A-**h** and B.2.6.

[f] "A13" here will be studied in Subsection 4.5.1-**i**, Appendices A-**i** and B.2.7.

[g] "A20" here will be studied in Subsection 4.5.1-**j**, Appendices A-**j** and B.2.8.

[h] "A27" here will be studied in Subsection 4.5.1-**k**, Appendices A-**k** and B.2.9.

[i] May 4 through 29, 2020. "My" here will be studied in Subsection 4.5.1-**l**, Appendices A-**l** and B.2.10.

2.1 More Recent U.S.-China Trade War Period

As summarized in Table 2 and as shaded in Figs. 2, the U.S.-China trade war period (June 15, 2018-May 29, 2020) is in part a period in concurrence with a novel coronavirus outbreak; see also Fig. 3 focusing on the trade war period. To study more closely the coronavirus outbreak period, the present subsection centers on more recent U.S.-China trade war period, as drawn in Fig. 4, and divide it into two further subperiods, a pre-coronavirus outbreak and a coronavirus outbreak.

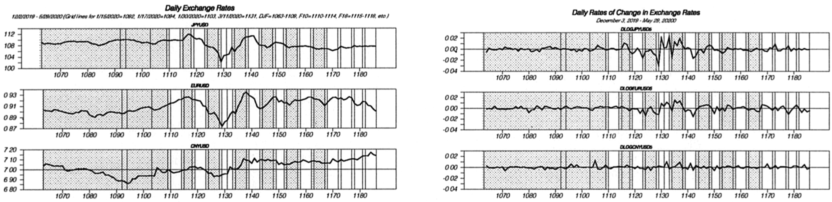

Figure 4 **[Left]** Daily Exchange Rates, December 2, 2019-May 29, 2020 (More Recent Part of the Shaded U.S.-China Trade War Period in Fig. 2-[Left]) Note 1: The figure is part of Fig. 3-[Left] focusing on the trade war period. Note 2: See Notes in Fig. 3. Note 3: The shaded [non-shaded] regions/weeks denoted in the subtitle of the figure by DJF, F18, etc. [F10, F24, etc.] are those being set in Table 2; MacRATS highlights sets of entries in such a way that each end of a shaded region has a little length of shading with an entry-number label in the center. **[Right]** Daily Rate of Change in Exchange Rates, December 3, 2019-May 29, 2020 (More Recent Part of the Shaded U.S.-China Trade War Period in Fig. 2-[Right]) Note: See also Fig. 3-[Right] concentrating on the trade war period.

Fig. 4 draws the three exchange rates[12] for the six-month period of December 2, 2019-May 29, 2020 (more recent part of the shaded U.S.-China trade war period in Fig. 3), with grid lines on Wednesday, January 15, Friday, January 17, on Thursday, January 30 and on Wednesday, March 11, 2020. On January 17 an outbreak of (deadly) novel coronavirus in

[12]Recall from Section 2 that the exchange rates "are daily *average* rates as determined by trades in the Toronto interbank market, ..." They thus differ from those exchange rates referred to in the electronic newspaper articles cited in the present subsection that are those in the Tokyo trading at a specific time such as 5 p.m.

the central Chinese city of Wuhan, a major business and transportation hub, was announced by the city: Pre-coronavirus outbreak period is the one until January 16, 2020 and coronavirus outbreak period is the one from January 17, 2020.[13]

Exchange rate variability and cross correlations between exchange rates are now studied, for each subperiod, in terms of descriptive statistics, respectively, in Sections 3 and 4; Fig. 4 will be again studied in Subsections 3.2 and 4.5.

Further, what possibly lies behind the daily JD, ED and CD behavior in December 2019 through May 2020 will be studied focusing on the U.S.-China trade war and the novel coronavirus outbreak, respectively, in Appendices B.1 and B.2; what is observed and found there will be referred to in Appendix A.[14]

3 Exchange Rate Variability, for Fig. 2

Coefficients of variability and standard deviations of daily exchange rates are computed for inferences on temporal homogeneity [1] and compiled in Table 3 and drawn in Fig. 5, for two subperiods (of the entire period, Period VI, drawn in Fig. 2): Pre-U.S.-China trade war period (September 1, 2015-June 14, 2018) and U.S.-China trade war period (June 15, 2018-May 29, 2020),[15] the latter of which is further divided into two subperiods, pre-COVID-19 outbreak (June 15, 2018-January 16, 2020) and COVID-19 outbreak (January 17-May 29, 2020).[16]

3.1 Pre-U.S.-China trade war period versus U.S.-China trade war period: The left half of Fig. 5

3.1.1 A graphics-based study

Fig. 5, or equivalently Table 3, shows that, for both Fig. 2-[Left] (Raw Daily Exchange Rates) and Fig. 2-[Right] (Logged Daily Exchange Rates

[13]For details see Appendix B.1.1-**b**.

[14]Incidentally the EUR has continued to depreciate (against a USD) since January 15 (1092nd day in Period VI) up until February 19 (1116th day in Period VI) (with exceptions on January 30 and 31); the currency then continuously appreciated since February 20 until February 28 (see a footnote in Appendix A-**a** for the 2/24/2020 week) and further until Monday, March 9, 2020 (see Appendix A-**d** for the 3/9/2020 week).

[15]See the left half of Fig. 5.

[16]See the right half of Fig. 5.

in First Differences, that is, Daily Rate of Change in Exchange Rates), both JD and ED are *much less variable* in the U.S.-China trade war period (shaded in Fig. 2), and that for Fig. 2-[Left] CD is *less* variable in the U.S.-China trade war period, whereas for Fig. 2-[Right] it is *slightly more* variable.

Table 3 Coefficients of Variability[a] and Standard Deviations[b] of the Exchange Rates, for Fig. 2 and Fig. 3.

Exchange Rate[c]	Pre-trade War Period[d]	Trade War Period[e]
		Pre-COVID-19 O.[f] / *COVID-19 O.*
Coefficients of Variability for Fig. 2-[Left] (Raw Daily Exchange Rates):		
JD	0.04832	0.01887 *0.01822 / 0.01576*
ED	0.04598	0.02150 *0.01834/ 0.01271*
CD	0.02962	0.02085 *0.02066 / 0.00982*
Standard Deviations for Fig. 2-[Right] (First Differenced, Logged Daily Exchange Rates[g]):		
dlogJD	0.00624	0.00415 *0.00310 / 0.00711*
dlogED	0.00518	0.00365 *0.00309 / 0.00544*
dlogCD	0.00209	0.00271 *0.00260 / 0.00311*

[a]See Note 3 of Fig. 5.

[b]See Note 3 of Fig. 5.

[c]For the notation under the column see Panel 1 of Table 1.

[d]September 1, 2015-June 14, 2018.

[e]June 15, 2018-May 29, 2020. For Pre-COVID-19 Outbreak Period and COVID-19 Outbreak Period see Fig. 3 centering on the trade war period.

[f]Outbreak is abbreviated as "*O.*"

[g]That is, daily rate of change in exchange rates.

Also shown *cross-sectionally* in Fig. 5 is that for Fig. 2 the variablility of CD is the smallest in the pre-U.S.-China trade war period, whereas it is the smallest for Fig. 2-[Right] in the U.S.-China trade war period and for Fig. 2-[Left] that of ED is the largest.

Exchange rate variability in the two subperiods may be summarized as follows: (For Fig. 2 and as consistent with Figs. 6-[Top] and -[Middle]) variability of JD and ED turns out *smaller* in the latter (trade war) period than the former period; the same holds true with that of raw CD (for Fig. 2-[Left] and as consistent with Fig. 6-[Bottom]), but (for Fig. 2-[Righ]) that of CD's rate of change is *larger* in the latter period.

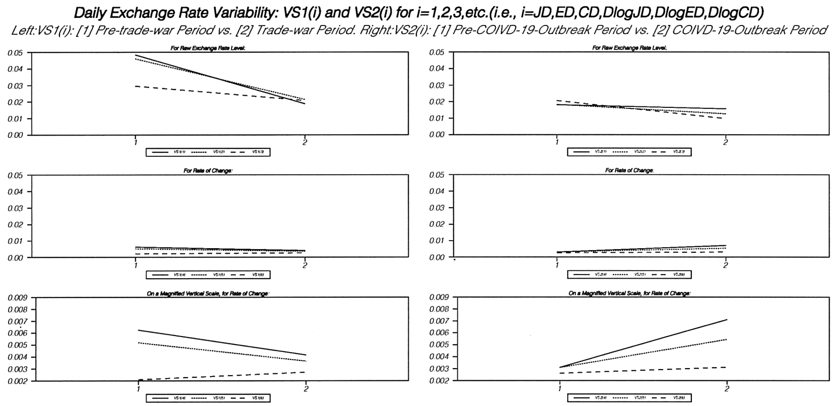

Figure 5 Daily Exchange Rate Variability. Note 1: The real line, the densely dotted line and the sparsely dotted line are exchange rate variability of, respectively, JD, ED and CD. Note 2: The **left half** is for [1] pre-U.S.-China trade war period (September 1, 2015-June 14, 2018) versus [2] U.S.-China trade war period (June 15, 2018-May 29, 2020) (see Fig. 2); the **right half** is for [1] pre-COVID-19 outbreak period (June 15, 2018-January 16, 2020) versus [2] COVID-19 outbreak period (January 17-May 29, 2020) (see Fig. 3). Note 3: In each half, the top [middle and bottom] chart[s] draws exchange rate variability as measured by coefficients of variability [standard deviations] of daily raw exchange rate levels (denoted by JD, etc.) [their rates of change (denoted by dlogJD, etc.)], where coefficients of variability are the (unbiased) sample standard deviation divided by the sample mean and standard deviations are unbiased estimates.

