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Albulescu, C. T., Pepin, D., Miller, S. M. (2019). The Micro-Foundations of an Open Economy Money Demand: An Application to Central and Eastern European Countries. *Journal of Macroeconomics, 60* 33-45. Elsevier.
http://dx.doi.org/10.1016/j.jmacro.2019.01.002

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The micro-foundations of an open economy money demand:

An application to Central and Eastern European countries

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Abstract

This paper investigates the effect of currency substitution between the currencies of Central and Eastern European (CEE) countries and the euro on CEE money demand functions. In addition, we develop a model with microeconomic foundations, which identifies the difference between currency substitution and money demand sensitivity to exchange rate variations. More precisely, we posit that currency substitution relates to the money demand sensitivity to interest rate spreads between CEE countries and the euro area. Moreover, we show how the exchange rate affects money demand absent a currency substitution effect. This model applies to any country in which an international currency offers liquidity services to domestic agents. The model generates empirical tests of long-run money demand using two complementary cointegrating equations. The opportunity cost of holding the money and the scale variable, either household consumption or output, explain the long-run money demand in CEE countries.

Keywords: Money demand; Open-economy model; Currency substitution; Cointegration; CEE countries

JEL codes: E41, E52, F41

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1. Introduction

Empirical estimations that rely on open-economy money demand models with currency substitution typically use a standard two-country portfolio balance model (e.g., McKinnon (1982), Cuddington (1983), Marquez (1987), and Leventakis (1993)). This macro-model does not include microeconomic foundations and, thus, is subject to Lucas's (1976) critique.[1] Because of its static nature, the estimated money demand may appear unstable for modified monetary policy strategies.

This paper investigates the effect of currency substitution between the currencies of CEE countries and the euro on CEE money demand functions. As CEE countries move toward more financial integration with the European Union (EU), standard theory suggests that CEE households should use an increasing share of euro money relative to their own domestic money.

Two policy implications emerge from our study. The monetary authorities in CEE countries should consider not only the opportunity cost of holding money, but also the effect of the exchange rate, which occurs even absent strong currency substitution. Given that CEE currencies and the euro are complements rather than substitutes, CEE countries need to continue pursuing higher monetary integration prior to the euro adoption.

The empirical studies of the money demand that incorporate the currency substitution effect typically do not provide a micro-founded theoretical model to justify the specification of their empirical money demand functions.[2] These models also test for currency substitution through the money demand's sensitivity to the exchange rate. This framework imposes important limitations, since one cannot examine one phenomenon (currency substitution)

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[1] According to Hueng (1998), Dreger et al. (2007), and Hsieh and Hsing (2009), the overall effect of the exchange rate on the domestic money demand is not straightforward. Moreover, it is not clear whether the level or the (expected) exchange rate variation should enter the money demand equation. In addition, different measures of variables enter the money demand equation in empirical studies without explicit theoretical support (Hueng (2000)).

[2] Chen (1973), Miles (1978, 1981), Bordo and Choudri (1982), and Hueng (1998, 2000) are exceptions.

independently of the other (exchange rate sensitivity). Moreover, these models examine open-economy money demand sensitivity without differentiating between currency substitution and currency complementarity.

We contribute to the existing literature in two ways. First, we develop a micro-founded model that describes a mechanism through which the exchange rate affects money demand even absent currency substitution. That is, money demand responds to exchange rate fluctuations even after removing currency substitution, because the exchange rate affects the liquidity service associated with foreign money holding. Indeed, our model measures currency substitution intensity without explicitly considering the exchange rate. The model also captures both the currency substitution and currency complementarity hypotheses, which enables the assessment of the currency substitution intensity.[3] Further, to capture recent economic circumstances in which interest rates went negative, we consider an additional opportunity cost of holding money (domestic or foreign), which keeps the overall opportunity cost positive, even where the interest rate itself becomes negative.

