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**Publication date**

2010

**Document Version**

Final published version

[Link to publication](#)

**Citation for published version (APA):**

Thiel, J. H., & van Giersbergen, N. P. A. (2010). *The effect of European integration on exchange rate dependence: the Polish accession to the EU*. (UvA-Econometrics discussion paper; No. 2010/10). Amsterdam School of Economics, Department of Quantitative Economics.

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Discussion Paper: 2010/10

# The effect of European integration on exchange rate dependence: the Polish accession to the EU

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# The Effect of European Integration on Exchange Rate Dependence: the Polish Accession to the EU

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December 22, 2010

## Abstract

This paper investigates the effect of the Polish accession to the European Union (EU) on the dependence between the euro-US dollar and Polish zloty-US dollar exchange rate. The dependence is estimated by means of copulas as suggested by Patton (2006). This approach allows to first specify and estimate the marginal models and subsequently estimate the dependence structure between these marginal models using a copula function. Two copulas are considered: the normal and the symmetrical Joe-Clayton (SJC) copula. In addition, two specifications of the copula parameters are estimated: a constant and dynamic specification. We find that the correlation between the exchange rates has increased significantly since Poland joined the EU. Furthermore, the variability of the correlation turns out to be much smaller after than before Poland joined the EU. Both findings suggest that the economic integration between Poland and the rest of the EU has increased. All copulas are tested for misspecification, although only the SJC copula with dynamic parameters seems to be correctly specified. A structural break due to accession of Poland was modeled through a traditional 0-1 step dummy and a logistic dummy. However, in none of the copula specifications considered in the paper, the smooth logistic dummy leads to significantly different results than the abrupt 0-1 dummy.

*Keywords:* Copulas, European Integration, Exchange rates

*JEL classification:* C32; C51; C52; F31.

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# 1 Introduction

For more than 50 years, the European Union (EU) has ensured peace and prosperity. It is not surprising that in recent decades many countries have joined the EU, hoping to share in this wealth. However, joining the EU as such does not result in increased prosperity. It is a result of economic integration, which includes the liberalization of financial markets and a larger market for local products. The final stage of accession to the EU is the adoption of the euro. However, before a country may adopt the euro, the local economy has to be sufficiently stable and integrated into the European economy.

Monetary policy is one aspect of economic integration. Before the introduction of the euro, its initiators more or less followed the monetary policy of the German Central Bank; see Ballabriga and Martinez-Mongay (2003). Hence, at the introduction of the euro, the initial participants only had to make small adjustments to their monetary policies to achieve a common monetary policy. However, Brada and Kutan (2001) noted that future members of the EU, especially members of the former Soviet Union, had great difficulty in following the policy of the German Bundesbank in Western Europe. A smooth economic integration of the countries that have joined the European Union over the past decade is therefore less obvious to occur than witnessed with the earlier member states. If the monetary policy of Poland after accession to the EU is closer to that of the European Central Bank (ECB), who mainly follows the same policy as the Bundesbank at that time, this would be an indication of economic integration. Due to the effect of the monetary policy on the exchange rate, a higher similarity between the monetary policies of Poland and the EU results in a higher exchange-rate dependence.

A second way in which economic integration affects the exchange rate dependence is through the absorption of real shocks by the economy. Before EU accession, the shocks experienced by Poland were significantly different than the rest of the EU; see Fidrmuc and Korhonen (2003) and Frenkel and Nickel (2005). If, due to economic integration, these

shocks resemble each other more, the movements of the euro and the Polish zloty against the US dollar should be more similar, which results in a higher exchange rate dependence.

In this paper, we study the degree of economic integration by looking at the dependence between the local currency-US dollar and the euro-US dollar exchange rate. We use the dollar as the common currency unit since it is considered the most important currency in the world. The idea is that this dependence is a measurement of economic integration, especially regarding monetary policy. Since the introduction of the euro, several Eastern European countries have joined the EU. However, not all of these countries have already adopted the euro. This paper focusses on one of these countries, namely Poland. We shall investigate whether the dependence between the euro-dollar (EUR-USD) and the Polish zloty-dollar (PLN-USD) exchange rate has increased since Poland has joined the EU.

The theory of copulas provides a convenient way to model and investigate dependence. It offers several advantages: the individual exchange rates can be modelled independently of the dependence structure which is modelled by a so-called copula; see for instance Trivedi and Zimmer (2005) for a nice econometric introduction into copula modeling. Copulas are very flexible and can model various kinds of dependencies including asymmetric ones; see for instance Patton (2006). Moreover, copulas can be used to describe the full joint distribution of the exchanges rates, which has important applications for investors like Value-at-Risk.

The paper is structured as follows. Section 2 considers the transition process for new EU member states. Section 3 provides some intuition about copulas. Section 4 introduces the various models, while Section 5 shows the estimation results. Section 6 concludes the paper.

## **2 The transition process for new member states**

Before a member state of the EU can adopt the euro and join the euro area, it must meet certain conditions known as ‘convergence criteria’. The convergence criteria are formally

defined as a set of macroeconomic indicators which measure:

- Price stability, to show inflation is controlled;
- Soundness and sustainability of public finances;
- Exchange-rate stability;
- Long-term interest rates, to assess the durability of the convergence achieved by fulfilling the other criteria.

These criteria are helpful to ensure the stability of the euro. Moreover, these criteria guarantee that the requirements for a successful monetary union as described by Mundell (1961) are fulfilled: that participating countries should be economic sufficiently similar such that the exchange rate is no longer required to absorb asymmetric economic shocks. Technically, new member states have to introduce the euro if certain requirements are fulfilled. On the one hand, it is quite easy to not meet the requirements if a country does not want to, like for instance Sweden; see Buiters and Grafe (2002). On the other hand, it is not so easy to meet these criteria, especially during the current economic crisis. This is evident from the fact that many new members have had to postpone their plans for the adoption of the euro. For instance Poland has delayed the introduction until at least 2014.

A final step for the introduction of the euro is participation in the Exchange Rate Mechanism II (ERM II). This means that if all the above criteria are met, the local currency is pegged to the euro for at least two years. In that period, the local currency is allowed to float within a range of  $\pm 15\%$  with respect to the euro. If successful, the member state can then enter the euro area.

## **2.1 Monetary Policy**

In making monetary policy, central banks in transition economies have to consider a number of conflicting goals as mentioned by Kröger and Redonnet (2001): reduce the costs of

disinflation, support economic growth and convergence, adjust to real shocks, control the possible destabilizing effects of international capital flows and prepare to join ERM II. It should therefore come as no surprise that in the preparatory stage to EU accession (and thereafter), very different monetary policy and exchange rate regimes were observed among the new member states; see e.g. Buiter and Grafe (2002).

The exchange rate regime chosen by a member state has the following influence on the dependence between exchange rates. In the case of a (more or less) fixed exchange rate with the euro, as was the case in e.g. Estonia, the dependence can be accurately approximated by a simple linear correlation close to 1. Choosing a (sort of) floating exchange rate, such as Poland, the dependence is determined mainly by two factors: the similarities in monetary policy and the similarities in real shocks. This can easily be seen in the decomposition of the nominal exchange rate; see for instance Gärtner (2003, p. 71):

$$E = \frac{P}{P^*}R, \tag{1}$$

where  $E$  denotes the nominal exchange rate,  $R$  the real exchange rate,  $P$  the price level of the home country and  $P^*$  the price level of another country. Monetary policy influences the nominal exchange rate through the price level. If inflation is higher in the home country than in the other country,  $P$  rises faster than  $P^*$ , leading to an increase in  $E$ . In other words, the currency devaluates.