3.1.2 (Right-sided) F-tests, based on residuals from time-series models

For statistical inference of exchange rate variability as graphically depicted in Fig. 5, F-tests of residuals variance ratio (a ratio of residuals variance of a time-series model during a subperiod to that during the other subperiod) may be conducted,[17] if residuals from a time-series model are not autocorrelated during a subperiod, they are normally dis-

[17] For searching for and detecting a variance shift in a time series, based on residuals variance, see Kojima (1994, pp.115-117), for example.

tributed, and they are independent of those during the other subperiod.[18]

Univariate modeling With X_t and a_t denoting, respectively, the raw data and the white-noise error term, and the usual notation, the univariate, multiplicative seasonal autoregressive integrated moving average model, SARIMA $(p, d, q; P, D, s, Q)$, for $X_t^{\ell}(=\log X_t)$ is written as

$$\phi(B)\Phi(B^s)(1-B)^d(1-B^s)^D X_t^{\ell} = \theta(B)\Theta(B^s)a_t \tag{1}$$

where $\phi(B), \Phi(B^s), \theta(B)$ and $\Theta(B^s)$ are, respectively, AR, SAR, MA and SMA multinomials of backshift operator B, which, with $\phi_0 = \Phi_0 = \theta_0 = \Theta_0 = -1$, are written as:

$$\begin{aligned} \phi(B) &= -\sum_{i=0}^{p} \phi_i B^i;\ \Phi(B^s) = -\sum_{i=0}^{P} \Phi_i B^{is}; \\ \theta(B) &= -\sum_{i=0}^{q} \theta_i B^i;\ \Theta(B^s) = -\sum_{i=0}^{Q} \Theta_i B^{is}. \end{aligned} \tag{2}$$

Also:

$$W_t^{\ell} = (1-B)^d(1-B^s)^D X_t^{\ell}. \tag{3}$$

(For further details see Kojima 2019, Subsection 3.1.)

Univariate time series models for exchange rates are identified as summarized in Kojima (2019, Subsection 3.1). Table 4 is quoted from there and will be subsequently referred to.

Two sets of conjectures/hypotheses A priori, whether variability of an exchange rate during the pre-trade war period is larger or smaller than that during the trade war period is not clear. If one intuitively believes, as an alternative hypothesis, that an exchange rate may be more variable during the trade war period, then a null and an alternative for (right-sided) F-tests will be:

$$\begin{aligned} H_0 &: \sigma_{pre}^2 \geq \sigma_{tc}^2 \text{ or } \tfrac{\sigma_{tc}^2}{\sigma_{pre}^2} \leq 1, \\ H_A &: \sigma_{pre}^2 < \sigma_{tc}^2 \text{ or } \tfrac{\sigma_{tc}^2}{\sigma_{pre}^2} > 1 \end{aligned} \tag{4}$$

where σ_p^2 are variances of residuals from a time-series model for $p = pre, tc$ (denoting here, respectively, the pre-trade war period and the trade war period).

[18] See DeGroot (1975, pp.425-428), for example.

Table 4 Time Framework for Raw (Undifferenced) Data, Differenced Data and Residuals Series

Raw (Undifferenced) Data X_t	Differenced, Logged Data W_t^ℓ	Residuals Series $e_t{}^a$
1		
2		
$\vdots$		
$1+d+sD$	1	
$\vdots$	$\vdots$	
$1+d+sD+\underline{\max\{p,sP\}}$	$1+\underline{\max\{p,sP\}}$	1
$\vdots$	$\vdots$	$\vdots$
T	$T'(=T-d-sD)$	$T'^r(=T'-\underline{\max\{p,sP\}})$

[a]For this notation see Kojima (2019, Subsection 5.3.3).

F-test results based on residuals from time-series models are tabulated in Table 5-Panel 1, showing, consistently with the rate-of-change part in Fig. 5, that the nulls for JD and ED are not rejected, while that for CD rejected: That is, the two former exchange rates vary more during the pre-trade war period, while the CD varies more during the trade war period. (Time-series models for the trade war period, estimated based on identification results, are graphically exhibited for JD, ED and CD, respectively, in Figs. 6-[Top], -[Middle] and -[Bottom].)

If one, however, conjectures, as an alternative hypothesis, that an exchange rate may vary more during the pre-trade war period, then the following hypotheses apply:

$$\begin{aligned} H_0 &: \sigma^2_{pre} \le \sigma^2_{tc} \text{ or } \frac{\sigma^2_{pre}}{\sigma^2_{tc}} \le 1, \\ H_A &: \sigma^2_{pre} > \sigma^2_{tc} \text{ or } \frac{\sigma^2_{pre}}{\sigma^2_{tc}} > 1. \end{aligned} \tag{5}$$

and the F-test results are shown in Table 5-Panel 2 documenting that the nulls for JD and ED are rejected, while that for CD not rejected: This is naturally consistent with Table 5-Panel 1 for the hypotheses (4).

The descriptive results in Subsections 3.1.1 and 3.1.2 are summarized in symbols in Table 8–Panel 1-A in Subsection 4.6, from which to make inferences on temporal homogeneity [1][19] in the concluding section.

[19]For [1] and its associated conjecture see Subsection 1.1.

Table 5 (Right-sided) F-tests, Based on Residuals from Time-series Models[a], along with the Residuals Normality Check

Exchange Rate	Computed F Statistics	Signif Level
Panel 1: For the hypotheses (4)		
JD	0.45846[b]	1.00000000
ED	0.49303[c]	1.00000000
CD	1.64351[d]	0.00000000
Panel 2: For the hypotheses (5)		
JD	2.18121[e]	0.00000000
ED	2.02829[f]	0.00000000
CD	0.60845[g]	1.00000000

Panel 3: The Residuals Normality Check for Figs. 6 and 7

Residuals for	Skewness	Signif Level (Sk=0)
Entire Period (Period VI):		
dlogJD (Fig. 6-[Top])	-0.397596	0.000000
dlogED (Fig. 6-[Middle])	-0.120432	0.092202
dlogCD (Fig. 6-[Bottom])	0.141747	0.048444
Trade War Period:		
dlogJD (Fig. 7-[Top])	-0.646522	0.000000
dlogED (Fig. 7-[Middle])	-0.303868	0.006741
dlogCD (Fig. 7-[Bottom])	0.474772	0.000020

[a]See Eqs. (1)-(3) and Table 4.

[b]F(488,675) where degrees of freedom are those of the variance ratio in the hypotheses (4): The degrees of freedom (for the trade war period) and denominator (for the pre-trade war period) are, respectively, $(1186-697)-1$ and $(697-1-20)-1$ for unbiased sample variances of the second and the first parts of residuals from the AR[18,20] time-series model in Fig. 6-[Top], estimated for the entire period (Period VI). For the number of residulas for the first part (the pre-trade war period) see T'^r in Table 4; note that that for the second part (the trade war period) will not be affected by d, D or p in particular, in Table 4.

[c]F(488,686) where the second degrees of freedom is computed as $(697-1-9)-1$ based on the first part of residuals from the AR[9] time-series model in Fig. 6-[Middle], estimated for (entire) Period VI.

[d]F(488,676) where the second degrees of freedom is computed as $(697-1-19)-1$ based on the first part of residuals from the AR[19] time-series model in Fig. 6-[Bottom], estimated for Period VI.

[e]F(675,488). See the second footnote.

[f]F(686,488). See the third footnote.

[g]F(676,488). See the fourth footnote.

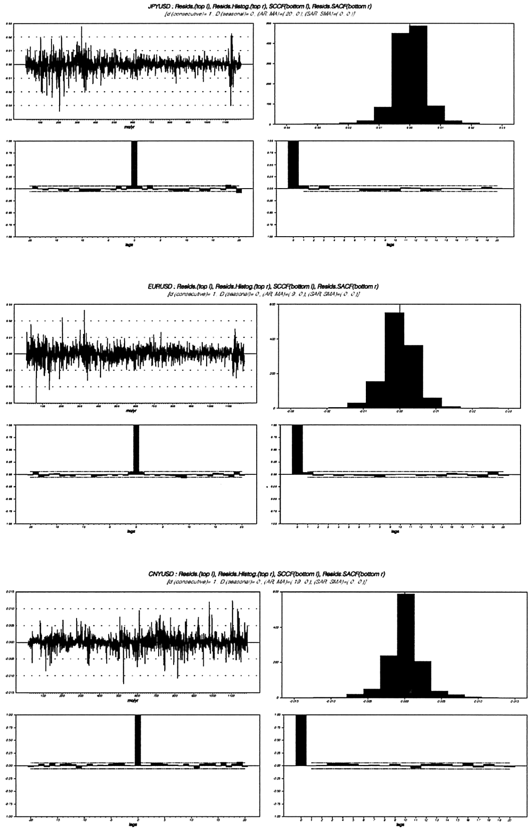

Figure 6 [**Top Four**] AR[18,20] Model without a Constant: Estimation for Logged Daily JD in First Differences (Daily Rate of Change in JD), Entire Period (Period VI). Note 1: The estimated results follow immediately below the figure. Note 2: See Eqs. (1)-(3) for a general univariate model, here and in the remaining figures with $W_t^\ell = (1 - B)X_t^\ell$. Note 3: See Table 5-Panel 3 for the residuals normality check based on skewness. [**Middle Four**] AR[9] Model without a Constant: Estimation for Logged Daily ED in First Differences (Daily Rate of Change in ED), Entire Period (Period VI). [**Bottom Four**] AR[19] Model without a Constant: Estimation for Logged Daily CD in First Differences (Daily Rate of Change in CD), Entire Period (Period VI).

Estimated AR[18,20] Model for Fig. 6-[Top]:

Box-Jenkins - Estimation by LS Gauss-Newton

Dependent Variable TRANSFRM (W_t^ℓ: Doan 2007a, p.420 and 2007b, p.9)

Usable Observations 1165 (T'^r=1186-1-20) Degrees of Freedom 1163 (=1165-2: See footnote g in Kojima(2020, Table 3).)

