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Linear and nonlinear exchange rate exposure ☆

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Abstract

This paper presents a new methodological approach to examine exchange rate exposure which takes account of the role of the market portfolio and macroeconomic variables in exposure regressions, exchange rate regimes based on periods of depreciation and appreciation, and nonlinear exposure. Within each regime we show that the stock market's own exposure to exchange rates should be taken into account before considering industry exposure. In addition, we adjust the exchange rate and the stock market for common economy-wide factors that are unrelated to exchange rates. Within this framework we show that exposure to bilateral exchange rates is statistically and economically important and that industries with extensive international trade are more often exposed than industries with low levels of international trade. The signs of exposure coefficients in each regime are consistent with the extent to which an industry exports. We also show that nonlinear exposure is often statistically and economically significant. Interestingly, there is little evidence that industries are exposed to a currency basket.

JEL classification: F3; F36; G12; G18

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Empirical evidence indicates that there are deviations from purchasing power parity that national economies are becoming increasingly integrated, product and financial markets are

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becoming globalized, and corporate profits are affected by currency movements. In the light of this, it is puzzling that the economic and statistical relationship between exchange rate changes and US stock returns is marginal at best. The majority of empirical studies test for a constant linear relationship between stock returns and exchange rate changes.[1] In contrast, the theoretical literature on the relationship between the value of a firm and the exchange rate generally posits a nonlinear relationship.[2] Furthermore, there are a number of theoretical models that illustrate how firm behavior will be different when the currency is depreciating relative to it appreciating.[3] Therefore, measuring exposure could be further complicated by the fact that exposure may depend on the exchange rate regime. These factors mean that the traditional method of measuring linear exposure may be inappropriate.

Consider Fig. 1 which illustrates both linear and nonlinear exposure for an exporter. The long straight line depicts the case where exposure is estimated as one linear relationship for the whole period and the hyperbola does the same for nonlinear exposure. We also plot two straight lines joined at zero but with different slopes where linear exposure is shown separately for appreciation and depreciation periods.

The figure illustrates the nature of the trade off between estimation methods. Estimating linear exposure for the whole period gives a line with a slope matching the nonlinear curve around zero. This line is useful for finding the effects of small changes in the exchange rate, but as the absolute level of depreciation or appreciation increases, it does a progressively worse job in showing the link between changes in exchange rates and stock returns. Estimating linear exposure separately for appreciation and depreciation periods allows the slope of the posited relationship to change across the two. However, even in this case, if the actual relationship is nonlinear then it would be necessary to use separate nonlinear terms in each regime. A small number of studies examine nonlinear exposure but in economic terms the estimated effects are limited, especially for developed markets, and in particular in the US.[4]

The contribution of our paper lies in assessing linear, nonlinear and regime specific exposure using a methodological innovation relative to the current literature. The central part of our work focuses on the role of the market portfolio in exposure regressions. The market portfolio is typically included in the exposure regression to proxy for omitted factors that may cause spurious correlation between stock returns and exchange rates. However, when it is included the resulting estimate of exposure is that which is in addition to the extent that the market is exposed. Therefore, if a firm's exposure coefficient is estimated to be zero it does not necessarily imply that the firm is not exposed. In light of this, the current methodology of assessing exchange rate exposure is not adequate to answer the question of whether firms are exposed to exchange rates.

Bodnar and Wong (2003) address the issue of the role of the market portfolio in exposure regressions. They focus on the return horizon and the choice of a value versus an equally weighted market portfolio and find that exposure estimates are sensitive to this choice. We

[1] See, for example, Jorion (1990), Bodnar and Gentry (1993), Amihud (1994), Griffin and Stulz (2001) and Doidge et al. (2000).

[2] Krugman (1987), Feenstra (1989), Marston (1990), Knetter (1991) and Marston (2001) provide theoretical models that consider how firms react to exchange rate changes. Mann (1986), Knetter (1989), Marston (1990) and Knetter (1993) report evidence on firms changing margins and prices when exchange rates change.

[3] See, for example, Krugman (1987), Baldwin (1988), Baldwin and Krugman (1989), Dixit (1989), Froot and Klemperer (1989), Knetter (1994), and Kogut and Kulatilaka (1994).

[4] See Allayannis (1997), Allayannis and Ihrig (2001), Bodnar et al. (2002), Doidge et al. (2000), Griffin and Stulz (2001) and Bartram (2002).

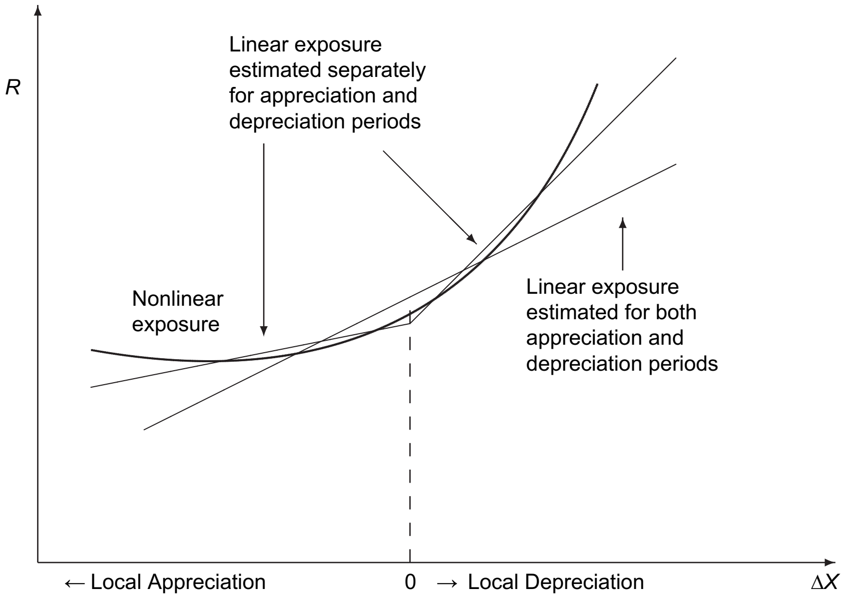

Fig. 1. Estimating exposure of exporter.

take an alternative route by developing an empirical methodology that orthogonalizes both the market portfolio and the exchange rates from common macroeconomic factors that may be correlated with individual stock returns, but have nothing to do with exposure. The advantage of this methodology is that the resulting estimates of exposure can be interpreted more closely as total exposure and thus offer a more reliable way of assessing whether firms are exposed as well as providing a measure of exposure that could be used in a firm's risk management policy.

Using 28 US industries that have varying degrees of international trade, we find linear exposure to bilateral exchange rates to be both statistically and economically important when we use an orthogonalized market portfolio in conjunction with estimating exposure separately for appreciating and depreciating regimes. Industries that have extensive international trade are more often exposed than industries with low levels of international trade. In contrast, using the actual (unorthogonal) exchange rate leads to the conclusion that industries are rarely exposed. We find that the signs of the exposure coefficients are consistent with the extent to which the industries export: an increase in the ratio of exports to total sales increases stock returns when the home currency depreciates and decreases stock returns when the home currency appreciates. When we allow for simple nonlinear effects they are statistically and economically important. This lends support to the theoretical results that firms alter decision making to take advantage of favorable movements in exchange rates and to mitigate unfavorable movements in the exchange rate.

The various results we present regarding the impact of exchange rates on industry stock returns are robust to the inclusion of a set of macroeconomic variables, the Fama and French small minus big stock portfolio (SMB) and high minus low book-to-market (HML) portfolio, and lagged exchange rates. Using a currency basket instead of the bilateral exchange rates leads to the conclusion that exchange rates have little impact on stock returns, a result consistent with the extant literature.

The paper is structured as follows. Section presents the data. Section 2 describes the empirical methodology for linear exposure estimation. The results from the linear exposure are presented and discussed in Section 3. In Section 4 we report results from estimating nonlinear exposure. Section 5 explores the robustness of the results. Section 6 concludes.

1. Data

1.1. Industry returns

Exchange rate exposure is often investigated at the industry level because an industry in one country often competes with the same industry in another country. An unexpected change in the exchange rate should have a similar impact on competitiveness and hence firm value within the industry. We use a sample of monthly value weighted returns for 28 manufacturing industry classifications provided by Ken French.[5] Excess returns are calculated by subtracting the three month treasury bill rate from the actual return.