Let  $E_{EUR}$  denote the EUR-USD exchange rate and  $E_{PLN}$  the PLN-USD exchange rate. If monetary policy is the same in both countries, then similar movements in inflation will be observed. This ensures that  $E_{EUR}$  and  $E_{PLN}$  are linearly related. However, if there are major differences in monetary policy, the paths of inflation will be quite different leading to different behavior between  $E_{EUR}$  and  $E_{PLN}$ . Overall, the larger the resemblance between the monetary policies in two countries, the higher the dependence between the exchange rates and vice versa.

Real shocks can be a second source for various forms of dependence between exchange

rates; see equation (1). For instance, if a negative demand shock takes place, then *ceteris paribus* import declines. This leads to a growing trading surplus, which causes the local currency to rise. This means that the real exchange rate  $R$  decreases. So, if two countries experience the same real shocks, the real and thus the nominal exchange rate against a reference currency will show similar movements, which imply a high dependence. If the shocks differ, however, the effects on the prices differ, leading to a smaller dependence. Overall, the relationship between the real shocks and the dependence between exchange rates is as follows: the larger the similarity between the real shocks in two countries, the higher the dependence between the exchange rates and vice versa.

The similarity between economic shocks in the EU and new Eastern European countries varies from country to country, but, until the beginning of this century, each country had undergone a large number of idiosyncratic shocks; see Fidrmuc and Korhonen (2003). Moreover, the adjustment process after shocks often were quite different across the EU, although Frenkel and Nickel (2005) find that differences have become smaller over time.

### 3 Copulas

Consider two exchange rates  $X$  and  $Y$  having marginal distributions  $F_X(x)$  and  $F_Y(y)$  and joint distribution  $F_{XY}(x, y)$ . In the bivariate case, a copula is defined as:

$$F_{XY}(x, y) = C(F_X(x), F_Y(y)|\boldsymbol{\theta}), \quad (2)$$

where  $C(\cdot)$  denotes the copula with parameters  $\boldsymbol{\theta}$ ; see Nelsen (2006) for a classical but rather technical introduction into copulas. It should be noted that the marginal distributions may come from different families. For equation 2, it is obvious that a copula models the dependence between the marginal distributions. According to the Sklar's theorem, every multivariate distribution has a copula representation under mild regularity conditions. It can be shown that the copula is unique if the marginal distributions are continuous.

The advantage of using copulas for empirical research is that every pair of marginal

distributions combined with a copula function yields a valid bivariate distribution. As noted earlier, the marginal distributions do not have to come from the same family as is the case with most known multivariate distribution such as the multivariate normal or student-t. Hence, the use of copulas has led to a enormous growth of multivariate distributions.

The theory of copulas is generalized by Patton (2006) to conditional copulas. This is necessary when dealing with model time series since we are interested in modelling moments (first and possibly second) conditional on the past. A conditional copula is defined as follows. Suppose  $X$ ,  $Y$  and  $W$  are three random variables with conditional distributions  $X|W = w \sim F_{X|W}(\cdot|w)$  and  $Y|W = w \sim F_{Y|W}(\cdot|w)$ , where  $F(\cdot|w)$  denotes the condition distribution given  $w$ . The conditional copula of  $(X, Y)|W = w$  is defined as the conditional joint distribution of  $U \equiv F_{X|W}(X|w)$  and  $V \equiv F_{Y|W}(Y|w)$  given  $W = w$ . The random variables  $U$  and  $V$  are the so-called *Probability Integral Transforms* (PITs). If  $X$  is a random variable with distribution  $F_X(x)$ , then  $F_X(X)$  is the PIT of  $X$  and we have  $F_X(X) \sim Unif[0, 1]$ . So,  $U$  and  $V$  are  $Unif[0, 1]$  distributed. A conditional copula can be viewed as the conditional joint distribution of two uniform distributions. Patton (2006) shows that the theorem of Sklar also holds for conditional bivariate distributions. Thus, for each conditional bivariate distribution  $F_{XY|W}(\cdot|w)$ , there exists a copula  $C(\cdot|w)$  such that

$$F_{XY|W}(x, y|w) = C(F_{X|W}(x|w), F_{Y|W}(y|w)|w) \quad (3)$$

and vice versa. As noted by Patton (2006), there is one important additional condition when using conditional copulas namely that both marginal distributions and the copula have to be conditioned on the same information set  $W$ . If this is not the case, the use of conditional copulas does not automatically yield a valid conditional bivariate distribution. So, if for example a variable is added to the conditional distribution of  $X$ , one has to assess whether it is also a significant variable in the model for  $Y$  and the copula  $C$ . Only if this variable is insignificant, it can be left out of the model for  $Y$  and/or copula  $C$ .

## 4 Modeling the Joint Distribution

In this paper, we investigate the dependence between the EUR-USD and PLN-USD exchange rates. The data were obtained from Datastream and run from 1st of January 1999, the introduction day of the euro, until February 19, 2010. In total there are 2,898 observations. Since May 1, 2005, Poland has been a member of the EU, so there are about as many data observations before as after the membership. Although more countries joined the EU about that time, Poland was the only country that throughout the whole period has known to have a floating exchange rate against the euro. Other countries had at least a part of this period a (more-or-less) fixed exchange rate. With a fixed exchange rate, the correlation between the euro-dollar exchange rate and local currency-US dollars is close to 1. Hence, during these fixed exchange rate periods, the data is unusable for estimating the dependence. Poland is currently the only country for which a long, continuous time period of data is available.

To investigate the effect of accession to the EU on the dependency of the exchange rates, two steps have to be taken. First, the marginal models for the separate exchange rates have to be specified and estimated. Then the copula, which models the dependency between the two exchange rates, has to be specified and estimated.

### 4.1 Specification of the Marginal Models

The marginal models were estimated using daily returns of the exchange rates. If  $E_{i,t}$  denotes the nominal exchange rate of currency  $i = EUR, PLN$  with respect to the US dollar at time period  $t$ , then the daily return is defined as  $r_{i,t} = 100 \cdot (\log(E_{i,t}) - \log(E_{i,t-1}))$ . The following t-GARCH models were estimated for the exchange returns:

$$r_{i,t} = \mu_i + \sum_{j=1}^m \phi_{i,j} \cdot r_{i,t-j} + \varepsilon_{i,t} \quad (4)$$

$$\sigma_{i,t}^2 = \omega_i + \sum_{j=1}^n \beta_{i,j} \cdot \sigma_{i,t-j}^2 + \sum_{j=1}^o \alpha_{i,j} \cdot \varepsilon_{i,t-j}^2 \quad (5)$$

$$\sqrt{\frac{\nu_i}{\sigma_{i,t}^2(\nu_i - 2)}} \cdot \varepsilon_{i,t} \sim t(\nu_i), \quad (6)$$

where  $i = EUR, PLN$ . The parameters  $m$ ,  $n$ , and  $o$  indicate the number of lags that are used in the mean and variance equations. The lag lengths as well as the degrees of freedom will be determined by the data. Furthermore, each marginal model should be based on the same information set, so the influence of variables included in one model has to be investigated in the other model.