Our micro-founded model, which integrates the liquidity production function and a constant elasticity of substitution (CES) consumption function, produces a money demand function close to Miles (1978), who, however, does not consider the consumption choice. Thus, we demonstrate that the Bordo-Choudri (1982) criticism of Miles's (1978) money demand function is not relevant, since the function does not reflect the omission of consumption or income.

Second, we parameterize our model to test the long-run sensitivity of an open-economy money demand. Our model fits the CEE case in which the euro offers liquidity

[3] Currency substitution is defined as "the tendency of residents to replace domestic money with foreign currencies in response to changes in their relative rate of return" (Filosa (1995)). Currency complementarity means that agents hold domestic and foreign money in fixed proportions, as little substitutability exists between them, and implies that the relative demands for domestic and foreign money marginally depend on the difference between the domestic and foreign interest rates.

services to domestic agents.[4] After their transition from centralized to market-based economic systems, CEE countries joined the European Union. Several CEE countries already belong to the euro area, while others continue the integration process. Investigating money demand in euro-area candidate countries offers information about their degree of monetary integration and about the liquidity services provided by the domestic currency compared to the euro.

Dreger et al. (2007), Hsieh and Hsing (2009), and Fidrmuc (2009) investigate money demand in CEE countries. These empirical analyses, however, do not provide a theoretical framework. Therefore, we test the long-run relationship between money demand and its explanatory variables in a micro-founded model that generates two cointegrating equations. The first equation captures the sensitivity of real money demand for foreign currency to the opportunity cost spread of holding that currency. The second equation captures the long-run relationship between real money demand for domestic currency and the opportunity cost of holding the domestic currency, the opportunity cost spread, and a scale variable.

We use Hansen's (1992) instability test to check for long-run relationships and the Dynamic OLS (DOLS) and the Fully-Modified OLS (FMOLS) methods to estimate the cointegrating relationships. We employ monthly data from 1999:M1 to 2015:M11 on four CEE countries – the Czech Republic, Hungary, Poland, and Romania -- that use a floating exchange rate mechanism.[5] Our model proves, nevertheless, compatible with any exchange

[4] In CEE countries, the agents hold foreign money not only for foreign goods consumption, but also for domestic goods consumption. Thus, even if the preference for foreign money decreases continuously (Albulescu and Pépin, 2018), an important part of real estate or car transactions still use foreign currencies, especially the euro. Using the euro for domestic transactions first embodies historical reasons. During the 1990s, the CEE countries experienced high inflation, which eroded the confidence in the value of domestic currencies (Dąbrowski et al. (2014) document that annual inflation exceeded 20% in almost all CEE countries in 1995). Therefore, the Deutsch mark and then the euro became the representative currencies for valuing durable goods traded on internal markets. Second, the remittances of CEE countries' workers bolstered euro-denominated transactions on the domestic market (Andreev (2009)). Third, the CEE economic context, characterized by the presence of the largest European banks and by low interest rates for foreign currencies loans, contributed to high stocks of assets and liabilities denominated in the euro (Cuaresma and Fidrmuc (2014)), which, in turn, facilitated domestic goods consumption.

[5] Croatia also uses a managed floating exchange rate regime. Until 2006, however, an exchange rate targeting regime was used. In addition, no data exist for the M2 monetary aggregate for Croatia. Therefore, to develop a consistent comparison of results for the CEE countries, we exclude Croatia from our sample.

rate regime. Also, investigating the effect of currency substitution requires flexibility, but not necessarily a free-floating mechanism (e.g., Fidrmuc (2009)).

The rest of the paper is structured as follows. Section 2 briefly describes the models of money demand in an open economy. Section 3 presents our micro-founded money demand model. Section 4 parameterizes the model and identifies the cointegrating equations. Section 5 reports our empirical investigation for CEE countries. Section 6 concludes.