We collect data on these 28 industries because data are available for them regarding exports, imports and total sales (shipments) from the US Census Bureau. These data are reported annually from 1979 to 1997 and we interpolate it to obtain monthly estimates. As our sample ends in 1998 we use the 1997 end of year values for each month in 1998. Table 1 is split into two panels based on the extent of international trade, defined as the ratio of the sum of exports and imports to total sales. Panel A reports data for those industries we term to have ‘‘Extensive International Trade’’, defined as having a ratio of international trade to total sales of 20% or more. There are 14 industries that satisfy this criteria. Panel B reports the data for industries with ‘‘Low International Trade’’, defined as having a ratio of international trade to total sales of less than 20%. Across the industries in panel A the average ratio of international trade to total sales is 0.40 whereas in panel B this ratio is only 0.09. Clearly, there is a considerable difference between the extent of international trade in these two groups of industries. Consequently, if exchange rates are important we would expect them to have a greater impact on the industries in panel A than on those in panel B.

The final two columns of Table 1 report the ratios of exports to total sales and imports to total sales. Most industries that have extensive international trade tend to have a high level of both exports and imports. This presents a problem in assessing exposure since whilst a net exporter may be expected to benefit from a local currency depreciation, this could be offset by imported costs becoming higher. Furthermore, consider a situation where a firm hedges its exports but not its imports (this is conceivable since firms control prices and quantities of exports but not prices of imports) then an exporter may actually have an exposure coefficient that is the opposite of what is expected based on its net terms of trade. Another issue to consider is that over time the exchange rate exposure may change sign due to changes in the extent of imports and exports. For example, Campa and Goldberg (1999) find that US industries increased their imported input use in the 1980s by a huge amount which could offset the benefits exporters would expect to have from a local currency depreciation. Furthermore, the recent globalization of product markets has led to an intensifying of international competition which could also affect the nature and sign of exposure.

As well as the possibility that export and import shares change over time, it should be noted that an industry with imports could experience either a positive or a negative exposure

[5] The level of aggregation is according to Level 4 SIC code. Data are available from Ken French’s homepage and we thank him for making the data available.

Table 1
Summary statistics

Industry	$\frac{X+I}{TS}$	$\frac{X}{TS}$	$\frac{I}{TS}$
Panel A: industries with extensive international trade			
6. Recreation	0.90	0.18	0.72
35. Computers	0.65	0.32	0.33
10. Apparel	0.58	0.06	0.52
24. Aircraft	0.44	0.34	0.10
23. Autos	0.41	0.12	0.29
37. Measuring and control equipment	0.39	0.25	0.14
36. Electronic equipment	0.36	0.16	0.20
21. Machinery	0.34	0.19	0.15
22. Electrical equipment	0.30	0.15	0.15
9. Consumer goods	0.30	0.08	0.22
12. Medical equipment	0.29	0.17	0.12
19. Steel	0.26	0.08	0.18
14. Chemicals	0.24	0.16	0.08
38 Business supplies	0.20	0.08	0.12
Panel B: industries with low international trade			
4. Beer and liquor	0.18	0.02	0.16
13. Pharmaceutical Products	0.17	0.09	0.08
17. Construction materials	0.14	0.06	0.08
16. Textiles	0.14	0.05	0.09
26. Defense	0.13	0.11	0.02
5. Tobacco	0.12	0.11	0.01
15. Rubber and plastics	0.11	0.05	0.06
25. Shipbuilding and railroad equipment	0.10	0.06	0.04
2. Food products	0.08	0.05	0.03
20. Fabricated products	0.06	0.04	0.02
3. Candy and soda	0.05	0.02	0.03
39. Shipping containers	0.03	0.02	0.01
8. Printing and publishing	0.03	0.02	0.01
34. Business services	0.02	0.01	0.01

The table reports the sample average values of the sum of exports and imports ($X+I$), to total sales (TS). Exports and imports and total sales (shipments) are from the US Census Bureau. Panel A reports data for industries that have more 20% or more of total sales from imports and exports. Panel B reports data for industries that have less than 20% of total sales from imports and exports. The data are sample over the period May 1979–December 1998.

coefficient depending on whether the imports are imported costs or imported competition. In the light of these problems in interpreting the sign of exposure coefficients, our initial analysis focusses on which industries are exposed and whether they have extensive international trade or low levels of international trade. Subsequently we examine whether the exposure coefficients are consistent with the extent of exports in the industry.

1.2. Currencies

Most studies use a currency basket to measure exposure. This imposes the same sign and size of exposure on a firm irrespective of the currency. If a firm exports in one currency and imports in another the sign and size of the exposure will depend on the extent of imports and exports and on the particular currency's movements. Since such effects will not be uncovered with the use of a currency basket we choose to use bilateral rates. This does of course have the limitation that we have to choose a small number of bilateral rates and may therefore only partially uncover exposure.

The dollar Yen (JPY) and dollar ECU rates are chosen as the exchange rates because of their large weights in US imports and exports.[6] The starting date for the analysis is May 1979, the inception of the ECU. In order to provide some comparison with previous results we also collect data on a trade weighted currency index provided by the Federal Reserve Bank of Atlanta.

Since the collapse of Bretton Woods in the early 1970s the US dollar (USD) has floated freely against other currencies. However, there have been specific, distinct periods of USD movements which we refer to as regimes. Fig. 2 plots the two bilateral rates and the currency index. From 1979 up until February 1985 the dollar appreciated substantially. In part, this was due to high real interest rates and consequently large inflows of foreign capital. The high real interest rates were essential to finance the growing budget and trade deficits. Note that the size of the USD appreciation varied across the two exchange rates, being much larger relative to the ECU.

The USD peaked in February 1985 and subsequently undertook a steep depreciation which was due to both the highest ever trade deficit and the coordinated international intervention through the Plaza Accord. Around the time of the Louvre Accord in 1987, fears were rising that the dollar had depreciated too much. Intervention ensued that the dollar stabilized briefly. However, the depreciation continued in the final years of the 1980s. The period from the end of 1990 to the end of the sample is characterized by a more stable period of USD rates. Relative to the JPY, the USD has continued to depreciate. However, relative to the ECU and the currency index the USD has appreciated. The extent of the average USD movements in this period is considerably smaller than in earlier periods. Based on this discussion we identify three USD regimes. The first is the appreciation between 1979 and February 1985. Second, the depreciation between March 1985 and December 1990. Third, the more stable period between January 1991 and December 1998.

The movements in the currency basket are sometimes clearly different from the two bilateral rates. For example, over the entire sample period the change in the currency basket is essentially zero whilst this is not the case relative to the JPY. There are also interesting differences in the subperiods. The extent of the USD appreciation in the first period is much smaller relative to the JPY than the currency basket or the ECU. In the second subperiod the movements are essentially of the same magnitude irrespective of currency. The patterns of the individual currencies and the currency basket provide a strong motivation for first, using different currencies rather than a basket and second, for estimating exposure in subperiods.

A further interesting implication of the patterns in the dollar over time is the potential for nonlinear exposure to arise. Nonlinear exposure arises when managers of firms decide to enact some change in policy aimed at either exploiting profitable opportunities arising from favorable changes in the exchange rate or limiting damage caused by unfavorable movements. It is clear from Fig. 2 that the swings in the dollar are of sufficient periods for managers to enact changes

[6] Strictly speaking the ECU is a currency basket which is a weighted average of the currencies of the members of the European Union. However, many of the members' exchange rates have been pegged together through the Exchange Rate Mechanism and often move together relative to the dollar. In unreported tests we have considered the British Pound (GBP) and DEM as alternatives to the ECU and found the results to be robust to the either the use of the ECU or the GBP and DEM.