## 4.2 Specification of the Copula's

Copulas from two different families will be estimated. Furthermore, two different parameter specifications are estimated for each copula. In the first specification, the parameters of the copulas are assumed to be constant. In the second specification, called the dynamic specification, the parameters of the copulas are allowed to change in a parametric way across time. The dynamic specification arises naturally since the variances are not constant due to the marginal t-GARCH models. If the second conditional moments are not constant, the dependencies will also vary in general.

The copulas will be estimated using the transformed residuals obtained in the marginal models. If  $\eta_{i,t}$  denote the transformed residuals according to formula (6), then  $U_t = F_t(\eta_{EUR,t} | \nu_{EUR})$  and  $V_t = F_t(\eta_{ZLO,t} | \nu_{ZLO})$  should be approximately  $Unif[0, 1]$  distributed; here  $F_t(\cdot | \nu)$  denotes the cumulative distribution function (c.d.f.) of a  $t$ -distribution with  $\nu$  degrees of freedom.

The first copula considered is the normal defined as

$$C_N(u, v | \rho) = \Phi_G(\Phi^{-1}(u), \Phi^{-1}(v); \rho), \quad (7)$$

where  $\Phi_G(\cdot|\rho)$  denotes the c.d.f. of a bivariate standard normal distribution with parameter  $\rho \in (-1, 1)$  and  $\Phi^{-1}(\cdot)$  the inverse c.d.f. of a standard normal distribution. Note that the parameter  $\rho$  only represents the correlation between the marginal distributions if both marginals are standard normally distributed.

Following Patton (2006), the parameter  $\rho$  is made dynamic according to

$$\rho_t = \tilde{\Lambda}(\omega_\rho + \beta_\rho \rho_{t-1} + \alpha \cdot \frac{1}{10} \sum_{j=1}^{10} \Phi^{-1}(u_{t-j}) \Phi^{-1}(v_{t-j})), \quad (8)$$

where  $\tilde{\Lambda}(x) \equiv (1 - e^{-x})(1 + e^{-x})^{-1}$  is the modified logistic transformation, so that  $\rho_t$  is restricted to the interval  $(-1, 1)$ . The last term can be interpreted as an estimate of the correlation between the preceding 10 observations, since  $\Phi^{-1}(U) \stackrel{d}{=} \Phi^{-1}(V) \sim N(0, 1)$  and  $E[\Phi^{-1}(U_t)\Phi^{-1}(V_t)] = Corr[\Phi^{-1}(U_t), \Phi^{-1}(V_t)]$ . This means that  $\rho_t$  is high if the correlation is high and vice versa.

The second copula is the symmetric Joe-Clayton copula. This is a variation introduced by Patton (2006) of the Joe-Clayton copula that is defined as

$$C_{JC}(u, v|\tau^U, \tau^L) = 1 - (1 - \{[1 - (1 - u)^\kappa]^{-\gamma} + [1 - (1 - v)^\kappa]^{-\gamma} - 1\}^{-1/\gamma})^{1/\kappa} \quad (9)$$

$$\kappa = 1/\log_2(2 - \tau^U) \quad (10)$$

$$\gamma = -1/\log_2(\tau^L), \quad (11)$$

where  $\tau^U \in (0, 1)$  and  $\tau^L \in (0, 1)$ .  $\tau^U$  and  $\tau^L$  are measures of *tail dependence*. *Lower tail dependence* is defined as

$$\tau^L = \lim_{\varepsilon \rightarrow 0} \Pr[U \leq \varepsilon | V \leq \varepsilon] = \lim_{\varepsilon \rightarrow 0} \Pr[V \leq \varepsilon | U \leq \varepsilon] = \lim_{\varepsilon \rightarrow 0} \frac{C(\varepsilon, \varepsilon)}{\varepsilon}, \quad (12)$$

while *upper tail dependence* is defined as

$$\tau^U = \lim_{\delta \rightarrow 1} \Pr[U > \delta | V > \delta] = \lim_{\delta \rightarrow 1} \Pr[V > \delta | U > \delta] = \lim_{\delta \rightarrow 1} \frac{1 - 2\delta + C(\delta, \delta)}{1 - \delta}. \quad (13)$$

Tail dependence measures the likelihood that one exchange rate will be extreme given that the other exchange rate is extreme. For the normal copula  $C_N(\cdot)$ , we have  $\tau^U = \tau^L = 0$  if

$Corr(U, V) < 1$ . This means that the tails can be considered independent under the normal copula. The estimation of the (symmetric) Joe-Clayton copula has the advantage that it allows us to investigate whether the relation between the exchange rates has changed under extreme circumstances after Poland has joined the EU.

The Joe-Clayton copula has the disadvantage that is asymmetric, i.e. equal values of  $\tau^U$  and  $\tau^L$  do not necessarily imply equal tail dependence. Hence, Patton (2006) proposes to use the symmetric Joe-Clayton (SJC) copula:

$$C_{SJC}(u, v | \tau^U, \tau^L) = 0.5 \cdot (C_{JC}(u, v | \tau^U, \tau^L) + C_{JC}(1 - u, 1 - v | \tau^L, \tau^U)) + u + v - 1. \quad (14)$$

This SJC-copula has the property that  $\tau^U = \tau^L$  implies equal tail dependence. Just like the normal copula we also estimate a dynamic version using the following evolution equations for the SJC-copula:

$$\tau_t^L = \Lambda(\omega_L + \beta_L \cdot \tau_{t-1}^L + \alpha_L \cdot \frac{1}{10} \sum_{j=1}^{10} |u_{t-j} - v_{t-j}|), \quad (15)$$

$$\tau_t^U = \Lambda(\omega_U + \beta_U \cdot \tau_{t-1}^U + \alpha_U \cdot \frac{1}{10} \sum_{j=1}^{10} |u_{t-j} - v_{t-j}|), \quad (16)$$

where  $\Lambda(x) \equiv (1 + e^{-x})^{-1}$  denotes the logistic transformation, which ensures that the parameters are restricted to the  $(0, 1)$  interval. These equations are similar to the evolution equation for  $\rho_t$  of the normal copula. Again, the last term is a measure of the correlation between the last 10 observations.

### 4.3 Structural Break

It could be that the accession of Poland to the EU has led to a structural break between the PLN-USD and EUR-USD exchange rate. To allow for a structural break, a dummy is included for *each* parameter in both the marginal models as well as in the copulas. Two types of dummies are included. First, a classical 0-1 step dummy is included, assuming the value zero before the accession and one thereafter. This type of dummy implies an abrupt change in the dependency of the exchange rates, which might not be very realistic.

Accession and integration are processes which could take some considerable time. For example, many European rules have to be adopted by new members before EU accession. In addition, financial markets usually anticipate long before the actual accession and its economic integration. On the one hand, this would mean that the effects of integration should be noticeable before the actual accession has taken place. On the other hand, the effective integration of markets can only take place after the accession since the borders are (relatively) closed. Entering into new business relationships, or also important in case of Poland the migration of labor affecting the financial flows into the home country, takes time and so the effects on the exchange rate is not noticeable immediately after accession.

It is therefore reasonable to assume that already before the actual membership of the EU the effects of European economic integration can be measured and that they continue after the accession. Therefore, besides the aforementioned 0-1 dummy also a *logistic dummy* is used to allow for a gradual change in the dependency between the exchange rates. This dummy is based on the logistic function  $\Lambda(x) = 1/(1 + \exp(-x))$ . This function has the properties  $\lim_{x \rightarrow -\infty} \Lambda(x) = 0$  and  $\lim_{x \rightarrow \infty} \Lambda(x) = 1$ . The logistic function is transformed so that the symmetry point  $\Lambda(x) = 1/2$  is at the accession date and the effect begins approximately one year before and ends one year after accession. In other words,  $\Lambda(x) \approx 0$  one year before accession and  $\Lambda(x) \approx 1$  one year after accession.