Centered R**2 0.979865 R Bar **2 0.979847

Uncentered R**2 0.999999 T x R**2 1164.998

Mean of Dependent Variable 4.7044928115

Std Error of Dependent Variable 0.0382959355

Standard Error of Estimate 0.0054365128

Sum of Squared Residuals 0.0343732453

Log Likelihood 4422.96681

Durbin-Watson Statistic 1.879467

Q(36-2) 37.282799

Significance Level of Q 0.32050376

Variable (W_{t-18}^ℓ, etc.) Coeff (ϕ_{18}, etc.)	Std Error T-Stat Signif
1. AR{18} 0.076076945	0.028960840 2.62689 0.00873020
2. AR{20} -0.089752781	0.028960267 -3.09917 0.00198722

Estimated AR[9] Model for Fig. 6-[Middle]:

Box-Jenkins - Estimation by LS Gauss-Newton

Dependent Variable TRANSFRM (W_t^ℓ)

Usable Observations 1176 (T'^r=1186-1-9) Degrees of Freedom 1175 (=1176-1)

Centered R**2 0.985739 R Bar **2 0.985739

Uncentered R**2 0.998686 T x R**2 1174.455

Mean of Dependent Variable -0.120521948

Std Error of Dependent Variable 0.038408022

Standard Error of Estimate 0.004586608

Sum of Squared Residuals 0.0247184413

Log Likelihood 4664.13523

Durbin-Watson Statistic 1.924523

Q(36-1) 37.136510

Significance Level of Q 0.37079954

Variable (W_{t-9}^ℓ) Coeff (ϕ_9)	Std Error T-Stat Signif
1. AR{9} -0.066695810	0.029080584 -2.29348 0.02199613

Estimated AR[19] Model for Fig. 6-[Bottom]:

Box-Jenkins - Estimation by LS Gauss-Newton

Dependent Variable TRANSFRM (W_t^ℓ)

Usable Observations 1166 (T'^r=1186-1-19) Degrees of Freedom 1165 (=1166-1)

Centered R**2 0.995137 R Bar **2 0.995137

Uncentered R**2 0.999998 T x R**2 1165.998

Mean of Dependent Variable 1.9072870233

Std Error of Dependent Variable 0.0341281253

Standard Error of Estimate 0.0023799525

Sum of Squared Residuals 0.0065987624

Log Likelihood 5389.44466

Durbin-Watson Statistic 1.991674

Q(36-1) 43.383722

Significance Level of Q 0.15625868

Variable (W_{t-19}^ℓ) Coeff (ϕ_{19})	Std Error T-Stat Signif
1. AR{19} 0.0749340205	0.0294498854 2.54446 0.01107291

3.2 Pre-COVID-19 outbreak period versus COVID-19 outbreak period: The right half of Fig. 5

3.2.1 A graphics-based study

Useful here are Fig. 3 focusing on the trade war period, which is divided into two subperiods: (Non-shaded) Pre-COVID-19 outbreak period and (shaded) COVID-19 outbreak period.

Also useful are Fig. 4 concentrating further on more recent part of Fig. 3.[20]

Further shown in Fig. 5, or equivalently Table 3, is that for Fig. 2-[Left] (or Fig. 3-[Left]) both JD and ED [CD] are *[much] less* variable in the COVID-19 outbreak period, whereas for Fig. 2-[Right] (or Fig. 3-[Right]) the two and CD are *more* variable in the COVID-19 outbreak period. The latter is evidenced by the following large spikes in Fig. 3-[Right] (or in Fig. 4-[Right] drawn for Fig. 4-[Left]), which are chronologically and numerically compiled in Table 6 as follows:[21]

dlogJD (daily JD's rate of change) has five positive spikes (that is, the JPY's significant depreciation) on February 19, March 10, 13, 17 and 19, 2020 (1116th, 1130th, 1133rd, 1135th and 1137th obs.) and six negative spikes (that is, the JPY's significant appreciation) on February 28, March 6, 9, 16, 26 and 27, 2020 (1123th, 1128th, 1129th, 1134th, 1142nd, and 1143rd obs.), followed by *no* spikes during the nine consecutive weeks, the 3/30 week through the 5/25 week;

dlogED (daily ED's rate of change) has five positive spikes (that is, the EUR's significant depreciation) on March 9, 12, and 17 through 19, 2020 (1129th and 1132nd, and 1135th through 1137th obs.) and seven negative spikes (that is, the EUR's significant appreciation) on February 27, March 2, 6, 9 and 26, April 7, and May 19, 2020 (1122nd, 1124tth, 1128th, 1129th, 1142nd, 1150th and 1178th obs.), with *no* spikes during the 3/30/2020 week, during the five weeks in a row (the 4/13 week through the 5/11 week) and during the 5/25 week; and

dlogCD (daily CD's rate of change) has four positive spikes on February 3 and March 12, 19 and 25, 2020 (1105th, 1132nd, 1137th and 1141st obs.),[22] the first and the second of which may be possibly due to, re-

[20]Fig. 4 will be studied in Subsection 4.5.

[21]Possible reasons behind the spikes are given in Appendices B.1.1, B.1.2, B.1.3, B.1.4, B.2.1, B.2.2, etc. For such spikes see also Subsection 4.5.

[22]They are followed by *no* spikes during the nine weeks in a row, the 3/30 week through the 5/25 week, which is observed for dlogJD as well.

spectively, the global health emergency the W.H.O. declared on January 30, 2020 (the 1103rd date) and the coronavirus pandemic the W.H.O. declared on March 11, 2020 (the 1131st date). Notice that the CD's rate of change has no negative spikes (that is, no significant appreciation) during the COVID-19 outbreak period.

Table 6 Spikes[a] of dlogJD, etc., i.e., Rates of Change in Exchange Rates, during the Trade War Period

Panel 1

Date Number[c]	dlogJD[b] (0.00415)[d]	Date Number	dlogED (0.00365)	Date Number	dlogCD (0.00271)
Pre-coronavirus Outbreak Period (698-1093):[e]					
				715	0.00705
				721	0.00845
		736	0.01317		
				746	-0.00837
				776	0.00757
				793	-0.00678
				814	-0.01039
				815	-0.00723
834	-0.01373				
				861	0.0069
				922	0.00681
				924	0.00749
				951	-0.0073
981	-0.01323				
				982	0.01213
				996	0.00838

(Continued to Panel 2 of the table)

[a]They are defined as those rates of change whose absolute values, i.e., |dlog· · · |, are greater than crtv×(unbiased) sample standard deviation of dlog· · · during the trade war period (drawn in Figs. 3-[Right] and, partially, 4-[Right]), where crtv is set equal to 2.5. Note, however, that, based on skewness, dlog· · · are not necessarily found normally distributed, as documented in the table in italic below: The histograms of dlog· · · for the trade war period are drawn in Fig. 13-[Right] in Subsection 4.3.2.

[b]Listed are those of dlogJD greater than 2.5× (unbiased) sample standard deviation in the parantheses immediately below. This applies to the remaining exchange rates as well.

[c]See Table 2 for exact dates in Period VI.

[d](Unbiased) Sample standard deviation of dlogJD during the trade war period. This applies to the remaining exchange rates as well.

[e]715 = July 11, 2018; 996 = August 26, 2019.

dlog· · ·	*Skewness*	*Signif Level (Sk=0)*
dlogJD	*-0.397119 (Skewed to the left)*	*0.000356*
dlogED	*-0.112887*	*0.310135*
dlogCD	*0.474772 (Skewed to the right)*	*0.000020*

Panel 2

Date Number	dlogJD	Date Number	dlogED	Date Number	dlogCD
Coronavirus Outbreak Period (1094-1186):					
DJF:[a]					
(1094:	*January 17, 2020)*[b]				
				1105	0.01212
F18:					
1116	0.01132				
F24:					
		1122	-0.00940		
1123	-0.01613				
M2:					
		1124	-0.01381		
1128	-0.01133	1128	-0.01054		
M9:					
1129	-0.02997	1129	-0.01111		
1130	0.02110				
(1131:	*March 11, 2020)*[c]				
		1132	0.01131	1132	0.01
1133	0.02269				
M16:					
1134	-0.01463				
1135	0.01351	1135	0.01500		
		1136	0.00976		
1137	0.01944	1137	0.01378	1137	0.00921
M23:					
				1141	0.00706
1142	-0.01666	1142	-0.01534		
1143	-0.01231				
M30: No Spikes.					
A6:					
		1150	-0.00963		
A13: No Spikes.					
A20: No Spikes.					
A27: No Spikes.					
My:					
		1178	-0.01095		

[a]See Table 2 for the notation.
[b]For the date see Note 2 of Fig. 1.
[c]For the date see Note 2 of Fig. 1.

Further, notice that the CD's rate of change has far more spikes even during the pre-COVID-19 outbreak period (lasting up until date number 1093) than the remaining two currencies having far more spikes during the COVID-19 outbreak period than during the pre-COVID-19 outbreak period. This is consistent with the right half of Fig. 5.

Also shown *cross-sectionally* in Fig. 5 is that for raw levels in Fig. 2-[Left] (or Fig. 3-[Left]) [rates of change in Fig. 2-[Right] (or Fig. 3-[Right])] the variability of CD is the largest [smallest] in the pre-COVID-19 outbreak period, whereas for both figures (that is, for both raw levels and rates of change) it is the smallest in the COVID-19 outbreak period.

3.2.2 (Right-sided) F-tests, based on residuals from time-series models

Two sets of conjectures/hypotheses Again, a priori, whether variability of an exchange rate during the pre-COVID-19 outbreak period is larger or smaller than that during the COVID-19 outbreak period is not clear. If one intuitively conjectures, as an alternative hypothesis,

Table 7 (Right-sided) F-tests, Based on Residuals from Time-series Models[a]

Exchange Rate	Computed F Statistics	Significance Level
Panel 1: For the hypotheses (4)		
JD	4.71221[b]	0.00000000
ED	2.87348[c]	0.00000000
CD	1.43168[d]	0.01064688
Panel 2: For the hypotheses (5)		
JD	0.21221[e]	1.00000000
ED	0.34801[f]	1.00000000
CD	0.69848[g]	0.98935312

[a]See Eqs. (1)-(3) and Table 4.

[b]F(92,382) where degrees of freedom are those of the variance ratio in the hypotheses (4): The degrees of freedom for numerator (for the COVID-19 outbreak period) and denominator (for the pre-COVID-19 outbreak period) are, respectively, $(1186-1093)-1$ and $(1093-697-1-12)-1$ for unbiased sample variances of the second and the first parts of residuals from the AR[6,8,12] time-series model in Fig. 7-[Top], estimated for the trade war period. For the number of residulas for the first part (the pre-COVID-19 outbreak period) see T'^r in Table 4; note that that for the second part (the COVID-19 outbreak period) will not be affected by d, D or p in particular, in Table 4.