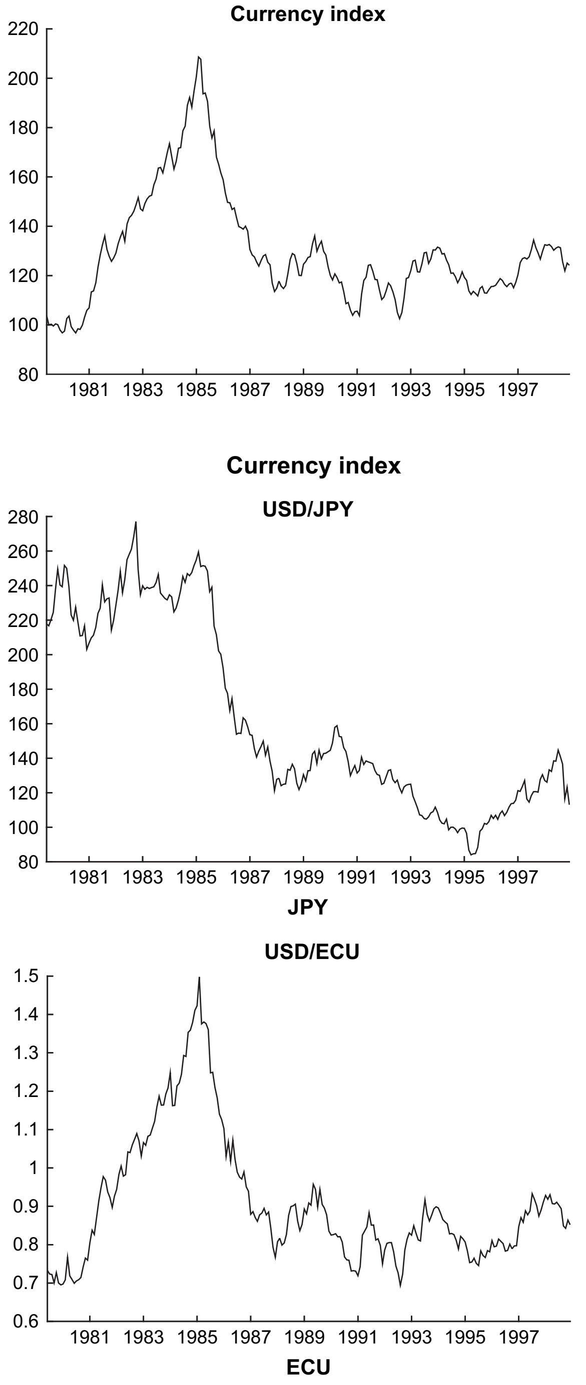

Fig. 2. Currency evolution. The figures document the development of three currency variables over the period 1979:5–1998:12. The top figure shows the evolution of the currency basket, the middle figure the evolution of the Japanese Yen and the bottom figure the evolution of the ECU.

in, for example, pricing, promotion, production and sourcing of inputs, which would give rise to nonlinear exposure.

2. Methodology

Following the work of Adler and Dumas (1983), exposure can be estimated as:

$$r_{it} = \alpha_{i0} + \alpha_{i,\mathrm{JPY}} x_{\mathrm{JPY},t} + \alpha_{i,\mathrm{ECU}} x_{\mathrm{ECU},t} + \varepsilon_{it} \quad (1)$$

where r_{it} is the excess return on asset i, $x_{\mathrm{JPY},t}$ is the percentage change in the JPY, $x_{\mathrm{ECU},t}$ is the percentage change in the ECU, α_{i0} is a constant, $\alpha_{i,\mathrm{JPY}}$ is the estimate of JPY exposure, $\alpha_{i,\mathrm{ECU}}$ is the estimate of ECU exposure and ε_{it} is an error term. There are two problems with this approach. First, the estimates of the exposure coefficients could be biased due to an omitted variables problem. For example, it is possible that there are factors that simultaneously affect stock returns and exchange rates which have nothing to do with exposure. Suppose there is a reduction in interest rates which simultaneously stimulates the economy and lowers the exchange rate. Since stock returns rose due to the stimulation from lower interest rates and simultaneously exchange rates fell, it may appear that there is a direct relationship between stock returns and exchange rates when in fact there is not.

The way round this problem that has dominated the exposure literature is to include a stock market portfolio in the regression model and estimate:

$$r_{it} = \alpha_{i0} + \beta_{\mathrm{im}} r_{\mathrm{m}t} + \alpha_{i,\mathrm{JPY}} x_{\mathrm{JPY},t} + \alpha_{i,\mathrm{ECU}} x_{\mathrm{ECU},t} + \varepsilon_{it} \quad (2)$$

where $r_{\mathrm{m}t}$ is the excess return on the market portfolio and ε_{it} is an error term. Now the second problem arises. The market portfolio is simply an aggregation of the individual stocks and thus, if the individual stocks are exposed, the market is exposed. Therefore, α_{ij} is not the total exposure of stock i to exchange rate j, but rather the exposure of stock i over and above that of the market portfolio.[7] For example, if the stock has the same exposure as the market portfolio then estimating Eq. (2) would result in the conclusion that the exposure of stock i is zero. However, because the market return contains a currency exposure component this would be incorrect. It is essential to address this issue given the evidence in Dumas and Solnik (1995) that cross-country aggregate stock returns are affected by currencies. In order to address this the stock market portfolio could be orthogonalized by estimating the following regression[8]:

$$r_{\mathrm{m}t} = a_{\mathrm{JPY}} x_{\mathrm{JPY},t} + a_{\mathrm{ECU}} x_{\mathrm{ECU},t} + v_{\mathrm{m}t} \quad (3)$$

where $v_{\mathrm{m}t}$ is an error term which is defined as the orthogonal market return, that is, that part of the return on the market portfolio that is uncorrelated with changes in the exchange rates. This method of orthogonalizing the market portfolio has been used in Allayannis (1996) and Griffin and Stulz (2001) without success. Jorion (1991) in his investigation of the pricing of currency

[7] Theoretically in Adler and Dumas (1983) both stock returns and exchange rates are endogenous. However, at a disaggregated level it is safe to assume that causality runs from exchange rates to stock returns.

[8] The regression is estimated without a constant term to preserve the mean of the exposure regression. One could alternatively do a regression with a constant term in it and then add the mean back into the residuals. We have experimented with this and it does not materially change our results.

risk in the US market undertook a similar orthogonalization. However, Jorion (1991) regressed the exchange rate on the market portfolio and used the residuals as the exchange rate component. At the industry level we assume that causation is from exchange rates to stock returns. Moreover, orthogonalizing as in Eq. (3) has the advantage of allowing interpretation of the exposure coefficient as total exposure.

The orthogonalization outlined above in Eq. (3) suffers from a similar problem to the one when not including a market portfolio (in Eq. (1)). In particular, it does not account for the fact that the market return and the exchange rate may be related to macroeconomic factors that are not related to exposure. Therefore, we wish to take these effects out of both the market portfolio and the exchange rate. We do so by orthogonalizing the market return with respect to the exchange rate and a set of macroeconomic factors:

$$r_{mt} = a_{JPY} x_{JPY,t} + a_{ECU} x_{ECU,t} + \mathbf{a_{mz} z_t} + u_{mt} \tag{4}$$

where $\mathbf{z}_t$ is a vector of macroeconomic variables and u_{mt} is the orthogonalized market portfolio. The macroeconomic variables we use are the term spread, the default spread, changes in industrial production and changes in the consumer price index. We also orthogonalize the exchange rates with respect to the macroeconomic factors:

$$x_{JPY,t} = \mathbf{a_{JPY,z} z_t} + u_{JPY,t} \tag{5}$$

$$x_{ECU,t} = \mathbf{a_{ECU,z} z_t} + u_{ECU,t} \tag{6}$$

where $u_{JPY,t}$ and $u_{ECU,t}$ are the orthogonalized JPY and ECU exchange rates.

The methodology outlined above should remove the correlation between exchange rates and stock returns that has nothing to do with exposure, but rather is due to their common correlation driven by macroeconomic factors. Using this orthogonalized market return and the orthogonal exchange rates we then estimate exchange rate exposure as:

$$r_{it} = \alpha_{i0} + \beta_{im} u_{mt} + \alpha_{i,JPY} u_{JPY,t} + \alpha_{i,ECU} u_{ECU,t} + \mathbf{a_i z_t} + v_{it} \tag{7}$$

The methodological approach suggested here should be a step forward in trying to disentangle the relationship between the industry stock returns, the market portfolio, the macroeconomic factors and the exchange rate. We think this is important given that the alternative of just including the market portfolio is likely to provide inaccurate estimates of industry specific exposure if the market itself is exposed.