## 5 Estimation Results

The models in the previous section will be estimated using a two-step *Maximum Likelihood* (ML) method: first, the marginal models will be estimated and subsequently the copula. Although this method is less efficient than estimating the full joint model at once, the number of parameters is too large to achieve convergence when the full likelihood is optimized in one step. In addition, the two-step procedure has the advantage that first the marginal models can be properly estimated and specified before the copula is estimated. Even if the

model is estimated in two steps, the ML estimator is consistent and asymptotically normally distributed.

## 5.1 Marginal Models Estimates

Table 1 shows the parameter estimates for the marginal t-GARCH models. Note that in the marginal model for  $r_{PLN}$ , two lags of  $r_{EUR}$  are included. This is due to the fact that the marginal models have to condition on the same information set and the lags were significant in both marginal models. A Wald test that all variables are redundant yields a  $p$ -value of 0.000<sup>1</sup>. Moreover, the goodness-of-fit tests that will be shown later reveal that the models are incorrectly specified if these variables are removed. Table 2 shows that  $r_{PLN,t-1}$  is not significant in the EUR-USD model, and the squared residuals of one marginal model do not contribute to the explanation of the other model. Hence, these variables are not included in the final marginal models.

Insert Tables 1 and 2 about here.

As suggested by Diebold et al. (1998), two specification tests are carried out in the marginal models. First, the Kolmogorov-Smirnov test is used to investigate whether the transformed residuals deviate from the  $Unif(0, 1)$  distribution. In the second test,  $(u_t - \bar{u})^k$  and  $(v_t - \bar{v})^k$  is regressed on lagged values of  $(u_t - \bar{u})^k$  and  $(v_t - \bar{v})^k$  for  $k = 1, 2, 3, 4$ . For  $k = 1$ , this corresponds to a LM-test for  $k^{th}$ -order autocorrelation. Under the null hypothesis of independence the explanatory variables should not be significant. The results of these tests are shown in Table 3, which reveal that both marginal models are well specified.

Insert Table 3 about here.

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<sup>1</sup>Under the null hypothesis, the coefficients of the following four variables are zero: the first and second lagged returns of the EUR-USD and their interaction effect with a dummy. This test is carried out in the model with a 0-1 dummy. The test statistic equals 49.744 leading to the reported  $p$ -value based on the  $\chi_4^2$ -distribution. Wald tests that only the first or second lag with corresponding dummy are redundant also give  $p$ -values of 0.000.

Two things are worth mentioning when considering the marginal models. First, the estimates in the model with the logistic dummy are hardly different from the estimates in the model with the simple 0-1 dummy. We have also looked at extending the transition period of the logistic dummy, but results are qualitatively the same. Secondly, a number of parameters in the EUR-USD model have changed after Poland joined the EU. Although at first sight this seems to be counterintuitive, this might be caused by the fact that a great number of Eastern European countries joined the EU at that time. This may have had effects on the economies of the countries that were already a member. It appears that a larger and thus harder to control EU may have suffered negative economic consequences while labor migration from Eastern Europe may also have influenced Western European economies.

## 5.2 Copulas Estimates

The copulas were estimated using the transformed residuals of the marginal t-GARCH models. Estimates are shown in Table 4. For both copulas with constant parameters, all dummies are individually significant at  $\alpha = 0.01$ . In dynamic parameters specification, none of the dummies, with exception of that for  $\alpha_L$ , is individually significant at  $\alpha = 0.05$ . However, the structural break as a whole is significant at any reasonable significance level. For the normal copula with dynamic parameters, a Wald test for the null hypothesis that the dummies are redundant yields a test statistic of  $\xi_W = 721970$  with a  $p$ -value of 0.000 based on the  $\chi^2$ -distribution with 3 degrees of freedom. For the SJC-copula with dynamic parameters, a Wald test statistic of  $\xi_W = 57972$  is obtained for the null hypothesis that all dummy variables are redundant with again a  $p$ -value of 0.000. Overall, the break is significant in all the copula specification considered: the parameters have changed after the accession of Poland to the EU.

Insert Table 4 about here.

The correlation according to the normal copula is shown in Figure 1. Note that  $\rho$  only represents the correlation coefficient if the marginal distributions are normal. The conditional correlation at time  $t$  is given by

$$Corr_t(U, V) = \int_0^1 (u - E[U])(v - E[V])c_N(u, v|\rho_t), \quad (17)$$

where  $c_N(\cdot) = \frac{\partial C_N}{\partial u \partial v} = \Phi(\Phi^{-1}(u), \Phi^{-1}(v)|\rho_t)/(\phi(\Phi^{-1}(u))\phi(\Phi^{-1}(v)))$  is the p.d.f. of the normal copula. Since  $U \stackrel{d}{=} V \sim Unif(0, 1)$ , we have  $\mathbb{E}[U] = \mathbb{E}[V] = 1/2$ . In general, we do not have a close form expression for the integral, so we have to use numerical integration to determine the correlation. Again, we follow Patton (2006) and use Gauss-Legendre quadrature, see for instance Judd (1998), with ten nodes on each margin leading to a total of one hundred nodes.

Comparing the dynamic to the constant parameter specification, we observe that on many days, the dynamic correlation deviates from the constant. However, for both specifications, it appears that the level of the correlation has increased substantially after the accession of Poland to the EU, while the variability of the correlation has decreased.

Insert Figure 1 about here.

Figures 2 and 3 show the lower and upper tail dependencies of the SJC-copula respectively. Here, the same picture emerges for the correlation as for the normal copula: both tail dependencies increase after the accession of Poland to the EU. In case of the lower tail dependency, the variability decreases such that the dynamic specification does not deviate significantly from the constant specification in the sense that the dynamic lower tail dependency is contained in the 95% confidence interval of the constant lower tail dependency for all days. This means that the exchange rates are very similar even in extreme circumstances.

Insert Figures 2 and 3 about here.

Overall, a structural break has occurred after the accession of Poland to the EU in the copulas containing a 0-1 dummy. Both the correlation and tail dependencies increase, while

the variability of both dependency measures decreases. All these results indicate that the dependency between the PLN-USD and EUR-USD exchange rate has increased after the Polish accession to the EU.