[c]F(92,386) where the degrees of freedom for denominator (for the pre-COVID-19 outbreak period) is $(1093-697-1-8)-1$ for unbiased sample variances of residuals from the AR[1,6,8] time-series model in Fig. 7-[Middle], estimated for the trade war period.

[d]F(92,394) where the degrees of freedom for denominator (for the pre-COVID-19 outbreak period) is $(1093-697-1)-1$ for unbiased sample variances of residuals from the white-noise time-series model in Fig. 7-[Bottom], estimated for the trade war period.

[e]F(382,92). See the second footnote.

[f]F(386,92). See the third footnote.

[g]F(394,92). See the fourth footnote.

that an exchange rate may be more variable during the COVID-19 outbreak period, then a null and an alternative for (right-sided) F-tests will be the hypotheses (4), where $p = pre, tc$ denote here, respectively, the pre-COVID-19 outbreakr period and the COVID-19 outbreak period. F-test results are tabulated in Table 7-Panel 1, showing, consistently with the rate-of-change part in Fig. 5, that the nulls are all rejected and the alternatives accepted at any conventional level of significance: That is, based on residuals from time-series models, all three exchange rates vary more during the COVID-19 outbreak period. (Time-series models for the trade war period, estimated based on identification results, are graphically exhibited for JD, ED and CD, respectively, in Figs. 7-[Top], -[Middle] and -[Bottom].)

If one, however, conjectures, as an alternative hypothesis, that an exchange rate may vary more during the pre-COVID-19 outbreak period, then the hypotheses (5) apply and the F-test results are shown in Table 7-Panel 2 documenting that none of the nulls are rejected: This is naturally consistent with Table 7-Panel 1 for the hypotheses (4).

The descriptive results in Subsections 3.2.1 and 3.2.2 are summarized in symbols in Table 8–Panel 2-A in Subsection 4.6, from which to make inferences on temporal homogeneity [1][23] in the concluding section.

[23] For [1] and its associated conjecture see Subsection 1.1.

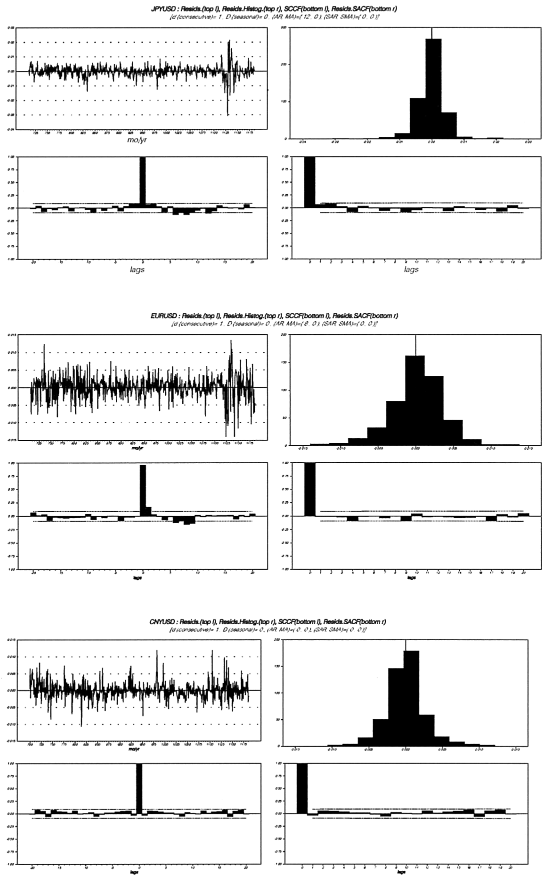

Figure 7 [**Top Four**] AR[6,8,12] Model without a Constant: Estimation for Logged Daily JD in First Differences (Daily Rate of Change in JD), Trade War Period (698-1186). Note: See Notes in Fig. 6. [**Middle Four**] AR[1,6,8] Model without a Constant: Estimation for Logged Daily ED in First Differences (Daily Rate of Change in ED), Trade War Period (698-1186). [**Bottom Four**] A White-noise Model with a Constant: Estimation for Logged Daily CD in First Differences (Daily Rate of Change in CD), Trade War Period (698-1186).

Estimated AR[6,8,12] Model in Fig. 7-[Top]:
Box-Jenkins - Estimation by LS Gauss-Newton (This line is omitted below.)
Dependent Variable TRANSFRM (W_t^ℓ)
Usable Observations 476 (T'^r=489-1-12) Degrees of Freedom 473 (=476-3)
Centered R**2 0.954086 R Bar **2 0.953892
Uncentered R**2 0.999999 T x R**2 476.000
Mean of Dependent Variable 4.6974649314
Std Error of Dependent Variable 0.0191092482
Standard Error of Estimate 0.0041033073
Sum of Squared Residuals 0.0079639627
Log Likelihood 1942.16791
Durbin-Watson Statistic 1.870186
Q(36-3) 24.414587
Significance Level of Q 0.86023747

Variable (W_{t-6}^ℓ, etc.) Coeff (ϕ_6, etc.)	Std Error T-Stat Signif
1. AR{6} -0.121448811	0.045440170 -2.67272 0.00778385
2. AR{8} -0.118021690	0.045167250 -2.61299 0.00926111
3. AR{12} -0.126332536	0.045327418 -2.78711 0.00553200

Estimated AR[1,6,8] Model in Fig. 7-[Middle]:
Dependent Variable TRANSFRM (W_t^ℓ)
Usable Observations 480 (T'^r=489-1-8) Degrees of Freedom 477 (=480-3)
Centered R**2 0.972776 R Bar **2 0.972662
Uncentered R**2 0.999120 T x R**2 479.577
Mean of Dependent Variable -0.116090161
Std Error of Dependent Variable 0.021242897
Standard Error of Estimate 0.003512351
Sum of Squared Residuals 0.0058845611
Log Likelihood 2033.11972
Durbin-Watson Statistic 2.010591
Q(36-3) 28.993873
Significance Level of Q 0.66697847

Variable (W_{t-1}^ℓ, etc.) Coeff (ϕ_1, etc.)	Std Error T-Stat Signif
1. AR{1} 0.177696392	0.044158446 4.02406 0.00006651
2. AR{6} -0.132319952	0.044265735 -2.98922 0.00294134
3. AR{8} -0.143891783	0.044509592 -3.23283 0.00131062

A White Noise Model in Fig. 7-[Bottom]:
Dependent Variable TRANSFRM (W_t^ℓ)
Usable Observations 488 (T'^r=489-1) Degrees of Freedom 487 (=488-1)
Centered R**2 0.982947 R Bar **2 0.982947
Uncentered R**2 0.999998 T x R**2 487.999
Mean of Dependent Variable 1.9332178636
Std Error of Dependent Variable 0.0207266099
Standard Error of Estimate 0.0027066092
Sum of Squared Residuals 0.0035676320
Log Likelihood 2193.14314
Durbin-Watson Statistic 2.066462
Q(36-0) 39.498699
Significance Level of Q 0.31642001

Variable (No W_{t-i}^ℓ) Coeff (Constant)	Std Error T-Stat Signif
1. CONSTANT 0.0002112146	0.0001225224 1.72389 0.08536317

3.2.3 Time-series models contrasted

Compiling the parameters for Figs. 6 and 7, respectively, in (entire) Period VI and the U.S.-China trade war period, the following table shows that no homogeneity in time series models may be inferred across the three exchange rates (Figs. 6-[Top] vs. -[Middle] vs. -[Bottom]) in (entire) Period VI, while two parameters are common across JD and ED (that is, cross-sectional homogeneity may be inferred for Figs. 7-[Top] vs. -[Middle]) in the trade war period, and that contrasting the two periods each exchange rate has no common parameters (that is, no temporal homogeneity may be inferred for Figs. 6-[Top] vs. 7-[Top], 6-[Middle] vs. 7-[Middle], and 6-[Bottom] vs. 7-[Bottom]). We notice that the ϕ_{19} parameter, which is a parameter found common, for Period III and Period V through 2016, to the three exchange rates in Kojima (Table 11, 2020, as Part I), is only included in the CD time series model for the entire period (Period VI).

	Period VI			Trade War Period		
AR Prameters for Figs.	6-[T]	6-[M]	6-[B]	7-[T]	7-[M]	7-[B]
Constant						*
ϕ_1					*	
ϕ_6				*	*	
ϕ_8				*	*	
ϕ_9		*				
ϕ_{12}				*		
ϕ_{18}	*					
ϕ_{19}			*			
ϕ_{20}	*					

The results here in the present subsection (3.2.3) are summarized in symbols in Table 8-Panel 1-C in Subsection 4.6, from which to make inferences on temporal homogeneity [3][24] in the concluding section.

4 Cross Correlations: Figs. 8 - 17

Cross correlations are computed and drawn for inferences on temporal homogeneity [2].

[24]For [3] and its associated conjecture see Subsection 1.3.

4.1 Entire sample period (Period VI): Figs. 8 and 9

For the entire period see Fig. 2.

4.1.1 Cross correlations: Fig. 8-[Left]

Fig. 8-[Left] draws (estimated) sample cross correlation functions (SCCFs) between raw daily exchange rates for the entire sample period (Period VI).[25]

The top (consistently negative) SCCF suggests that JD ($srs1_t$) and CD ($srs2_{t-k}$) comove in the *opposing* directions, that is, for lag $k \geq 0$ the current JPY appreciates [depreciates] as the current and past CNYs depreciate [appreciate], and for lag $k < 0$ the current JPY appreciates [depreciates] as the future CNYs depreciate [appreciate]. We thus observe the JPY behavior as a safe haven, as related to the CNY, for the whole sample period.

Meanwhile, the middle and bottom SCCFs, respectively, between ED ($srs1_t$) and CD ($srs2_{t-k}$) and between JD ($srs1_t$) and ED ($srs2_{t-k}$) suggest that $srs1_t$ and $srs2_{t-k}$ comove in the *same* directions, that is, for lag $k \geq 0$ the current currency of $srs1_t$ appreciates [depreciates] as the current and past currencies of $srs2_{t-k}$ appreciate [depreciate], and for lag $k < 0$ the current currency of $srs1_t$ appreciates [depreciates] as the future currencies of $srs2_{t-k}$ appreciate [depreciate].