3. Empirical results

This section of the paper reports the results from estimating linear exposure over the three regimes and the whole sample period. Before we look at the impact of the orthogonalization, we first report results from the estimation of linear exposure to the ECU and JPY using a linear regression of excess stock returns on the macroeconomic factors, the excess return on the market portfolio and the two exchange rates. This is consistent with the extant literature's methodology. Subsequently we estimate Eq. (7) to assess the impact of the orthogonalization.

Following the extant literature, in each regime we examine the statistical significance of the exposure coefficients using the traditional *t*-ratio on the exposure estimate. The economic significance of the exposure coefficients is examined by looking at the size of the coefficients and the change in the adjusted R^2 (DRBSQ) when moving from a regression of industry returns on the market portfolio and the macroeconomic factors to a regression also including exchange rates as explanatory variables.

3.1. Traditional linear exposure

Table 2 reports the results of the estimates from the traditional, non-orthogonalized exposure regressions where excess returns for each industry are regressed on the excess

Table 2
Linear exposure

Industry	1979–1985			1985–1990			1991–1998			1979–1998		
	Y	E	$\Delta\bar{R}^2$	Y	E	$\Delta\bar{R}^2$	Y	E	$\Delta\bar{R}^2$	Y	E	$\Delta\bar{R}^2$
Panel A: industries with extensive international trade												
Recreation	0.03	0.18	−1.4	−0.09	0.12	−1.1	−0.34*	0.20	3.2	−0.20	0.21	0.4
Computers	−0.06	−0.02	−1.3	−0.19	0.12	−0.9	−0.07	−0.19	0.4	−0.14	−0.06	−0.3
Apparel	0.09	0.05	−1.7	0.19	0.04	0.8	0.11	−0.03	−1.4	−0.13	0.02	0.7
Aircraft	0.11	0.16	−0.4	0.11	0.11	0.6	−0.10	−0.02	−0.8	0.01	0.14	−0.2
Autos	−0.18	0.39	2.2	−0.25*	0.27	0.4	−0.04	0.24	1.4	−0.11	0.26*	2.4
Measuring and control equipment	0.05	0.22	−0.3	0.06	−0.30	0.0	−0.29*	0.29	1.7	−0.26	0.19	0.1
Electronic equipment	0.03	0.03	−0.6	0.04	−0.12	−0.3	−0.23	0.23	0.9	−0.11	0.09	0.0
Machinery	−0.22*	0.23*	1.1	0.15	−0.11	−0.5	−0.29*	0.23*	4.6	−0.16*	−0.21*	0.7
Electrical equipment	−0.11	0.25	0.2	0.19	−0.25*	0.3	−0.17	0.12	0.7	−0.14	0.11	0.1
Consumer goods	−0.21	0.28*	2.9	0.09	−0.20	0.3	−0.07	0.18*	1.1	−0.09	0.13*	0.6
Medical equipment	−0.24	0.14	0.4	−0.05	0.03	−0.9	0.22	−0.20	1.8	0.02	−0.12	−0.4
Steel	−0.17	0.09	−0.8	0.21	−0.11	−1.2	−0.06	0.08	−1.1	−0.01	0.02	−0.6
Chemicals	−0.11	0.17	0.1	0.00	−0.11	−0.1	0.10	−0.03	−0.6	0.04	−0.01	−0.2
Business supplies	−0.24	0.31	1.5	0.14	−0.31	0.6	−0.13	0.22*	1.9	−0.12	0.11	0.1
Panel B: industries with low international trade												
Beer and liquor	0.09	−0.20	−1.6	−0.20	−0.08	2.1	0.07	−0.15	−1.1	0.02	−0.15	0.5
Pharmaceutical products	−0.04	−0.06	−1.8	−0.21	0.01	−0.2	0.26*	−0.28*	4.8	0.11	−0.11	0.3
Construction materials	−0.14	−0.04	0.2	0.11	−0.12	−0.2	−0.10	0.16	0.6	−0.04	0.02	0.1
Textiles	−0.09	0.12	−1.6	−0.30	0.34	−0.3	0.08	0.10	−0.6	−0.03	0.11	0.0
Defense	0.12	0.18	−0.1	0.17	−0.21	−0.7	−0.16	0.02	−0.3	−0.04	0.01	−0.6
Tobacco	−0.00	0.16	−2.2	−0.00	−0.13	−1.5	0.08	−0.22	−3.4	0.01	−0.11	−1.1
Rubber and plastics	−0.23	0.27	1.4	−0.11	0.08	−0.3	−0.09	0.07	−1.0	−0.12	0.15	0.3
Ship and rail equipment	0.27	−0.19	−1.0	−0.00	0.09	−1.5	−0.16	0.44*	13.1	−0.04	0.21	0.9
Food products	−0.10	−0.03	−0.9	−0.22	0.01	1.2	0.09	−0.33	−1.3	−0.05	−0.07	0.1
Fabricated products	−0.07	−0.18	−0.9	−0.03	−0.05	−1.5	−0.04	0.55*	12.4	−0.12	0.23	0.4
Candy and soda	−0.19	0.08	−8.5	−0.01	−0.30	2.6	0.10	0.06	−0.6	−0.15	−0.03	−0.9
Shipping containers	−0.14	0.18	0.4	0.05	−0.20	0.2	−0.12	−0.02	−1.4	−0.09	−0.03	0.0
Printing and publishing	−0.34	0.27	3.0	−0.04	0.08	−0.5	0.03	0.00	−1.2	−0.12	0.10	0.1
Business services	−0.06	−0.04	−0.3	0.05	−0.06	−0.5	−0.13	0.22*	1.9	0.02	−0.10	−0.1

This table reports estimates from the linear regression of excess stock returns on the orthogonal market portfolio and orthogonal exchange rates and a set of macroeconomic variables. Y is Yen, E is ECU. $\Delta\bar{R}^2$ is the change in the $\bar{R}^2$ when adding the exchange rates to the regression. * indicates statistically significant at the 5% level. Data are sampled monthly 1979:5–1998:12.

return on the market, the macroeconomic factors and the change in exchange rates. The table reports results for each of the three regimes and the whole sample. Panel A reports the estimates of the exposure coefficients for the industries with extensive international trade and shows that over the first regime, from 1979 to 1985, there is one industry that has a statistically significant exposure coefficient relative to the Yen, and two industries that have a statistically significant exposure to the ECU (one of these, machinery, is the same industry that has a statistically significant Yen exposure). Panel B reports the results from running the same regression for those industries with low levels of international trade. Over this first regime there are no industries with a statistically significant exposure to either the Yen or the ECU. The DRBSQ for each industry is low and often negative and the average across all industries in panel A is 0.14 and across panel B is −0.99. Therefore, similar to the extant literature, we find very little evidence that industry stock returns are exposed to exchange rate changes, either statistically or economically.

Considering the next regime, over the period 1985–1990, we find a very similar result: two industries that have extensive international trade have a statistically significant exposure coefficient, one to the Yen and one to the ECU. None of the exposure coefficients of the industries with low levels of international trade are statistically significant. The average DRBSQ across the industries with extensive international trade is −0.14 and for those industries with low levels of international trade this average is −0.08. It is interesting to note that the exposure coefficients tend to change sign in this regime. This change in sign of exposure coefficients across different subperiods is also found in Allayannis (1996), Griffin and Stulz (2001) and Allayannis and Ihrig (2001).

In the final regime, over the period 1991–1998, there are five industries with extensive international trade that have a statistically significant exposure coefficient. The DRBSQs tend to be larger in this period, for example, the average across industries in panel A is 0.99 and in panel B 1.56. As the level of international trade has been systematically increasing over time it is not that surprising that at the end of the period more industries are exposed. Four of the industries with low levels of international trade have a statistically significant exposure coefficient. Note that the signs of the exposure coefficients have changed in this regime as well.

When we consider the whole period from 1979 to 1998 we find that for this non-orthogonalized version of the model there are three industries with extensive international trade that have a statistically significant exposure coefficient and none of the industries with low levels of international trade have a statistically significant exposure coefficient. The DRBSQ for the industries with extensive international trade is 0.19 and for the industries with low levels of international trade it is 0.0.