Table 4 also reports the results of the copulas if the 0-1 dummy is replaced by a logistic dummy, while Figure 4 shows the correlation graphically. As mentioned earlier, the marginal models at first glance hardly differ. Hence, a more formal test will be used to discriminate between the two approaches. Since the models are non-nested, it is not possible to compare one model to the other by simply testing parameter restrictions. Hence, likelihood ratio tests for non-nested hypotheses of Vuong (1989) are used as follows. Suppose  $F_\theta$  and  $G_\gamma$  are two models parameterized by the vectors  $\theta$  and  $\gamma$  respectively. Let  $Y_t$  denote the variable to model,  $Z_t$  the information set to condition on and let  $\theta_*$  and  $\gamma_*$  denote the true parameter values. Under the null hypothesis that these models are equivalent, i.e.  $H_0 : \mathbb{E}^0[\log \frac{f(Y_t|Z_t;\theta_*)}{g(Y_t|Z_t;\gamma_*)}] = 0$ , we have

$$V = n^{-1/2} LR(\hat{\theta}, \hat{\gamma}) / \tilde{\omega} \xrightarrow{D} N(0, 1),$$

where  $n$  denotes the number of observations,  $\hat{\theta}$  and  $\hat{\gamma}$  the estimated parameters,

$$LR(\hat{\theta}, \hat{\gamma}) \equiv L^f(\hat{\theta}) - L^g(\hat{\gamma}) = \sum_{i=1}^n \log \frac{f(Y_i|Z_i;\hat{\theta})}{g(Y_i|Z_i;\hat{\gamma})}$$

denotes the difference in log likelihoods and  $\tilde{\omega}^2 = \frac{1}{n} \sum_{i=1}^n [\log \frac{f(Y_i|Z_i;\hat{\theta})}{g(Y_i|Z_i;\hat{\gamma})}]^2$  is the estimated variance of  $LR(\hat{\theta}, \hat{\gamma})$ . The null hypothesis of equivalent models is rejected if  $V < -z_{\alpha/2}$  or  $V > z_{\alpha/2}$ , where  $z_\alpha$  denotes the critical value based on the standard normal distribution with nominal significance level  $\alpha$ . On the one hand, if  $V < -z_{\alpha/2}$ , the null hypothesis is rejected for the alternative  $H_f : \mathbb{E}^0[\log \frac{f(Y_t|Z_t;\theta_*)}{g(Y_t|Z_t;\gamma_*)}] > 0$ , which implies that  $F$  is a better model than  $G$ . On the other hand, if the null hypothesis is rejected against the alternative  $H_g : \mathbb{E}^0[\log \frac{f(Y_t|Z_t;\theta_*)}{g(Y_t|Z_t;\gamma_*)}] < 0$ , then  $G$  is better than  $F$ .

Insert Figure 4 about here.

Table 5 shows the results for comparing the model including a 0-1 dummy to the model including a logistic dummy for all four copula specifications considered. In none of the four cases, the null hypothesis that the two models with different kind of dummies are equivalent is rejected at any reasonable level of significance. Therefore, the logistic dummy does not improve the model specification significantly. Adjusting the width of the logistic dummy does not qualitatively change this finding.

Insert Table 5 about here.

To test whether the copulas are well specified, so-called *joint hit tests* are carried out as suggested by Patton (2006). Let  $\mathcal{S}$  denote the support of a bivariate random variable  $W_t$ , which is divided in  $K + 1$  mutually exclusive  $R_j$  such that  $R_i \cap R_j = \emptyset$  for  $i \neq j$  and  $\bigcup_{j=0}^K R_j = \mathcal{S}$ . Let  $\pi_{jt}$  be the true probability that  $W_t \in R_t$  and  $p_{jt}$  the probability as implied by the model. In addition, define  $\Pi_t \equiv [\pi_{0t}, \pi_{1t}, \dots, \pi_{Kt}]'$ ,  $P_t \equiv [p_{0t}, p_{1t}, \dots, p_{Kt}]'$  and  $M_t \equiv \sum_{j=0}^K j \cdot \mathbf{1}\{W_t \in R_t\}$ , where  $\mathbf{1}\{\cdot\}$  denotes the indicator function which equals one if the argument is true and zero otherwise. Under the null hypothesis that the model is well specified, we have  $\Pi_t = P_t$  for all  $t$ . The hypothesis that the model is correctly specified in all regions can be written as  $H_0 : M_t \sim \text{Multinomial}(P_t)$  versus  $H_1 : M_t \sim \text{Multinomial}(\Pi_t)$ . However, the true probabilities  $\Pi_t$  are unknown. Therefore  $\Pi_t$  is estimated using a Logit model:

$$\pi_{1t}(Z_t, \beta, P_t) = \Lambda \left( \lambda_1(Z_{1t}, \beta_t) - \log \left[ \frac{1 - p_{1t}}{p_{1t}} \right] \right) \quad (18)$$

$$\pi_{jt}(Z_t, \beta, P_t) = \left( 1 - \sum_{i=1}^{j-1} \pi_{it} \right) \cdot \Lambda \left( \lambda_j(Z_{jt}, \beta) - \log \left[ \frac{1 - \sum_{i=1}^j p_{it}}{p_{jt}} \right] \right) \quad (19)$$

for  $j = 2, \dots, K$

$$\pi_{0t}(Z_t, \beta, P_t) = 1 - \sum_{j=1}^K \pi_j(Z_t, \beta, P_t), \quad (20)$$

where  $\Lambda(x) = (1 + e^{-x})^{-1}$  denotes the logistic transformation,  $Z_t$  represents the information set for time period  $t - 1$ ,  $\beta$  a vector of parameters and  $\lambda_j(\cdot)$  is any function of regressors and parameters such that  $\lambda_j(Z_t, 0) = 0$  for all  $Z_t$ . We have  $\pi_{jt} = p_{jt}$  if  $\beta = 0$  for all  $j, t$ .

Therefore,  $H_0$  can be tested versus  $H_1$  by estimating  $\beta$  by Maximum Likelihood and test the restriction  $\beta = 0$ . The function to optimize is  $L(\Pi(Z, \beta, P)) = \sum_{t=1}^T \sum_{j=0}^K \log \pi_{jt} \cdot \mathbf{1}\{M_t = j\}$  and the restriction  $\beta = 0$  can be tested by means of a Likelihood Ratio test. The test statistic equals  $LR = -2 \cdot (L(P) - L(\Pi(Z, \hat{\beta}, P)))$  and under  $H_0$  we have  $LR \sim \chi_M^2$  asymptotically, where  $M$  is the dimension of the parameter  $\beta$ .

The support of the copulas is divided into eight regions, each with a specific economic interpretation. Regions 1 and 2 correspond to the lower and upper joint 10% tails for each variable, which contain simultaneously extreme values for both exchange rates. Regions 3 and 4 contain less extreme values that correspond to 10th and 25th, or 75th and 90th quantiles. Region 5 contains the middle 50% values that are contained between the 25th and 75th quantiles. Regions 7 and 8 contain extremely asymmetric days and correspond to the lower 25% tail of one variable when the other variable is in its upper 25% tail. Region 0 contains that part of the support that is not covered by regions 1 to 7.

The explanatory variable in the regression function for  $\pi_{jt}$  are the following: a constant and three variables that count how many times the variables were contained in the same region for the last, the last five and the last ten observations, that is  $\lambda_j(Z_t, \beta) = \beta_1 + \beta_2 \cdot \mathbf{1}\{M_{t-1} = j\} + \beta_3 \sum_{i=1}^5 \mathbf{1}\{M_{t-i} = j\} + \beta_4 \sum_{i=1}^{10} \mathbf{1}\{M_{t-i} = j\}$ .

The results of the *joint hit test* are reported in Table 6. The only model in which the null hypothesis of correct specification is not rejected at  $\alpha = 0.05$  is the SJC-copula with dynamic parameters. Since the normal and SJC-copula only differ substantially from each other in modelling the tail behavior, this implies that the tail behavior is important for these exchange rates.

Insert Table 6 about here.