Notice in Fig. 8-[Left] that among the three SCCFs those between ED ($srs1_t$) and CD ($srs2_{t-k}$) turn out the largest (in absolute value) for any lags.

4.1.2 Cross correlations: Fig. 8-[Right]

Fig. 8-[Right] draws SCCFs between logged daily exchange rates in first differences, September 2, 2015-May 29, 2020. It suggests that for every

[25] The SCCFs bettween two times series $srs1_t$ and $srs2_{t-k}$ for lag k are computed by

$$r_{srs1srs2}(k) = \frac{\Sigma(srs1_t - \overline{srs1})(srs2_{t-k} - \overline{srs2})}{\sqrt{\Sigma(srs1_t - \overline{srs1})^2 \Sigma(srs2_t - \overline{srs2})^2}}.$$

See Doan (2007a, p.68).

"Under a null of no correlation at any lead or lag, the asymptotic variance of each of the correlation estimates is $1/T$ where T is a sample size." See Doan (2007a, p.69). In the figures the dotted lines are drawn at twice the standard error of the estimates $2\sqrt{1/T}$.

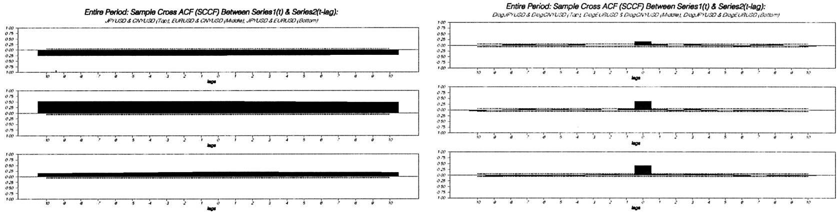

Figure 8 **[Left]** Cross Correlations (SCCFs) Between Raw Daily Exchange Rates, for the Whole Sample Period (Period VI) of September 1, 2015-May 29, 2020. Note: The dotted lines are drawn at ±twice the standard error of the correlation estimates $\pm 2\sqrt{1/T}$ (see the first footnote in Subsectrion 4.1.1-"Entire sample period"). This applies to all remaining SCCF figures. For the entire sample period (Period VI) $\pm 2\sqrt{1/T} = \pm 0.05807$ with $T = 1186$. **[Right]** Cross Correlations (SCCFs) Between Logged Daily Exchange Rates in First Differences, September 2, 2015-May 29, 2020. Note: The dotted lines are drawn at $\pm 2\sqrt{1/T} = \pm 0.05810$ with $T = 1185$.

pair the daily rates of change are positively correlated, only contemporaneously (that is, at lag 0). How to interpret this in the economic context of "a safe haven in troubled times" for the JPY, for example, is not straightforward, however.[26] The only implication we can derive is statistical in nature: The current daily rate of change $srs1_t$ increases [decreases] as the current daily rate of change $srs2_{t-k}$ increases [decreases]; there are observed no cross correlations between current $srs1_t$ and either past ($k > 0$) or future ($k < 0$) $srs2_{t-k}$.

It is true that spurious correlations (embodying time factor/trend) may be avoided by taking first differences of logged daily data (as computed and drawn for daily exchange rates in Figs. 8-[Right] here and 9-[Right] below (and Figs. 10-[Right] and 11-[Right], etc. later). As argued above, however, deleting time factor in this manner may not be appropriate for the exchange rate data, since temporal relations (*inclusive of time factor/trend*) between two exchange rates have critical economic implications, in particular, for the JPY such as "a safe haven in troubled times." Therefore, possible correlations as drawn for daily rates of change

[26] If positive, then the current daily rate of change $srs1_t$ (dlogJD) either increases or decreases with the JPY's fall/depreciation (larger JD); if negative, then the current daily rate of change $srs1_t$ (dlogJD) either increases or decreases (in negative) with the JPY's appreciation (smaller JD).

(*excluding time factor/trend*) in Figs. 8-[Right] and 9-[Right] (and Figs. 10-[Right] and 11-[Right], etc.), which contemporaneously turn out all positive, do not have economic implications (other than statistical ones mentioned above) for exchange rate behavior.

4.1.3 Scatter diagrams

Figs. 9 draws scatter diagrams documenting contemporaneous correlations, respectively, between a pair of raw exchange rate levels and between a pair of first-differenced logged exchange rates, the slopes of straight lines to be approximately drawn for which are consistent with the magnitudes of the contemporaneous correlations as drawn (at lag zero) in Fig. 8.

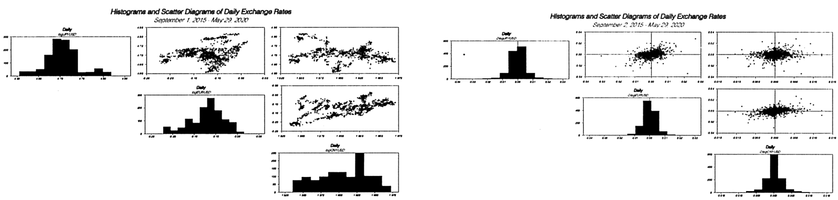

Figure 9 [**Left**] Histograms and Scatter Diagrams of Raw Daily Exchange Rates, for the Whole Sample Period of September 1, 2015-May 29, 2020 (Period VI). [**Right**] Histograms and Scatter Diagrams of First Differences of Logged Daily Exchange Rates (Daily Rates of Change in Exchange Rates), for September 2, 2015-May 29, 2020 (in the Whole Sample Period). Note: Dlog··· in the figure is the same as dlog··· in the text; this applies to the remaining figures.

4.2 Pre-trade war period: Figs. 10 and 11

See non-shaded regions in Fig. 2.

4.2.1 Cross correlations and scatter diagrams

Fig. 10 for the pre-trade war period appears nearly the same as Fig. 8 for the entire Period VI: Subsections 4.1.1 and 4.1.2 apply here, too.

Fig. 11 for the pre-trade war period appears nearly the same as Fig. 9 for the entire Period VI: Subsection 4.1.3 applies here, too; the two figures, [Left] and [Right], are *contemporaneously* (that is, *at lag 0*) consistent, respectively, with Fig. 10-[Left] and -[Right].

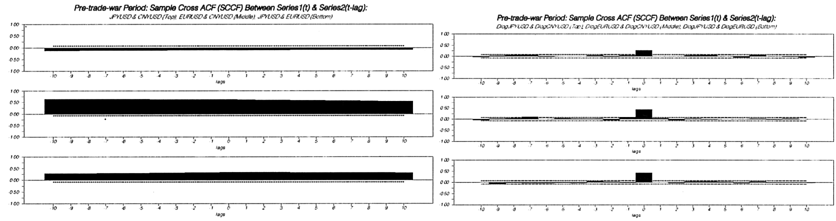

Figure 10 [**Left**] Cross Correlations (SCCFs) Between Raw Daily Exchange Rates, for the Pre-trade War Period of September 1, 2015-June 14, 2018. Note: For the sample period the dotted lines are drawn at $\pm 2\sqrt{1/T} = \pm 0.07576$ with $T = 697$. [**Right**] Cross Correlations (SCCFs) Between Logged Daily Exchange Rates in First Differences, September 2, 2015-June 14, 2018. Note: The dotted lines are drawn at $\pm 2\sqrt{1/T} = \pm 0.07581$ with $T = 696$.

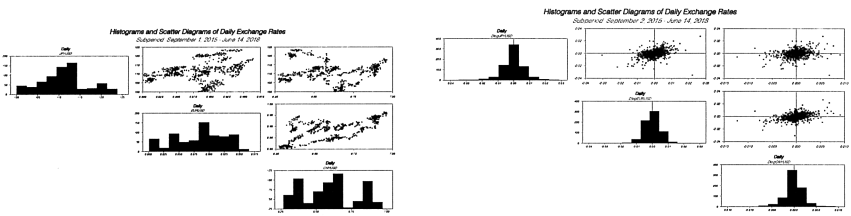

Figure 11 [**Left**] Histograms and Scatter Diagrams of Raw Daily Exchange Rates, for Pre-U.S.-China Trade War Period (September 1, 2015-June 14, 2018). [**Right**] Histograms and Scatter Diagrams of First Differences of Logged Daily Exchange Rates (Daily Rates of Change in Exchange Rates), for September 2, 2015-June 14, 2018 (in the Pre-U.S.-China Trade War Period).

4.3 Trade war period: Figs. 12 and 13

See Fig. 3 focusing on the trade war period (or, equivalently, shaded regions in Fig. 2).

4.3.1 Cross correlations

Fig. 12-[Left] for the trade war period is different from Fig. 10-[Left] for the pre-trade war period in that top and bottom SCCFs are larger (in absolute value) at any lags and that JD and ED *negatively* cross correlated at all lags. That is, JD ($srs1_t$) and ED ($srs2_{t-k}$) comove in the *opposing* directions: For lag $k \geq 0$ the current JPY appreciates [depreciates] as the current and past EURs depreciate [appreciate], and for lag $k < 0$ the current JPY appreciates [depreciates] as the future EURs depreciate [appreciate]. We thus observe the JPY behavior as a safe haven, as related to the EUR, during the trade war period.[27] A possible reason behind this is the large positive correlation between ED and CD. (Notice that the correlations between ED and CD are somewhat large positive irrespective of period studied.)

On the other hand, Fig. 12-[Left] appears the same as Fig. 10-[Left] in that top and middle SCCFs have the same signs. In particular, the correlations between JD and CD are largest negative in the trade war period (and the pre-coronavirus outbreak period); this is again supportive of the usual observation "the JPY as a safe haven in troubled times (such as the trade war that has led to the depreciation of the CNY)."[28]

Fig. 12-[Right] for the trade war period is different from Fig. 10-[Right] for the pre-trade war period in that for the pair of dlogJD and dlogCD the daily rates of change are *not* correlated, even contemporaneously.