In summary, very few industries are found to have a statistically significant exposure coefficients and this exposure is not particularly important economically, much in line with the extant literature. On the odd occasion an industry does have a statistically significant exposure coefficient, it tends to be an industry with extensive international trade. Whilst we also note that the exposure coefficients tend to change sign across the regimes, allowing for regimes only appears to uncover slightly more exposure in the final regime where there is much more international trade than the earlier regimes. Explanations for the change in sign could be that firms experience different exposures in different time periods because of changes in terms of trade, changes in tariffs and quotas, changes in the level of imported costs, competition, exporters behavior, hedging policies, and the extent of the exchange rate change. We discuss these in more detail in the next section.

3.2. Orthogonalized linear exposure: Regime 1: 1979–1985

Table 3 reports the results when using the orthogonalized regression (7), which is split into two panels based on the extent of international trade. Looking at the 1979–1985 regime in panel A for the industries with extensive international trade, we find that there are six industries with a statistically exposure coefficient relative to the ECU and no industries have a statistically significant exposure to the Yen. In total 43% of the industries with extensive international trade

Table 3
Orthogonalized linear exposure

Industry	1978–1985			1985–1990			1991–1998			1979–1998		
	OY	OE	$\Delta\bar{R}^2$	OY	OE	$\Delta\bar{R}^2$	OY	OE	$\Delta\bar{R}^2$	OY	OE	$\Delta\bar{R}^2$
Panel A: industries with extensive international trade												
Recreation	0.14	−0.44	1.2	0.12	0.38	3.8	−0.45*	0.32	10.0	−0.10	0.32*	1.0
Computers	0.10	−0.49*	7.5	−0.04	0.33	1.6	−0.22	0.00	0.8	−0.01	0.06	−0.6
Apparel	0.27	−0.42*	4.5	0.47*	0.27	13.8	−0.01	0.15	−1.0	0.21*	0.08	2.6
Aircraft	0.22	−0.44	1.4	0.30	0.34	13.0	−0.21	0.09	1.3	0.11	0.14	0.8
Autos	−0.04	−0.03	−5.9	−0.03	0.51*	6.1	−0.15	0.37*	6.3	−0.01	0.26*	4.1
Measuring and control equipment	0.22	−0.45	1.2	0.32	−0.04	1.2	−0.47*	0.53*	9.6	−0.12	0.19	0.4
Electronic equipment	0.17	−0.58*	6.1	0.24	0.12	3.5	−0.38*	0.42*	7.2	−0.03	0.19	0.4
Machinery	−0.11	−0.36*	5.2	0.40*	0.17	10.7	−0.43*	0.40*	12.3	−0.13	0.21*	0.8
Electrical equipment	0.03	−0.30	1.0	0.40*	0.00	5.8	−0.29*	0.25*	4.2	−0.04	0.21*	0.4
Consumer goods	−0.12	−0.06	−0.5	0.24*	0.07	3.9	−0.18*	0.31*	5.4	0.18	0.03	1.1
Medical equipment	−0.11	−0.30	4.8	0.09	0.25	3.7	0.10	−0.05	−1.6	0.12	−0.02	−0.3
Steel	−0.00	−0.51*	6.3	0.43	0.11	10.7	−0.17	0.22	1.9	0.01	0.12	−0.3
Chemicals	−0.00	−0.38*	4.4	0.23	0.15	4.1	0.00	0.09	−1.1	0.11	0.01	0.1
Business supplies	−0.13	−0.21	1.7	0.36*	−0.05	3.4	−0.24*	0.36*	8.7	−0.01	0.21	0.4
Panel B: industries with low international trade												
Beer and liquor	0.19	−0.53*	15.8	0.00	0.15	−0.6	−0.01	−0.05	−3.8	0.10	−0.13	−0.2
Pharmaceutical products	0.03	−0.36*	10.6	0.02	0.30	2.8	0.15	−0.14	−0.0	0.12	−0.11	0.3
Construction materials	−0.01	−0.61*	11.2	0.29*	0.08	7.8	−0.21*	0.30*	4.8	0.00	0.12	0.0
Textiles	0.12	−0.31	0.4	0.02	0.56	8.4	−0.01	0.23	1.7	0.03	0.17	1.1
Defense	0.21	−0.46	1.6	0.31	0.04	3.8	−0.26*	0.16	3.5	0.05	0.01	−0.4
Tobacco	0.02	−0.15	−3.0	0.07	0.14	−1.0	−0.02	−0.10	−6.4	0.01	−0.03	−1.3
Rubber and plastics	−0.05	−0.26	1.7	0.14	0.37*	6.1	−0.20	0.18	1.8	−0.12	0.15*	0.8
Ship and rail equipment	0.34	−0.77*	9.4	0.26	0.25	7.9	−0.24	0.52*	25.1	0.04	0.31	2.7
Food products	−0.03	−0.32*	12.1	−0.05	0.22	−0.4	0.01	0.05	−2.2	−0.05	−0.08	−0.7
Fabricated products	−0.01	−0.65*	12.3	0.11	0.15	1.6	−0.16	0.69*	20.8	−0.01	0.23*	1.3
Candy and soda	−0.19	0.00	−8.9	0.12	−0.05	−0.8	−0.02	0.21	−0.0	−0.02	0.03	−1.0
Shipping containers	−0.07	−0.17	1.8	0.22	0.03	2.1	−0.20	0.08	1.9	−0.02	0.01	−0.5
Printing and publishing	−0.24	−0.18	4.5	0.22	0.31	7.0	−0.05	0.10	−0.9	−0.01	0.21*	0.7
Business services	0.07	−0.68*	9.7	0.36*	−0.05	3.4	−0.11	0.05	−0.8	0.12	−0.03	−0.1

This table reports estimates from the linear regression of excess stock returns on the orthogonal market portfolio and orthogonal exchange rates and a set of macroeconomic variables. OY is orthogonal Yen, OE is orthogonal ECU. $\Delta\bar{R}^2$ is the change in the $\bar{R}^2$ when adding the exchange rates to the regression. * indicates statistically significant at the 5% level. Data are sampled monthly 1979:5–1998:12.

are exposed to exchange rates and the average DRBSQ across the industries with extensive international trade is 2.78. If we consider only the industries with a statistically significant exposure coefficient the DRBSQ is 5.66%. Therefore, there is considerable evidence that industries are exposed both statistically and economically once the orthogonalization is undertaken.

This regime is a period when the dollar appreciated against both the JPY and the ECU. However, note that the appreciation against the ECU is four times that of the JPY, which may explain why the exposures to the ECU are statistically significant while to the Yen they are not. Baldwin (1988) and Baldwin and Krugman (1989) present arguments based on, for example, entry costs of exporting which suggest that the size of the change in the exchange rate is important in dictating whether firms change behavior and hence become exposed to the exchange rate. If entry costs are high, then it requires a large change in the exchange rate before it becomes profitable to enter a market. Therefore, the exposure only becomes noticeable on a firm's stock return when the exchange rate change is large, as is the case in the ECU, but not the Yen.

Given this period is one of a dollar appreciation we would expect that if an industry has a negative exposure it suffers from a dollar appreciation. Industries that are exporters or have imported competition should suffer. Whilst US firms were actively exporting to the EU area, exports to Japan were more limited due to trade barriers. This is borne out in trade balance figures between the US and the EU, which over the sample period were often positive. In contrast, the trade balance with Japan was negative and very large. For those industries facing import competition, the large appreciation of the dollar relative to the ECU could have made exporting to the US from the EU profitable in the sense that the change in the exchange rate was so large it overcame the entry costs and made EU exporting firms competitive relative to domestic US firms. This has the effect of reducing domestic US firms stock returns in the face of this increased competition.

Overall, in this first subperiod, the evidence indicates that when the dollar is appreciating, exchange rate exposures have an important economic role to play in determining US industry returns: a dollar appreciation relative to the ECU decreases returns which suggests the industries that are exposed are either exporters or face imported competition.

Panel B of Table 2 reports the results for the industries with low levels of international trade. Half of the industries have a statistically significant exposure coefficient, all of them with respect to the ECU. The average DRBSQ overall the industries is 5.65. Over this first regime it does not seem to matter that an industry has low levels of international trade or extensive international trade in terms of which industries are exposed.

3.3. Orthogonalized linear exposure: Regime 2: 1985–1990

The second regime over the period 1985–1990 is characterized by the dollar depreciating by roughly equal amounts to the JPY and the ECU. In this period there are six industries with extensive international trade that have a statistically significant exposure coefficient, five of these to the Yen and one to the ECU. Thus, relative to the non-orthogonalized results in Table 2, we once again find that the orthogonalization uncovers more exposure. Looking at panel B, only three (23%) industries with low levels of international trade have a statistically significant exposure coefficient. The average DRBSQ for the industries with extensive international trade is 6.09, roughly double that of the DRBSQ for the industries with low levels of international trade.