## 6 Conclusion

This paper has investigated the effect of accession of Poland to the European Union on the dependence between the euro-US dollar (EUR-USD) and Polish zloty-US dollar (PLN-USD) exchange rate. This dependence is a measure of economic integration between Poland and the EU. There are two ways in which the exchange rate is affected by economic integration. The first is monetary policy. If countries implement the same monetary policy, the movements in exchange rates should be very similar. The second way in which economic integration affects the exchange dependence is through real shocks in the economy. Through trade, real shocks affect the individual exchange rates and hence the exchange rate dependence. Before EU accession, the shocks experienced by Poland were significantly different than the rest of the EU. If, due to economic integration, these shocks resemble each other more, the movements of the Euro and the Zloty against the dollar should be more similar, which results in a higher exchange rate dependence.

The copula approach is used to investigate the dependence between the EUR-USD and PLN-USD exchange rates. This approach allows to first estimate the marginal models, and subsequently estimate the dependence structure between these marginal models. For the marginal models, t-GARCH models are estimated using daily returns on EUR-USD and PLN-USD exchange rates. Specification test as suggested by Diebold et al. (1998) do not reject the null hypothesis of correct specification of both models. Subsequently, the modified residuals of these marginal models are used to estimate different copulas. We focus on the normal and so-called Joe-Clayton (SJC) copulas. In addition, two specifications of the parameters of the copulas are considered, a constant and dynamic one. In the normal copula, the correlation between the exchange rates increased significantly after Poland had joined the EU. Furthermore, the variability of the correlation was much smaller after than before Poland joined the EU.

In contrast to the normal copula, the SJC copula allows for tail dependency: this cap-

tures the behavior of the exchange rates during extreme events. Both the lower and upper tail dependency increased significantly after the accession of Poland to the EU. This means that the probability that we will observed an extremely large change in the PLZ-USD exchange rate given that the EUR-USD exchange rate has extremely changed has increased. As before, a lower variability of the dependence measures is observed. These findings suggest that the economic integration has increased.

The estimated copulas are tested for misspecification, one of these tests being the joint hit test. The only copula for which the null hypothesis of correct specification could not be rejected is the SJC copula with dynamic parameters. This means two things. First, since the normal and SJC copulas only substantially deviate from each other in the tails, modelling the tail behavior is apparently important for these two exchange rates. Secondly, the fact that the SJC copula with constant parameters was rejected implies that making the parameters dynamic is really necessary.

A structural break due to accession of Poland was modeled with a traditional 0-1 dummy. The question is whether such an abrupt transition is a good assumption. For example, long before the actual date of accession it is known that a specific country joins the EU. Moreover, it takes quite some time for the local market to integrate with the European market. So, the economic integration begins before the accession date and continues thereafter. This gradual adjusted is investigated by replacing the 0-1 dummy with a logistic dummy to model a smooth increase in the dependence. Using the likelihood ratio test for non-nested hypotheses, it was investigated whether this model performed better than a simple step dummy. In none of the copula specifications considered in the paper, the null hypothesis that the models are equivalent was rejected. This could mean that either (i) the data is not informative about the shape of the transition or (ii) the transition on the exchange markets is quite faster than for the economic integration.

A limitation of this research is that it does not distinguish the different causes of economic integration. Hence, it might be interesting to investigate in the future through which

channels economics integration channels has taken place and whether the effects are indeed as positively as expected.

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Table 1: Estimation results for the marginal models before and after the accession of Poland to the EU. Estimates were obtained by ML with asymptotic standard errors in parentheses. An estimate between the before and after columns means that the value does not change significantly ( $\alpha = 5\%$ ) after the accession. See main text for the description of the variables included.

	0-1 dummy		Logistic dummy	
	Before	After	Before	After
<hr/> PLN-USD <hr/>				
Constant	-0.0111 (0.016)	-0.068 (0.019)	-0.014 (0.016)	-0.065 (0.020)
AR(1)	-0.073 (0.030)	-0.019 (0.036)	-0.071 (0.031)	-0.029 (0.037)
$r_{EUR,t-1}$	0.168 (0.025)	0.040 (0.053)	0.165 (0.026)	0.057 (0.054)
$r_{EUR,t-2}$	0.074 (0.025)	0.010 (0.037)	0.079 (0.026)	0.000 (0.039)
GARCH constant	0.048 (0.013)	0.005 (0.003)	0.046 (0.012)	0.005 (0.003)
$\varepsilon_{t-1}^2$	0.117 (0.025)	0.061 (0.013)	0.114 (0.025)	0.061 (0.014)
Lagged variance	0.779 (0.043)	0.938 (0.013)	0.783 (0.043)	0.939 (0.013)
Degrees of Freedom		6.181 (0.683)		6.175 (0.679)
<hr/> EUR-USD <hr/>				
Constant		-0.014 (0.011)		-0.015 (0.011)
AR(1)		-0.042 (0.018)		-0.041 (0.018)
GARCH constant	0.103 (0.026)	0.001 (0.001)	0.080 (0.016)	0.001 (0.001)
$\varepsilon_{t-1}^2$		-0.013 (0.015)		-0.013 (0.015)
$\varepsilon_{t-2}^2$	0.074 (0.030)	0.052 (0.018)	0.074 (0.028)	0.055 (0.018)
Lagged variance	0.714 (0.066)	0.959 (0.010)	0.762 (0.050)	0.956 (0.010)
Degrees of freedom		12.329 (3.176)		12.106 (2.960)

Table 2: The  $p$ -values for the Wald statistics that test the null hypothesis that the variable is redundant.

	$p$ -value
$r_{ZLO,t-1}$ in het model for $r_{EUR,t}$	0.080
$\varepsilon_{EUR,t-1}^2$ in het model for $\sigma_{ZLO,t}^2$	0.247
$\varepsilon_{ZLO,t-1}^2$ in het model for $\sigma_{EUR,t}^2$	0.463

Table 3: Specification tests of the marginal models. The Kolgomorov-Smirnov test investigates whether the transformed residuals  $U_t$  and  $V_t$  are  $Unif(0,1)$  distributed. The moment tests are based on regressing  $(u_t - \bar{u})^k$  (for PLN-USD) or  $(v_t - \bar{v})^k$  (for the EUR-USD) on ten lags of both terms for  $k = 1, 2, 3, 4$ . The  $p$ -values shown refers to an F-statistic for the null hypothesis that all coefficients (except the constant) are zero. The null hypothesis of these tests corresponds to independence of the time series.

	ZLO-USD		EUR-USD	
	0-1 dummy	Logistic dummy	0-1 dummy	Logistic dummy
Kolgomorov-Smirnov tests	0.482	0.486	0.216	0.157
First moment test	0.446	0.439	0.652	0.641
Second moment test	0.231	0.256	0.318	0.282
Third moment test	0.698	0.706	0.594	0.616
Fourth moment test	0.107	0.120	0.558	0.508

Table 4: Estimation results for the copulas before and after the accession of Poland to the EU. Estimates were obtained by ML with asymptotic standard standard errors in parentheses. Asymptotic standard errors in parentheses.