4.3.2 Scatter diagrams

Figs. 13 for the trade war period is *contemporaneously* (that is, *at lag 0*) consistent with Fig. 12.

The descriptive results in Subsections 4.2 and 4.3 are summarized in

[27] "The Japanese yen (JPY), a safe haven in troubled times" and "the safe-haven yen" (as indicated by $\subset \cdots \supset$ in the table in Subsection 1.2) are evidenced in Subsections 4.1 through 4.5: For example, Appendix A-**k**-*(ii)*-Wednesday & Friday; Appendix A-**l**-*(i)* related to Appendix B.2.10-*12* (Wed.5/13); and Appendix B.2.10-*22 & 27* (Fri.5/22 & 29).

There are, however, weeks "F18," "M9" and "M16" through earlier days of "M23" (Appendix A-**a**, -**d**, -**e**, **etc.**) when 'Japan's yen may lose its long-standing status as a "safe-haven asset"' (as indicated by $[\cdots]$ in the table in Subsection 1.2 and as first mentioned in Appendix A-**a** for F18, the 2/18/2020 week - JD behavior).

[28] That is, the U.S.-China trade war will most likely cause depreciation of the CNY, which will in turn lead to appreciation of the JPY.

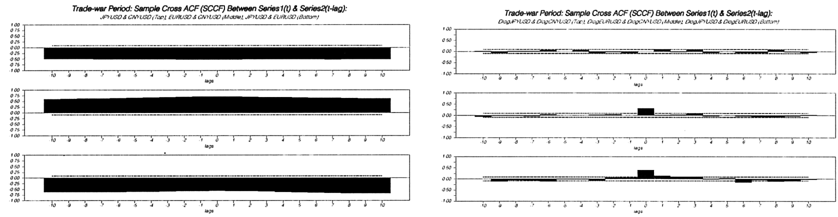

Figure 12 [**Left**] Cross Correlations (SCCFs) Between Raw Daily Exchange Rates, for the Trade War Period of June 15, 2018-May 29, 2020. Note: For the sample period the dotted lines are drawn at $\pm 2\sqrt{1/T} = \pm 0.09044$ with $T = 489$. [**Right**] Cross Correlations (SCCFs) Between Logged Daily Exchange Rates in First Differences, June 18, 2018-May 29, 2020. Note: The dotted lines are drawn at $\pm 2\sqrt{1/T} = \pm 0.09053$ with $T = 488$.

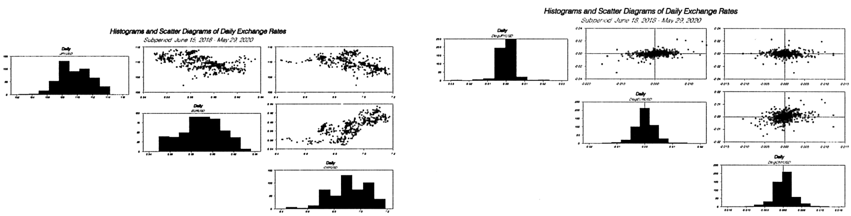

Figure 13 [**Left**] Histograms and Scatter Diagrams of Raw Daily Exchange Rates, for the U.S.-China Trade War Period (June 15, 2018-May 29, 2020). [**Right**] Histograms and Scatter Diagrams of First Differences of Logged Daily Exchange Rates (Daily Rates of Change in Exchange Rates), for June 18, 2018-May 29, 2020 (in the U.S.-China Trade War Period).

symbols in Table 8–Panel 1-B in Subsection 4.6, from which to make inferences on temporal homogeneity [2][29] in the concluding section.

4.4 Pre-coronavirus outbreak period: Figs. 14 and 15

Recall that non-shaded regions in Fig. 3 correspond to the pre-coronavirus outbreak period.

[29] For [2] and its associated conjecture see Subsection 1.2.

Now the trade war period (June 15, 2018-May 29, 2020) is further divided into two subperiods, the pre-coronavirus outbreak period (June 15, 2018-January 16, 2020) and the coronavirus outbreak period (January 17, 2020-May 29, 2020).

For the exchange rate variability during the pre-COVID-19 outbreak period (versus the COVID-19 outbreak period) see Subsection 3.2.

4.4.1 Cross correlations and scatter diagrams

Fig. 14 for the pre-coronavirus outbreak period appears nearly the same as Fig. 12 for the trade war period:[30] "Cross correlations: Fig. 12-[Left]" and "Cross correlations: Fig. 12-[Right]" of Subsection 4.3 apply here, too. This suggests that cross correlations during the (longer) trade war period are dominated by those during the pre-coronavirus outbreak period, which is first part of the trade war period.

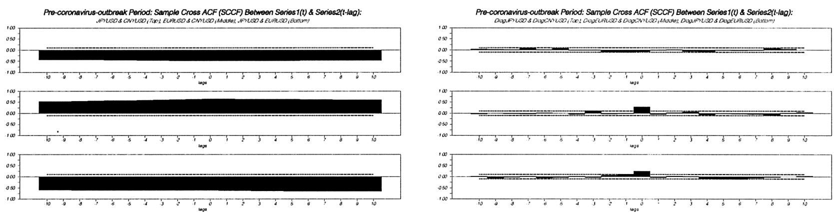

Figure 14 [**Left**] Cross Correlations (SCCFs) Between Raw Daily Exchange Rates, for the Pre-coronavirus Outbreak Period of June 15, 2018-January 16, 2020. Note: For the sample period the dotted lines are drawn at $\pm 2\sqrt{1/T} = \pm 0.10050$ with $T = 396$. [**Right**] Cross Correlations (SCCFs) Between Logged Daily Exchange Rates in First Differences, June 18, 2018-January 16, 2020. Note: The dotted lines are drawn at $\pm 2\sqrt{1/T} = \pm 0.10063$ with $T = 395$.

Fig. 15 for the pre-coronavirus outbreak period appears nearly the same as Fig. 13 for the trade war period: "Scatter diagrams" of Subsection 4.3 applies here, too. This suggests that scatter diagrams during the (longer) trade war period are dominated by those during the pre-coronavirus outbreak period, which is first part of the trade war period.

[30]This will be indicated by the symbol * (for Figs. 12-[Left] and 14-[Left]) in Table 8 later in Subsection 4.6.

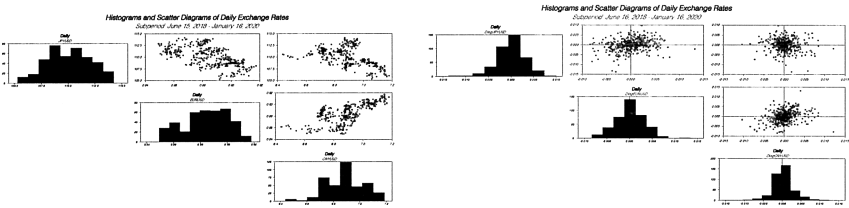

Figure 15 [**Left**] Histograms and Scatter Diagrams of Raw Daily Exchange Rates, for the Pre-coronavirus Outbreak Period (June 15, 2018-January 16, 2020). [**Right**] Histograms and Scatter Diagrams of First Differences of Logged Daily Exchange Rates (Daily Rates of Change in Exchange Rates), for June 18, 2018-January 16, 2020 (in the Pre-coronavirus Outbreak Period).

4.5 Coronavirus outbreak period: Figs. 16 and 17

Recall that shaded regions in Fig. 3 correspond to the coronavirus outbreak period. Also, recall that Fig. 4 focuses further on more recent part of Fig. 3. For the exchange rate variability during the COVID-19 outbreak period see Subsection 3.2.

4.5.1 Cross correlations: Fig. 16-[Left]

On the condition that a sample size is small, Fig. 16-[Left] for the coronavirus outbreak period is notably different from Fig. 14-[Left] for the pre-coronavirus outbreak period in that top and bottom SCCFs, respectively, between JD ($srs1_t$) and CD ($srs2_{t-k}$) and between JD ($srs1_t$) and ED ($srs2_{t-k}$) are, respectively, *not* significant for $k \geq -2$ and *positive* for $-1 \leq k \leq 3$. This suggests, for ED ($srs1_t$) and CD ($srs2_{t-k}$) and for JD ($srs1_t$) and ED ($srs2_{t-k}$), that $srs1_t$ and $srs2_{t-k}$ comove in the *same* direction: The current $srs1_t$ is positively correlated with the past $srs2_{t-k}$ and with the current and future $srs2_{t-k}$ as well. Recall that the positive corrlations are only observed for ED ($srs1_t$) and CD ($srs2_{t-k}$) during the pre-coronavirus outbreak period (see again Fig. 14-[Left]).[31]

[31] Meanwhile, the U.S. dollar (USD) plays a role as a safe haven (as indicated by $[\cdots]$ in the table in Subsection 1.2) and as a risk asset (as indicated by $\subset \cdots \supset$ in the table), as evidenced in:

Appendix B.2.10-*24* (Thu. 5/27: "worries about the U.S. response to China's proposed security law for Hong Kong supported safe-haven demand for the greenback") [Note: China started discussions on a national security law for Hong Kong at

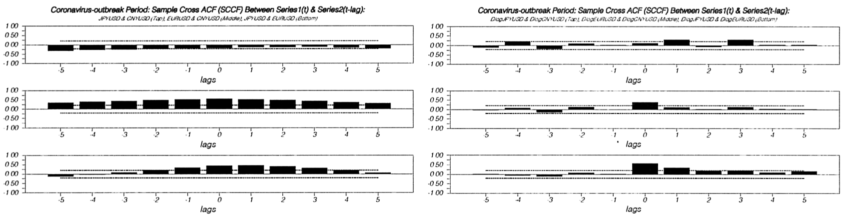

Figure 16 [**Left**] Cross Correlations (SCCFs) Between Raw Daily Exchange Rates, for the Coronavirus Outbreak Period of January 17, 2020-May 29, 2020. Note: For the sample period the dotted lines are drawn at $\pm 2\sqrt{1/T} = \pm 0.20739$ with $T = 93$. [**Right**] Cross Correlations (SCCFs) Between Logged Daily Exchange Rates in First Differences, January 18, 2020-May 29, 2020. Note: The dotted lines are drawn at $\pm 2\sqrt{1/T} = \pm 0.20851$ with $T = 92$.