Therefore, relative to the non-orthogonalized results, we find much more exposure and that this exposure is predominately in industries with extensive international trade. Note also that there is a change in sign of the exposure coefficients in the orthogonal results, just as there was in the non-orthogonal results. The change in the sign of the ECU exposures from negative to positive indicates that for this regime the depreciation of the dollar also leads to a fall in stock returns, although this is only statistically significant in one case. A depreciation of the USD should help exporters and domestic firms facing imported competition and at first glance it may appear puzzling that the opposite happens since in the first regime we argued that US exporters to the EU and domestic firms facing imported competition suffered under a large dollar appreciation against the ECU. However, we would also expect that a positive exposure in this period could arise if the industry has imported costs. How might such a situation arise? Over the 1980s there was a tremendous increase in the amount of imported costs in US firms (see Campa and Goldberg, 1999) which offsets exporters' ability to improve performance in the light of a depreciating home currency. In the early 1980s the trade balance with the EU was positive, it started to turn negative in the mid-1980s and doubles between 1985 and 1989 despite the dollar depreciation relative to the ECU. This provides a simple explanation of the change in sign of the ECU exposures.

In addition, the pricing behavior of EU firms, in terms of actively managing pass-through and margins in order to maintain market share, in the face of the cheaper dollar exports, could offset the benefits US exporters had from a depreciation of the dollar. A similar process appeared in the 1990s and is highlighted in Goldberg and Knetter (1997) who discussed the 34% depreciation of the dollar relative to the Yen between January 1994 and April 1995. They ask why, given an implied 30% reduction in costs did Japanese industrial production continue to grow faster than US industrial production: that is, why did not US exporters benefit at the expense of Japanese firms? One reason is that Japanese firms price to market and offset advantages that foreign firms have through changes in the exchange rate. Another reason is that domestic Japanese firms price to offset the advantages of US exporters. A similar process could have happened relative to EU firms in this second regime.

A potential explanation of why the dollar depreciation relative to the Yen does not help US firms, but actually reduces their returns must stem from the fact that the export side of the economy in the US is much smaller than the import side and in this period there were trade restriction for US firms into Japan. As the dollar depreciates imports into the US from Japan and the EU become more expensive and hence there is a negative impact on US firms that are known over the 1980s to have been increasing their shares of imported costs (Campa and Goldberg, 1999).

Relative to both the Yen and the ECU, it is possible to rationalize the fact that exporters do not benefit in this regime of depreciation if the costs of expanding into Japan and ECU for use exporters are very high. In addition, exporters may not benefit if domestic firms in the foreign markets price to market to offset advantages US exporters have from the depreciating dollar.

3.4. Orthogonalized linear exposure: Regime 3: 1991–1998

In the final regime, over the period 1991–1998, the USD depreciated further against the Yen but appreciated against the ECU. Eight, that is 57%, of industries with extensive international trade have a statistically significant exposure to the exchange rate. The economic impact is also high in this period with a DRBSQ of 4.57% across all industries and 7.96% across the industries with a statistically significant exposure coefficient. The statistically significant Yen exposures, of which there are seven, are negative and the ECU exposures, of which there are also seven, are positive.

The negative sign of the JPY exposures is consistent with the theory that for exporters, as the dollar depreciates, stock returns rise. The fact that exporters are now exposed in the third period and were not in the second period may be due to the fact that in the third period the dollar had depreciated by such a large amount relative to the Yen that the benefits of exporting had overcome the fixed costs of entering the market that prevented firms exporting in the second regime. Furthermore, the final period is characterized by a reduction in trade barriers in Japan which made it easier for US firms to export there. The statistically significant ECU exposures are all positive, as they were in the second period, which suggest that as the USD appreciates relative to the ECU in this period, stock prices rise. This makes sense when the exposed industries are importers and now face lower imported costs. The negative trade balance relative to the EU continued into the 1990s suggesting US firms continued in their purchase of imports from the EU. Consequently, it is not surprising that the industries maintain their positive exposure.

Panel B shows that only four industries with low levels of international trade have a statistically significant exposure and the DRBSQ is 3.25%. Thus, once more, exposure is more important both statistically and economically in industries that have more international trade.

3.5. Whole sample period

Using the orthogonalized version of the model, we find that there are five industries with extensive international trade that have a statistically significant exposure coefficient and three industries with low levels of international trade that have a statistically significant exposure coefficient. Thus, there are more industries exposed when the orthogonalization is undertaken, but this is less than in the individual regimes. Also note that the DRBSQ is on average 0.78 for the industries with extensive international trade and 0.19 for the industries with low levels of international trade. The economic significance of the exposures, whilst higher in the industries that have extensive international trade, is lower over the whole sample than the regimes. Thus, the regimes appear to be important for uncovering exposure, both statistically and economically. Allayannis (1996) and Griffin and Stulz (2001) show, just like the results in this subsection, that exposure estimates are not affected by orthogonalizing the market portfolio. Therefore, it is the use of regimes in conjunction with the orthogonalization that is important in terms of uncovering exchange rate exposure.

3.6. Interpreting exposure

In this section of the paper we attempt to assess whether the signs on the exposure coefficients are consistent with the extent that an industry is an exporter or an importer. We would expect that as an industry exports more then its exposure coefficient should become more negative such that in a dollar depreciation the industry benefits more and in an appreciation the industry suffers more. Due to the reasons outlined above, it is not necessarily the case that a net exporter will have a negative exposure, however, an increase in the amount of exports should make a negative exposure more negative and a positive exposure smaller.

We do not assess the impact of a change in imports to total sales on stock returns because there are some technical difficulties involved with this. Over the sample period the export and import ratios have trended upwards and the correlation coefficient between the two ratios is over 0.95 in each industry. Therefore, undertaking a time series regression of returns on the change in the exchange rate interacted with these two ratios, or undertaking a cross-sectional regression of the exposure coefficient on the two ratios would be difficult to interpret: it is not possible to identify the impact of the exports separately from that of imports. Even the growth rates of the ratios of exports to total sales and imports to total sales are highly correlated such that identification of the separate effects would be difficult. In addition to this, since the import coefficient could be negative or positive, we lose nothing in terms of interpretation by omitting it.

We follow the methodology in Bodnar and Gentry (1993) and Allayannis (1997) which involves interacting the export to total sales ratio with the exchange rate and use this as an independent variable to get exposure coefficients weighted by the export to total sales. This would, in principle, allow us to see if the signs on the exposure coefficients are consistent with the extent of exporting in each industry.[9] Because we cannot identify the exports to Japan and the EU separately, we do one regression where the Yen is interacted and one regression where the ECU is interacted. Following Bodnar and Gentry (1993) we take the industries that have a statistically significant exposure coefficient in each regime and estimate a system of seemingly unrelated regressions (SUR) for the Yen:

$$\mathbf{r_t} = \alpha_0 + \boldsymbol{\beta}_{\mathbf{m}} u_{mt} + \boldsymbol{\alpha}_{\mathbf{JPY}} u_{\mathrm{JPY},t} + \boldsymbol{\delta}_{\mathbf{JPY}}(u_{\mathrm{JPY},t} \times (\mathbf{X/TS})) + \mathbf{a_i z_t} + \mathbf{v_t} \tag{8}$$

where $\mathbf{r_t}$ is a vector of returns, $\boldsymbol{\beta}_{\mathbf{m}}$ is a vector of industry specific market betas, $\boldsymbol{\alpha}_{\mathbf{JPY}}$ is a vector of industry specific exposure estimates relative to the Yen, $\boldsymbol{\delta}_{\mathbf{JPY}}$ is the coefficient of interest and tells us what happens to the Yen exposure as exports to total sales (**X/TS**) changes, $\mathbf{a_i}$ is a vector of coefficients relating the macroeconomic variables, $\mathbf{z_t}$, to the industry returns, and $\mathbf{v_t}$ is a vector of industry specific error terms. The system for the ECU is:

$$\mathbf{r_t} = \alpha_0 + \boldsymbol{\beta}_{\mathbf{m}} u_{mt} + \boldsymbol{\alpha}_{\mathbf{ECU}} u_{\mathrm{ECU},t} + \boldsymbol{\delta}_{\mathbf{ECU}}(u_{\mathrm{ECU},t} \times (\mathbf{X/TS})) + \mathbf{a_i z_t} + \mathbf{v_t} \tag{9}$$

where $\boldsymbol{\delta}_{\mathbf{ECU}}$ is the coefficient of interest and tells us what happens to the ECU exposure as exports to total sales (**X/TS**) changes.