	0-1 dummy		Logistic dummy	
	Before	After	Before	After
Normal copula - constant parameter				
$\rho$	0.368 (0.022)	0.748 (0.009)	0.364 (0.022)	0.749 (0.009)
SJC-copula - constant parameters				
$\tau^L$	0.231 (0.034)	0.558 (0.020)	0.218 (0.035)	0.570 (0.020)
$\tau^U$	0.140 (0.035)	0.554 (0.020)	0.115 (0.037)	0.569 (0.020)
Normal copula - dynamic parameter				
$\omega_\rho$	0.007 (0.007)	-0.090 (0.547)	0.003 (0.011)	0.538 (0.595)
$\alpha_\rho$	0.080 (0.023)	0.138 (0.062)	0.055 (0.023)	0.129 (0.077)
$\beta_\rho$	2.027 (0.034)	2.581 (0.754)	2.025 (0.056)	1.775 (0.801)
SJC-copula - dynamic parameters				
$\omega_L$	1.163 (1.411)	0.083 (2.288)	0.907 (0.682)	2.179 (0.158)
$\alpha_L$	-8.372 (3.904)	1.281 (2.383)	-8.048 (1.134)	2.366 (0.570)
$\beta_L$	-1.153 (2.936)	-0.099 (4.536)	-0.919 (1.444)	-4.096 (0.026)
$\omega_U$	1.583 (1.302)	1.580 (3.216)	1.599 (1.995)	3.477 (0.407)
$\alpha_U$	-13.993 (5.091)	-5.398 (4.956)	-14.729 (6.590)	-6.165 (2.516)
$\beta_U$	-1.311 (2.195)	-0.936 (4.549)	-1.529 (3.593)	-3.984 (0.165)

Table 5: Non-nested likelihood ratio tests of Vuong (1989) for the null hypothesis that the model with 0-1 dummy and the logistic dummy are equivalent. See the main text for a description of the variables. Two-sided  $p$ -values are reported based on the asymptotic distribution of  $V$ .

Copula	$LR(\hat{\theta}, \hat{\gamma})$	$\tilde{\omega}^2$	$V$	$p$ -value
Normal copula - constant parameter	1.9397	0.0115	0.3355	0.737
SJC-copula - constant parameters	0.533	0.0060	0.1274	0.899
Normal copula - dynamic parameter	-1.4423	0.0075	-0.3104	0.756
SJC-copula - dynamic parameters	-0.117	0.0053	-0.4130	0.680

Table 6: Joint hit tests.

Model	$LR$	$p$ -value
Normal copula - constant parameter	20.770	0.000
SJC-copula - constant parameters	10.212	0.037
Normal copula - dynamic parameter	19.590	0.001
SJC-copula - dynamic parameters	8.232	0.083

Figure 1: The conditional correlation between the daily returns on the PLN-UDS and EUR-USD exchange rates using a normal copula. The horizontal line represents the constant correlation with 95% confidence bands. The vertical line represents the date of the Polish accession to the EU.

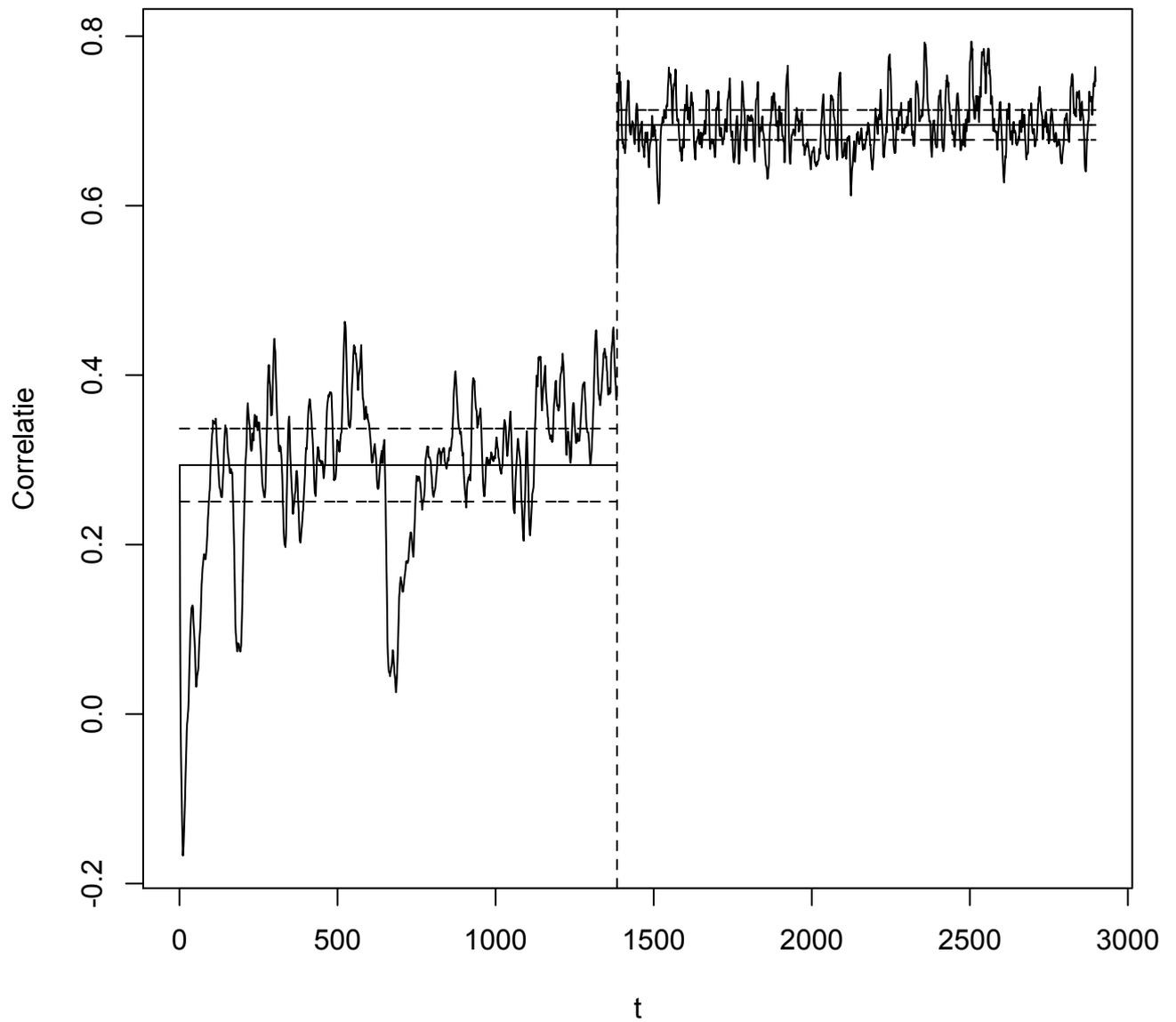


Figure 2: Lower tail dependence from the Symmetrized Joe-Clayton copulas between the daily returns on the PLN-USD and EUR-USD exchange rates. The smooth line represents the constant correlation with 95% confidence bands. The vertical line represents the date of the Polish accession to the EU.