The comovement in the same direction during the coronavirus outbreak period, in particular, is documented on a daily and weekly basis, in **a**, **c** through **f**, **h** through **k**, and **l** (though not quite so in **g**) in Appendix A, a summary part *(i)* of each of which is quoted below (with footnotes and daily details *(ii)*, etc. being omitted):

a. F18 and F24 in Table 2 and Fig. 4 *(i) Summary:* The exchange rate behavior during the week of 2/18 to 2/21/2020 (F18. 1115 to 1118, in Table 2 and shaded in Fig. 4), the reason behind which is documented in Appendix B.1.3, and the exchange rate behavior during the week

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a meeting of the National People's Congress, which started earlier Friday, May 22, 2020.];

Appendix B.2.10-*17* (Tue. 5/19, in particular; with the risk sentiment being improved, USD as a safer asset is less demanded than riskier assets like the euro, which, though, appears inconsistent with Appendix A-**i** below);

Appendix A-**l**-*(i)*, related to Appendix B.2.10-*9* (Tue. 5/12, in particular; USD as a safe haven);

Appendix A-**j** (Monday, 4/20, Wed, 4/22 and Thu. 4/23, in particular; USD as a safe haven); and

Appendix A-**i** (the footnote for Wednesday and Thursday, in particular), where "risk sentiment" (risk appetite/preference, risk aversion) and "less plunging (or rising) oil price→greater optimism and risk appetite→(see the footnote for *In Japan -5* on Friday in Appendix A-**g** for M30) USD's appreciation" are referred to. For "risk appetite gradually growing(, leading to USD's appreciation)" see also Appendix B.2.10-*19 & 20* (Wed. & Thu. 5/20 & 21).

of 2/24 to 2/28/2020 (F24. 1119 to 1123, in Table 2 and Fig. 4), the reason behind which is documented in Appendix B.1.4, show that during the 2/18/2020 week [the 2/24/2020 week] *both* the CNY and the JPY depreciated [appreciated, depreciated and again (sharply this time) appreciated].

This in turn means that the 2/24/2020 week and the preceding 2/18/2020 week are complete opposites in that while 'Japan's yen may lose its long-standing status as a "safe-haven asset"' during the 2/18/2020 week, the JPY appears to have quickly regained the status during the subsequent 2/24/2020 week (especially on Monday, Tuesday, Thursday and Friday).

b. DJF and F10 in Table 2 and Fig. 4 *(i) Summary:* The exchange rate behavior during the weeks in December and January until the week of 2/3 to 2/7/2020 (DJF. 1063 to 1109, in Table 2 and Fig. 4), the reason behind which is documented in Appendix B.1.1, and the exchange rate behavior during the week of 2/10 to 2/14/2020 (F10. 1110 to 1114, in Table 2 and Fig. 4), the reason behind which is documented in Appendix B.1.2, show that the CD and the JD behavior for the period from 12/2/2019 up until the week of 2/3/2020 to 2/7/2020 (DJF. 1063 to 1109, in Table 2 and shaded in Fig. 4) appears to in part show the opposite: The CNY depreciated during the period from January 20 through February 3, whereas the JPY consistently behaved as a safe haven in troubled times (such as the coronavirus outbreak), that is the currency appreciated during the period from January 21 to January 31.

The CD and the JD behavior for the week of 2/10 to 2/14/2020 (F10. 1110 to 1114, in Table 2 and not shaded in Fig. 4) shows that the CNY and the JPY were both unstable so that there does not seem to be observed an evident correlation between the two.

c. M2 in Table 2 and shaded in Fig. 4 The exchange rate behavior during the week of 3/2 to 3/6/2020 (M2. 1124 to 1128, in Table 2 and shaded in Fig. 4), the reason behind which is documented in Appendix B.2.1, shows that nearly everyday all three currencies appreciated. Recall, in particular, <u>a fear trade</u> as observed in the U.S. financial markets during the 2/24 and 3/2 weeks (F24 and M2 in Table 2 and Fig. 4).

d. M9 in Table 2 and Fig. 4 *(i) Summary:* The exchange rate behavior during the week of 3/9 to 3/13/2020 (M9. 1129 to 1133, in

Table 2 and Fig. 4), the reason behind which is documented in Appendix B.2.2, shows the JPY's and EUR's appreciation followed by the continuous depreciation, and the CNY's depreciation followed by the appreciation.

e. M16 in Table 2 and shaded in Fig. 4 *(i) Summary:* The exchange rate behavior during the week of 3/16 to 3/20/2020 (M16. 1134 to 1138, in Table 2 and shaded in Fig. 4), the reason behind which is documented in Appendix B.2.3, shows the JPY's and EUR's appreciation followed by the continuous depreciation, and the CNY's depreciation followed by the appreciation. (Note that this is exactly the same as for **d** above for the 3/9/2020 week.)

f. M23 in Table 2 and in Fig. 4 *(i) Summary:* The exchange rate behavior during the week of 3/23 to 3/27/2020 (M23. 1139 to 1143, in Table 2 and in Fig. 4), the reason behind which is documented in Appendix B.2.4, shows the JPY's depreciation followed by the appreciation, the EUR's appreciation throughout the week, and the CNY's volatile behavior.

g. M30 in Table 2 and shaded in Fig. 4 *(i) Summary:* The exchange rate behavior during the week of 3/30 to 4/3/2020 (M30. 1144 to 1148, in Table 2 and in Fig. 4), the reason behind which is documented in Appendix B.2.5, shows the JPY's appreciation followed by depreciation, the EUR's continuous depreciation and the volatile CNY, all against the USD.

h. A6 in Table 2 and in Fig. 4 *(i) Summary:* The exchange rate behavior during the week of 4/6 to 4/9/2020 (A6. 1149 to 1152, in Table 2 and in Fig. 4), the reason behind which is documented in Appendix B.2.6, shows the continuous gradual appreciation of the JPY and the volatile comovement in the same direction of the ED and the CD.

i. A13 in Table 2 and shaded in Fig. 4 *(i) Summary:* The exchange rate behavior during the week of 4/13 to 4/17/2020 (A13. 1153 to 1157, in Table 2 and in Fig. 4), the reason behind which is documented in Appendix B.2.7, shows the three exchange rates' comovement in the same direction throughout the week except on Monday.

j. A20 in Table 2 and in Fig. 4 *(i) Summary:* The exchange rate behavior during the week of 4/20 to 4/24/2020 (A20. 1158 to 1162, in Table 2 and in Fig. 4), the reason behind which is documented in Appendix B.2.8, shows everyday's comovement of a pair of exchange rates, with somewhat unstable CD.

k. A27 in Table 2 and shaded in Fig. 4 *(i) Summary:* The exchange rate behavior during the week of 4/27 to 5/1/2020 (A27. 1163 to 1167, in Table 2 and in Fig. 4), the reason behind which is documented in Appendix B.2.9, shows EUR's continuous appreciation and JD's and CD's unstable behavior, with comovement of the JD and the ED on Monday through Wednesday.

l. My in Table 2 and in Fig. 4 The exchange rate behavior during the four weeks of 5/4 through 5/29/2020 (My. 1168 to 1186, in Table 2 and in Fig. 4), the reason behind which is daily documented in Appendix B.2.10, is summarized on a biweekly, rather than daily, basis as follows:

(i) Summary of the firs two weeks (1168 to 1172 and 1173 to 1177): Fig. 4 shows the EUR and the CNY appear to comove, though weakly, in the same direction, while the JPY and the remaining two appear to behave, though weakly, in opposing directions.

(ii) Summary of the second two weeks (1178 to 1181 and 1182 to 1186): Fig. 4 shows that the JD was stable, that the ED and the CD comoved in the same direction during the first half while the two moved in the opposing direction during the second half, and that the CNY tended to depreciate during the two weeks, with a large depreciation on Wednesday, May 27.

4.5.2 Cross correlations: Fig. 16-[Right]

On condition that a sample size is small, Fig. 16-[Right] for the coronavirus outbreak period differs from Fig. 14-[Right] for the pre-coronavirus outbreak period in that SCCFs for pairs of daily rates of change, dlogJD ($srs1_t$) and dlogCD ($srs2_{t-k}$), dlogED ($srs1_t$) and dlogCD ($srs2_{t-k}$), and dlogJD ($srs1_t$) and dlogED ($srs2_{t-k}$), are positive, respectively, for lags $k = 1, 3$, $k = 0$, and $k = 0, 1$, suggesting that every pair of daily rates of change comoves at the these lags in the same direction.[32]

[32]Recall from Subsection 4.5.1 titled "Cross correlations: Fig. 16-[Left]" that SCCF between JD ($srs1_t$) and CD ($srs2_{t-k}$) is for $k \geq 0$ negative, though not significant.

4.5.3 Scatter diagrams

On the condition that a sample size is small, Fig. 17 for the coronavirus outbreak period appears *contemporaneously* (that is, *at lag 0*) consistent with Fig. 16.

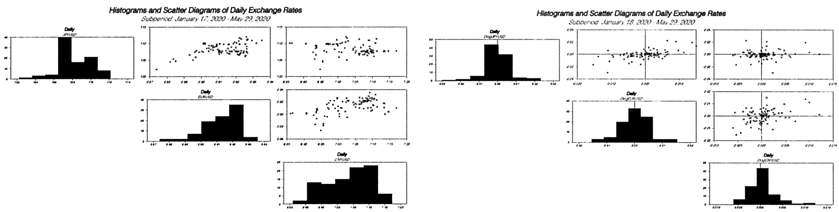

Figure 17 [**Left**] Histograms and Scatter Diagrams of Raw Daily Exchange Rates, for the Coronavirus Outbreak Period (January 17, 2020-May 29, 2020). [**Right**] Histograms and Scatter Diagrams of First Differences of Logged Daily Exchange Rates (Daily Rates of Change in Exchange Rates), for January 18, 2020-May 29, 2020 (in the Coronavirus Outbreak Period).