The results are reported in Table 4 and show that in each regime an increase in the growth rate of exports to total sales leads to the exposure coefficient to become more negative and in many cases this is statistically significant. This is exactly what the theory suggests should happen: even though an industry could have a positive or a negative exposure irrespective of whether it is a net importer or a net exporter, and even though the exposure coefficients change over time, the interaction term tells us that as exports increase the exposure will, if positive become smaller, or if negative, more negative. The only time this is not the case is for the Yen in the 1991–1998 period.

3.7. Summarizing the linear results

The results indicate that exchange rate exposure is important statistically and economically. However, a crucial finding is that the extent of the exposures is only fully revealed when we consider the dollar regimes and simultaneously use an orthogonalized market portfolio. The size of the exposure coefficients and the DRBSQ indicate that exchange rates have an important economic effect in all regimes. As in the case of the non-orthogonalized results and the extant literature, the exposure coefficient changes sign in each regime which is consistent with,

[9] Jorion (1990) uses a cross-sectional method that involves estimating the exposure coefficient and then regressing this on the export ratio.

Table 4
Impact of growth in exports on exposure coefficients

	1978–1985	1985–1990	1991–1998	1985–1995
$OE(\Delta\frac{X}{TS})$	−1.581	−0.768	−3.572	−4.116
t-Ratio	(0.79)	(0.32)	(1.83)	(3.10)
$OY(\Delta\frac{X}{TS})$		−3.736	1.208	−1.113
t-Ratio		(3.52)	(1.04)	(2.08)

This table reports coefficient estimates of the impact of an increase in exports to total sales on the exposure coefficients across industries that have a statistically significant exposure coefficient. $OE(\Delta X/TS)$ is the orthogonal ECU multiplied by the change in exports to total sales. $OY(\Delta X/TS)$ is the orthogonal Yen multiplied by the change in exports to total sales. The numbers in parentheses are *t*-ratios.

amongst other things, changing imported inputs, trade balances, costs of expanding exports, and competitive behavior. The signs of the exposure coefficients when interacted with the export to total sales ratio are consistent with theoretical predictions that an increase in exports increases returns in a depreciation and decreases returns in an appreciation.

4. Nonlinear exposure

We model a nonlinear relationship between exchange rates and stock returns using a simple extension of the linear exposure framework by adding the squared values of the ECU and Yen exchange rate changes to the specification in Eq. (7):

$$r_{it} = \alpha_{i0} + \beta_{im}u_{mt} + \alpha_{i,\mathrm{JPY}}u_{\mathrm{JPY},t} + \alpha_{i,\mathrm{ECU}}u_{\mathrm{ECU},t} + \gamma_{i,\mathrm{JPY}}u^2_{\mathrm{JPY},t} + \gamma_{i,\mathrm{ECU}}u^2_{\mathrm{ECU},t} + \mathbf{a_i z_t} + \varepsilon_{it} \qquad (10)$$

where $u^2_{\mathrm{JPY},t}$ and $u^2_{\mathrm{ECU},t}$ are the squared values of (orthogonalized) exchange rate changes, and $\gamma_{i,\mathrm{JPY}}$ and $\gamma_{i,\mathrm{ECU}}$ measure the sensitivity of stock i to nonlinear effects. Whilst the exact nonlinear relationship may be a complex function of firm specific characteristics such as export and import ratios, export and import price elasticities, and competition, amongst others, we believe that the use of a squared exchange rate may be useful in capturing simple nonlinearities. In particular, squared values provide a simple convex relationship which we might expect to observe.[10]

If there is a dollar appreciation, exporters' products become relatively more expensive. We would consequently expect nonlinearities to slow down the effect a unit appreciation has on returns. For example, we would expect an exporter to alter behavior to offset the lack of competitiveness caused by the appreciation, such as sourcing inputs from abroad. The second effect of a USD appreciation is on importers where an appreciation of the dollar makes imports cheaper and should increase their stock returns. A nonlinear effect here would lead to an appreciation increasing the impact of the exchange rate on returns. Of course, holding all else constant, opposite effects should occur when the USD depreciates.

[10] This is, for example, argued by Sercu and Uppal (1995). In Bartram (2002) a number of functional forms are considered, and he advocates the use of a cubic specification. We have chosen a simpler specification because we expect some of the nonlinearities which are captured in the more complicated functional form are captured in the regimes in our paper. We therefore impose a functional form, the quadratic, which is reasonable for one-sided moves of the exchange rates, but may not be that good at capturing nonlinear exposure when the regimes can be both positive and negative.

Panel A of Table 5 reports the estimates of the nonlinear coefficients in each of the regimes for the industries with extensive international trade. In the first regime there are two industries that have exposure coefficients to the Yen that are statistically significant and eight industries that have exposure coefficients to the ECU that are statistically significant. The signs on the statistically significant nonlinear terms are negative (except for one of the Yen exposures). The negative coefficient on the nonlinear effects would indicate that exporters are affected since as the USD appreciates stock returns will fall. However, given the convex relationship, the

Table 5
Orthogonalized nonlinear exposure

Industry	1979–1985			1985–1990			1991–1998			1979–1998		
	OY^2	OE^2	$\Delta\overline{R}^2$	OY^2	OE^2	$\Delta\overline{R}^2$	OY^2	OE^2	$\Delta\overline{R}^2$	OY^2	OE^2	$\Delta\overline{R}^2$
Panel A: industries with extensive international trade												
Recreation	2.39	−14.2*	13.7	2.21	5.77	6.4	−1.46	1.11	−1.0	0.49	−4.06	1.4
Computers	3.57	−12.8*	17.7	−2.60	0.18	0.1	2.29	−2.70	0.8	3.74*	−7.44*	6.3
Apparel	0.21	−6.91	5.3	2.70	6.71*	16.5	1.45	0.87	−2.3	2.57	−0.56	3.2
Aircraft	−9.89*	−20.9*	24.4	1.07	6.14	15.2	2.74	−2.27	2.8	2.63*	−5.60*	3.8
Autos	−0.15	−9.76*	0.1	−0.85	8.03*	8.3	2.79*	−5.98*	11.3	2.81*	−3.79*	6.5
Measuring and control equipment	1.52	−19.4*	14.3	0.95	−5.51	0.9	1.90	−1.05	5.6	2.43	−5.87*	2.3
Electronic equipment	2.53	−14.8	16.5	2.53	0.06	3.5	1.36	2.71	2.1	2.66*	−2.33	1.2
Machinery	−2.05	−14.7*	15.7	−0.17	0.57	9.8	3.02*	4.19*	12.1	2.33*	−4.50*	2.8
Electrical equipment	−1.05	−11.3	6.3	2.61	0.46	6.0	2.39*	1.73	3.4	2.51	−1.89	1.3
Consumer goods	2.23	−6.84*	4.3	−3.08	2.89	9.7	2.98	4.97	2.2	1.45	−0.90	0.7
Medical equipment	1.13	−3.64	3.4	−2.44	6.18	4.9	1.78	12.1	16.4	1.80	2.00	0.4
Steel	−9.21*	−21.2*	34.3	−2.88	4.59	9.9	1.40	−2.10	1.4	0.43	−4.32	0.8
Chemicals	−2.92	−13.8	15.8	2.07	2.85	4.7	0.91	−2.93	−0.5	1.00	−2.95	0.8
Business supplies	−0.72	−12.6	9.5	1.72	5.49	4.9	2.50*	−2.17	10.1	2.64	−1.85	1.7
Panel B: industries with low international trade												
Beer and liquor	1.16	−14.5*	56.6	2.41	8.70*	4.0	3.86*	7.88	29.1	4.11*	0.43	4.0
Pharmaceutical products	0.74	−3.23	9.2	1.06	9.47*	8.4	−0.13	6.62*	3.2	0.95	0.73	0.1
Construction materials	−1.62	−14.3*	20.8	−0.64	3.67	7.9	3.71*	−2.04	9.5	2.82*	−3.08	1.7
Textiles	−6.41	−10.4*	10.3	−3.03	0.46	6.6	1.32	−2.11	0.8	−0.37	−3.57	1.9
Defense	−8.14	−24.8*	28.5	0.13	5.25	3.8	1.11	2.52	0.6	1.28	−3.39	0.2
Tobacco	−2.09	−3.88	−5.4	4.51	12.3*	11.4	4.27	1.81	0.2	3.99*	−0.31	1.7
Rubber and plastics	−3.46	−12.1*	10.9	3.66	3.45	7.4	3.78*	1.95	8.2	2.91*	−2.69*	2.3
Ship and rail equipment	−15.7*	−17.8*	38.0	0.07	7.59	9.5	2.52	15.7*	19.4	1.10	3.76	3.3
Food products	−1.68	−7.12*	17.3	8.75*	3.90	8.8	2.79*	5.88*	14.2	3.88*	0.76	4.0
Fabricated products	−9.35	−20.6*	49.3	−1.43	7.04	3.2	2.86	3.49	23.4	1.46	0.41	0.9
Candy and soda	−1.48	0.31	−15.5	4.21	11.43	2.6	6.11*	−0.47	15.6	4.83*	2.51	6.9
Shipping containers	−0.64	−7.22*	6.3	0.09	3.09	1.9	3.06*	−1.15	0.0	1.10	3.79	3.3
Printing and publishing	0.84	−13.58	16.4	−2.10	10.1	10.7	2.08*	−3.37	2.8	2.74*	−4.30	3.1
Business services	1.47	−14.7	18.5	2.74	1.61	5.3	−1.09	5.77*	1.1	1.41	−2.78*	0.4