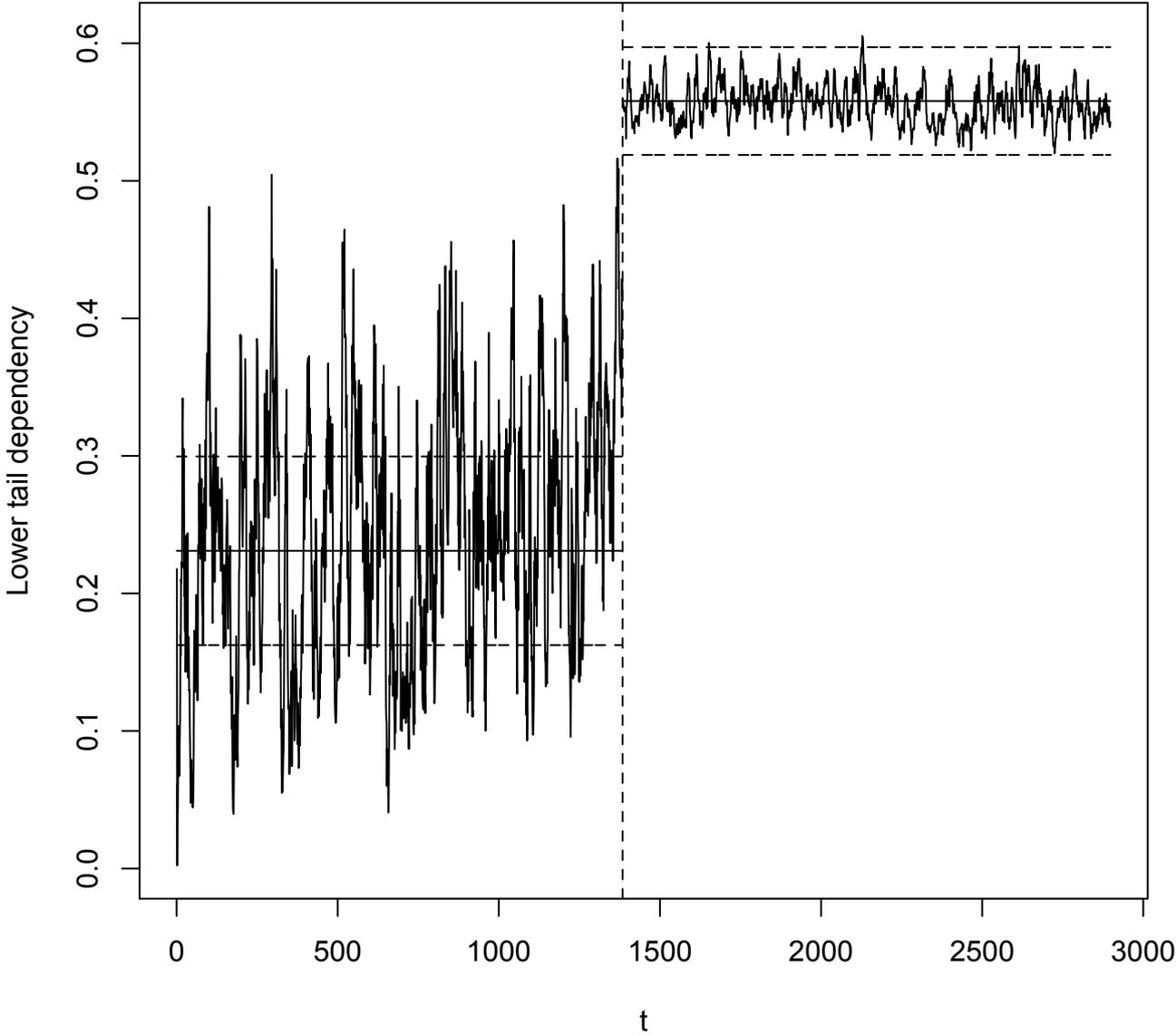


Figure 3: Upper tail dependence from the Symmetrized Joe-Clayton copulas between the daily returns on the PLN-USD and EUR-USD exchange rates. The smooth line represents the constant correlation with 95% confidence bands. The vertical line represents the date of the Polish accession to the EU.

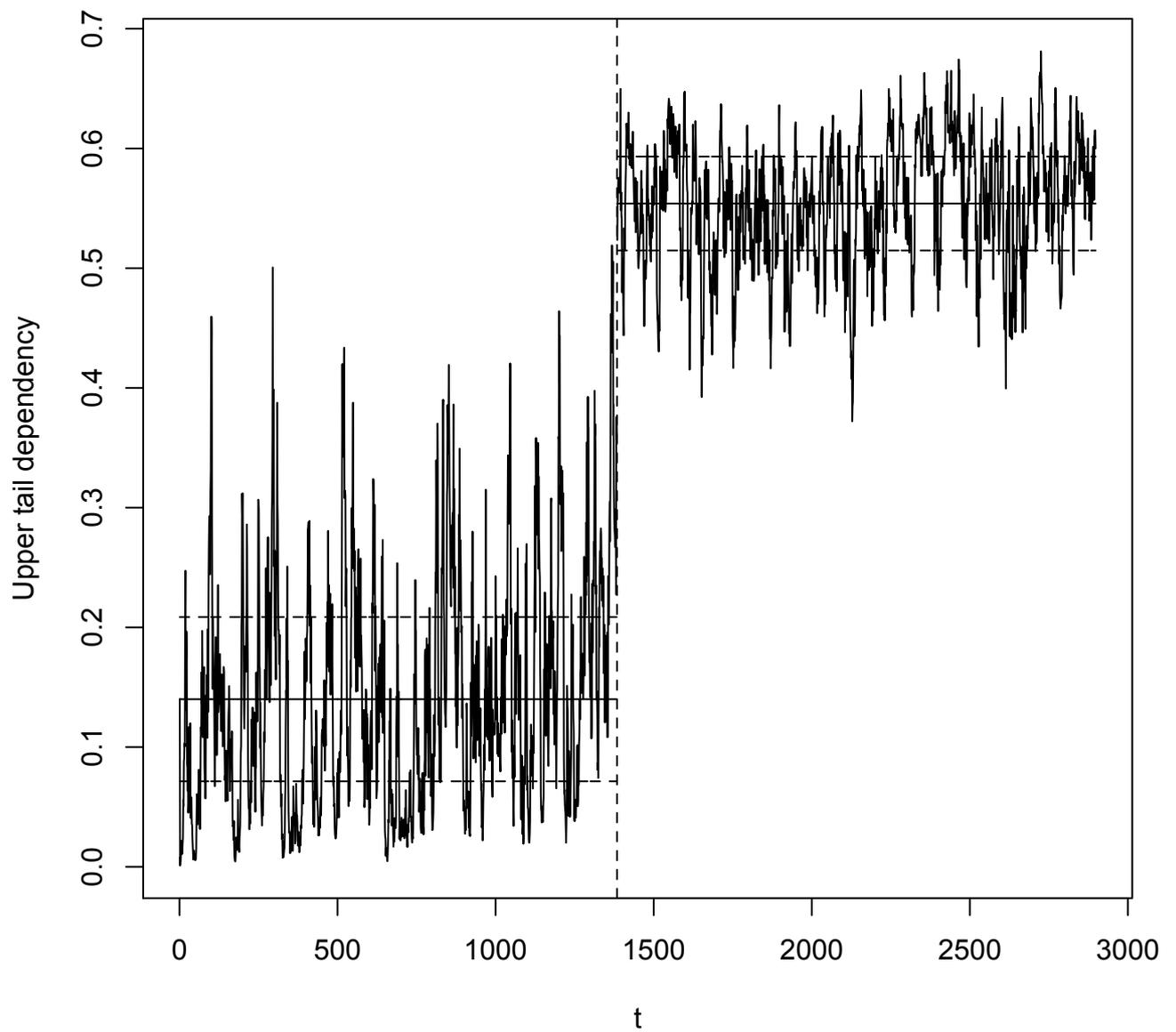


Figure 4: The conditional correlation between the daily returns on the PLN-UDS and EUR-USD exchange rates using a normal copula and logistic dummy. The smooth line represents the constant correlation with 95% confidence bands. The vertical line represents the date of the Polish accession to the EU.