The descriptive results in Subsections 4.4 and 4.5 are summarized in symbols in Table 8–Panel 2-B in Subsection 4.6, from which to make inferences on temporal homogeneity [2][33] in the concluding section.

4.6 Summary table: Descriptive statistical findings

Table 8 summarizes our descriptive statistical findings in Sections 3 and 4, from which to draw inferences on temporal homogeneity [1] - [3] as defined and associated with three conjectures, respectively, in Subsections 1.1 through 1.3. The table describes by symbols what lies behind temporal homo/heterogeneity, with two consecutive subsample periods being contrasted; temporal homo/heterogeneity itself will be inferred from the descriptive results as symbolized here, next in Section 5.

[33] For [2] and its associated conjecture see Subsection 1.2.

Table 8 Summary Table: What Lies behind Homo/heterogeneity in Time (and in Currency) of the Exchange Rate Behavior[a]

Panel 1

	Before the Trade War		During the Trade War	
A. Variability:				
	Table 3 (Fig. 5-left half), Table 5			
level JD		$>$		
ED		$>$		
CD		$>$		$\Rightarrow^b$ Inferences on [1]
dlogJD		$>$		
dlogED		$>$		
dlogCD		$<$		
B. Cross Correlations:				
	Fig. 10-[Left]		Fig. 12-[Left]	
JD vs. CD	$-$	$\approx$	$-*$	
ED vs. CD	$+$	$\approx$	$+*$	
JD vs. ED	$+$	$>$	$-*$	
	Fig. 10-[Right]		Fig. 12-[Right]	
dlogJD vs. dlogCD	$+$	$>$	0	$\Rightarrow^c$ Inferences on [2]
dlogED vs. dlogCD	$+$	$\approx$	$+$	
dlogJD vs. dlogED	$+$	$\approx$	$+$	
	During Period VI		During the Trade War	
C. Time Series Models:				
	Table in Subsection 3.2.3			
dlogJD		$\neq$	$\bowtie$	$\Rightarrow^d$ Inferences on [3]
dlogED		$\neq$	$\bowtie$	
dlogCD		$\neq$		

(Continued to Panel 2 of the table)

[a]The symbol $\approx$ indicates homogeneity in time, whereas $<, >, \neq$ heterogeneity in time. The symbol $\bowtie$ indicates homogeneity in currency, which is also indicated by $\approx, <, >$ or $\neq$ of temporal homogeneity or heterogeneity detected across a multiple currencies. Each of $-, 0, +$ indicates a sign of statistically significant cross correlations. The symbol * is referred to back in Subsection 4.4.1.

[b]The descriptive results expressed by symbols in the left columns are derived in Subsections 3.1.1 and 3.1.2, to draw inferences on temporal homogeneity [1] in Section 5. (The symbol $\Rightarrow$ indicates drawing inferences on temporal homogeneity from those symbols in the left columns.)

[c]The descriptive results expressed by symbols in the left columns are derived in Subsections 4.2 and 4.3, to draw inferences on temporal homogeneity [2] in Section 5.

[d]The descriptive results expressed by symbols in the left columns are derived in Subsection 3.2.3, to draw inferences on temporal homogeneity [3] in Section 5.

Panel 2

	Before the COVID-19 Outbreak		During the COVID-19 Outbreak	
A. Variability:				
	Table 3 (Fig. 5-right half), Table 7			
level JD		$>$		
ED		$>$		
CD		$>$		$\Rightarrow^{a}$ Inferences on [1]
dlogJD		$<$		
dlogED		$<$		
dlogCD		$<$		
B. Cross Correlations:				
	Fig. 14-[Left]		Fig. 16-[Left]	
JD vs. CD	$-*$	$<$	0	
ED vs. CD	$+*$	$\approx$	$+$	
JD vs. ED	$-*$	$<$	$+$	
	Fig. 14-[Right]		Fig. 16-[Right]	
dlogJD vs. dlogCD	0	$\approx$	0	$\Rightarrow^{b}$ Inferences on [2]
dlogED vs. dlogCD	$+$	$\approx$	$+$	
dlogJD vs. dlogED	$+$	$\approx$	$+$	

[a]The descriptive results expressed by symbols in the left columns are derived in Subsections 3.2.1 and 3.2.2, to draw inferences on temporal homogeneity [1] in Section 5.

[b]The descriptive results expressed by symbols in the left columns are derived in Subsections 4.4 and 4.5, to draw inferences on temporal homogeneity [2] in Section 5.

5 Concluding Remarks

Applying descriptive statistics, the paper studies how the behavior of the three daily exchange rates (JD, ED and CD) has been affected by the U.S.-China trade war and the novel coronavirus outbreak/pandemic. Following the symbol $\Rightarrow$ in the final column of Table 8 we now draw inferences on temporal homogeneity [1] - [3] of the exchange rate behavior during Period VI (September 1, 2015-May 29, 2020) and its subperiods as set in Panel 2 of Table 1:

Before and during the U.S.-China trade war:

Temporal homogeneity [1] (Table 8-Panel 1-A: Exchange rate variability, over two successive periods). We infer no temporal homogeneity [1] over the two periods: The related conjecture at the end of Subsection 1.1 is rejected.[34] The inference suggests a variance shift in such a way that business/economic/financial events that had occurred in the *pre*-trade war period likely led to more variable exchange rate behavior in the pe-

[34]Meanwhile, cross-currency/exchange rate homogeneity is inferred.

riod (than, for example, the COVID-19 outbreak itself in the trade war period). With a variance shift (nonstationarity) inferred as such, it will be desired to estimate and qualitatively characterize, for each subperiod, univariate time series models for every exchange rate.

Temporal homogeneity [2] (Table 8-Panel 1-B: Moving in the same direction or the opposing direction, over two successive periods). Unlike those on temporal homogeneity [1], inferences here are cross-sectionally mixed in that we do infer temporal homogeneity [2] for two pairs, JD and CD, and ED and CD,[35] but not for the remaining pair of JD and ED: The related conjecture at the end of Subsection 1.2 is accepted for the former two pairs but rejected for the latter. A safe haven currency (the JPY in particular) enters the picture here for both two periods.

Temporal homogeneity [3] (Table 8-Panel 1-C: Time series models, over two differing periods). Even with trade war included in both periods (Period VI and the trade war period), business/economic/financial events that had occurred in the *pre*-trade war period, together with the variance shift, appear to have led to temporal *heterogeneity* in time series modeling for the two periods: The related conjecture at the end of Subsection 1.3 is rejected.

During the U.S.-China trade war period (Before and during the COVID-19 outbreak/pandemic):

Temporal homogeneity [1] (Table 8-Panel 2-A: Exchange rate variability, over two successive periods). No temporal homogeneity [1] is inferred for the two periods: The related conjecture at the end of Subsection 1.1 is rejected.[36] What is meant by the inference is a variance shift in such a way that business/economic/financial events that occurred in the *pre*-COVID-19 outbreak period have likely led to more variable exchange rate in level (JD, etc.) in the period (than the COVID-19 outbreak itself during the COVID-19 outbreak period), whereas the COVID-19 outbreak did indeed cause rates of change in exchange rates (dlogJD, etc.) to be more variable in the outbreak period than in the pre-outbreak period. With a variance shift as such possibly occuring, it will be desired to estimate and qualitatively characterize, for each subperiod, univariate time series models for every exchange rate, once sufficient data become available for the latter period.

Temporal homogeneity [2] (Table 8-Panel 2-B: Moving in the same direction or the opposing direction, over two successive periods). Un-

[35] Cross-currency/exchange rate homogeneity for both two periods is also inferred.
[36] Meanwhile, cross-currency/exchange rate homogeneity is inferred.

like those on temporal homogeneity [1], again, inferences here are cross-sectionally mixed in that we infer temporal homogeneity [2] over the two periods for the pair of ED and CD,[37] but not for two remaining pairs, JD and CD, and JD and ED: The related conjecture at the end of Subsection 1.2 is accepted for the former pair but rejected for the latter two. Also, from the observation * in Panels 1 and 2 of Table 8[38] we infer significant temporal homogeneity [2] for the two partially overlapping periods (the pre-coronavirus outbreak period and the trade war period), as well as cross-currency/exchange rate homogeneity for the pre-coronavirus outbreak period. A safe haven currency (the JPY) enters the picture here, only in the former (the pre-COVID-19 outbreak) period.[39]

One question that remains for a future study is: How will the national security law for Hong Kong in particular, as well as the trade war and the COVID-19 pandemic, affect the exchange rate behavior in June 2020 and beyond? China started discussions on the law at a meeting of the National People's Congress, which started earlier Friday, May 22, 2020. And, after a swift and secretive process, China passed the contentious security law granting it sweeping powers to quash dissent in Hong Kong, on Monday, June 29, 2020.[40] As a result, the U.S. pressure over Hong Kong and other sensitive matters could jeopardize Chinese purchases of U.S. exports under a "Phase One" trade deal.[41] Temporal homogeneity of the JD, ED and CD behavior during the ongoing trade war will thus continue to be a research topic for a future study as Part III.

Appendices

Three appendices, A, B and C, detail, respectively, [a] comovement in the same direction of the JD, ED and CD during the coronavirus out-

[37] Cross-currency/exchange rate homogeneity for the coronavirus outbreak period is, too, inferred.

[38] The symbol * is referred to toward the end of the table's first footnote.

[39] In the latter (the COVID-19 outbreak) period the USD plays a role as a safe haven (as indicated by [···] in the table in Subsection 1.2) and as a risk asset (as indicated by $\subset \cdots \supset$ in the table): See the very first footnote attached to Subsection 4.5.1.

[40] *The New York Times*: BREAKING NEWS (Monday, June 29, 2020 10:27 PM EST).

[41] *The Wall Street Journal*: What's News: Here's Your 4-Minute Briefing: Trade Watch (Tue., June 30, 2020).

break period, [b] what possibly lies behind the JD, ED and CD behavior during the more recent U.S.-China trade war period, and [c] selected non-business topics on the outbreak of (deadly) novel coronavirus in China. Involving and refering to two hundred newspaper articles (dated June 15, 2018 through May 30, 2020), the appendices are too long to include in the paper and thus are provided as a pdf file, which is available from the author upon request.

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