This table reports estimates from the linear regression of excess stock returns on the orthogonal market portfolio, squared orthogonal exchange rates, orthogonal exchange rates, and a set of macroeconomic variables. OY^2 is the squared orthogonalized Yen, OE^2 is the squared orthogonalized ECU. $\Delta\overline{R}^2$ is the change in the $\overline{R}^2$ when adding the exchange rates to the regression. * indicates statistically significant at the 5% level. Data are sampled monthly 1979:5–1998:12.

effect is reduced relative to the linear case. Recall that the linear coefficient was negative and suggested that exporters to the EU and domestic US firms that have import competition suffered. The negative sign on the nonlinear term suggests that the loss they incur is offset as the exchange rate change gets larger.

The economic impact of exchange rates is considerably greater when we include nonlinear effects. The average DRBSQ across all the industries is 13%, confirming the economic, as well as the statistical, importance of the nonlinear effects. For the non-orthogonalized version of the model (not reported) there are no JPY and two ECU nonlinear exposures that are statistically significant. Therefore, the orthogonalization is clearly important for uncovering nonlinear exposure. Looking at the industries with low levels of international trade in panel B there is one industry that has a statistically significant nonlinear exposure to the Yen and nine industries that have a statistically significant ECU nonlinear exposure. Across all the industries in panel B the DRBSQ is 18.7%.

In the second regime there are no Yen and only two ECU nonlinear exposures that are statistically significant when looking at the industries with extensive international trade. A similar number are uncovered in panel B for the industries with low levels of international trade. In this second regime nonlinear exposure does not seem to be particularly important. For the non-orthogonalized version of the model (not reported) there are no Yen and two ECU nonlinear exposures that are statistically significant.

The final regime over the 1991–1998 period records four statistically significant nonlinear exposures to the Yen and two to the ECU. This third subperiod is characterized by the dollar depreciating against the Yen and appreciating against the ECU. Once more, consistent with the two earlier periods, the vast majority of statistically significant exposures are positive under a depreciating dollar which suggest that exporters benefit. We find that for the non-orthogonalized version of the model there is one JPY and five ECU nonlinear exposures that are statistically significant.

Over the whole sample period we find that five nonlinear exposures to the Yen and five to the ECU are statistically significant for the industries with extensive international trade. Seven Yen and two ECU coefficients are statistically significant across the industries with low levels of international trade. The numbers are two and three for the non-orthogonalized model.

The extent of nonlinear exposure does not seem to be different across firms with extensive international trade and those with low levels of international trade. Perhaps it is not surprising that firms with low levels of international trade are also exposed nonlinearly, since as the exchange rate change gets very large it may become profitable for firms who previously did not export or import much to begin doing so. In addition, as the exchange rate change gets large it may become profitable for foreign competitors to enter the US market and hence effect the returns on domestic US firms.

5. Robustness tests

In this section we address the robustness of the exposure results. We consider whether the inclusion of lagged exchange rates and the SMB and HML risk factors, as additional explanatory variables in the industry regressions, affect the extent of exposure. We also examine whether the use of individual currencies is important by considering the use of the traditional currency basket.[11]

[11] A full set of results is available on request.

When estimating the exposure regression including Fama and French's SMB and HML factors and lagged exchange rates, the results, in terms of the number of statistically significant coefficients and the economic significance of the coefficients, are little altered. Of those industries with a statistically significant exposure in the three regimes, across both panels A and B, only in two cases (the electronic equipment and recreation industries) are the exposure coefficients affected. In the 1991–1998 regime both the ECU and the Yen exposures are statistically significant at the 10% rather than the 5% level. Otherwise the results are unaffected by the inclusion of these additional factors.

Most of the literature on exchange rate exposure has measured exposure relative to a trade weighted currency basket. To gauge how much of our results are due to the use of individual currencies, we have also undertaken estimations replacing the two individual currencies with such a basket. Generally, when using a currency basket there is little difference between the number of statistically significant exposure coefficients if an orthogonalization is undertaken or not: there is only limited evidence that industries are exposed. The number of statistically significant exposure coefficients for the orthogonalized market portfolio in the 1979–1985 period is three for industries with extensive international trade and two for industries with low levels of international trade. In the 1985–1990 regime there is one industry with extensive international trade that has a statistically significant exposure to the orthogonal currency basket and none for the industries with low levels of international trade. In the final regime over the 1991–1998 period there is one industry with extensive international trade and two with low levels of international trade that have a statistically significant exposure to the orthogonal currency basket.

6. Conclusion

This paper has uncovered evidence that US industries are exposed to changes in exchange rates. Previous empirical evidence has concluded that such exposures are negligible. We uncover these new findings by considering the effect of the dollar's regimes on exposure estimates. In addition, we show that exchange rate exposure must be estimated relative to individual currencies, not a currency basket. Simultaneously to the above two points, the overall currency exposures of the stock market and common economy-wide macroeconomic factors that affect the stock market and currencies should be accounted for in the empirical estimates of industry exposures.

The results show that, in general, industries with extensive international trade have greater incidence of statistically significant exposure and that this exposure is more important economically. Exposure is regime specific and is not uncovered when considering the whole sample period. Similar to the extant literature, we find that exposure coefficients change sign over different regimes which is consistent with changes in terms of trade, tariffs and quotas, imported costs, international competition, hedging policies, and firm behavior.

We are able to show that as firms export more they benefit from a dollar depreciation and suffer from a dollar appreciation, exactly as predicted in theory. Thus, although the sign of the exposure coefficient could be negative or positive, an increase in exports always increases stock returns when the dollar depreciates and decreases stock returns when the dollar appreciates.

Nonlinear exposure effects are also found to be statistically and economically important. They improve the explanation of returns over and above that of the linear exposure coefficients. Nonlinear exposure appears to be just as important in industries with low levels of international trade as it is in industries extensive international trade. This finding is perhaps not too surprising since the nonlinear term captures the effects of large changes in exchange rates. Industries that previously have had only small amounts of international trade might find it profitable to increase imports and, or, exports as changes in the exchange rate make international trade profitable relative to the costs of undertaking it.

Using non-orthogonalized regressions fails to uncover exchange rate exposure, either in the regimes or over the whole sample. We investigate the robustness of our results and show that the exposure estimates are not materially affected by a large list of additional explanatory variables. However, we do show that using an orthogonalized currency basket instead of orthogonalized individual currencies drastically affects the results. With a currency basket we find very little evidence that any industry, irrespective of the extent of international trade and the regime considered, is exposed to the exchange rate.

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