2. The open-economy money demand models

Two different strands of literature characterize open-economy money demand models. The first considers micro-founded money demand models (e.g., Miles (1978, 1981), Bordo and Choudri (1982), and Hueng (1998, 2000)). The second empirically tests various money demand functions with currency substitution, without considering the microeconomic foundations of their specifications (e.g., see early contributions of Cuddington (1983) and Leventakis (1993)). Dreger et al. (2007), Hsieh and Hsing (2009), and Fidrmuc (2009) specifically examine money demand in CEE countries.

Consider the first group of papers on micro-founded models. Miles (1978) uses Chetty's (1969) CES liquidity production function to derive the demand for domestic money relative to foreign money.[6] Bordo and Choudri (1982), however, argue that Miles (1978) misspecified his model, since he omitted income. In effect, Miles's portfolio choice model does not depend on the consumption-saving decision. Therefore, money demand does not depend on income. The money demand derives from the maximization of monetary service flows subject to an asset constraint. Therefore, the ratio of domestic to foreign money demand depends only on the opportunity costs (i.e., domestic and foreign interest rates).

Bordo and Choudri (1982) derive money demand from a money-in-the-utility-function model. Their simplified static model, however, assumes that agents spend their

[6] Chen (1973) is a special case of Miles (1978), assuming a Cobb-Douglas demand function, which constrains the elasticity of substitution to equal one.

entire income each period and that perfect interest rate arbitrage exists, thus, eliminating the effect of the exchange rate.

Hueng (1998, 2000) constructs cash-in-advance and shopping-time models, respectively, to motivate money demand in an open economy. The cash-in-advance model in a two-country world, first studied by Stockman (1980), Lucas (1982), and Guidotti (1989), hinges on the assumption that agents purchase domestic and foreign goods with domestic and foreign currencies, respectively. The shopping-time model assumes that the time spent in purchasing domestic (foreign) consumption goods depends on the holdings of domestic (foreign) money. Thus, in Hueng's two models, foreign (domestic) money provides liquidity service only for foreign (domestic) good consumption. This critical assumption makes Hueng's models of limited interest in economies in which agents hold foreign money not only to purchase foreign goods, but also to purchase domestic goods. In addition, in some countries (i.e., CEE countries), the agents can partially (or even totally) substitute an international money for their domestic money to purchase goods, regardless of the goods' origin.[7]

The second group of papers empirically examines whether currency substitution plays an important role in the demands for domestic and foreign money. Leventakis's (1993) two-country portfolio balance model shows that a change in the expected exchange rate affects the demand for domestic money by inducing its substitution for foreign money, which is the (direct) currency substitution effect, and for foreign bonds, which is the capital mobility effect.[8] If the exchange rate elasticity is high (i.e., if money demand is very sensitive to the

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[7] In our model, we make no distinction between foreign and domestic consumption goods. The representative agent's utility depends on the agent's entire consumption bundle, which mixes foreign and domestic goods, and on domestic and foreign money that produce liquidity services. The agent can invest in a portfolio composed of domestic and foreign money and bonds. By maximizing the (inter-temporal) utility function, we derive the money demand.

[8] The capital mobility effect is one of the two parts of the indirect currency substitution defined by McKinnon (1982). The second part is the substitution of domestic money with domestic bonds (under the assumption that

exchange rate), this may indicate that currency substitution plays an important role in money demand.[9] If agents can switch between foreign and domestic money, then this may affect their money holdings.

Starting from this theoretical assumption, Dreger et al. (2007), Hsieh and Hsing (2009), and Fidrmuc (2009) examine the money demand in CEE countries. Dreger et al. (2007) study money demand in the new EU member states from 1995 to 2004. A well-behaved long-run money demand relationship exists only if the exchange rate appears as part of the opportunity cost. In the long-run cointegrating vector, the output elasticity exceeds unity. Over the entire sample, the exchange rate vis-à-vis the U.S. dollar proves significant and a more appropriate variable in money demand than the euro exchange rate.

Fidrmuc (2009) investigates the money demand with monthly data between 1994 and 2003 in six CEE countries (the Czech Republic, Hungary, Poland, Romania, Slovakia, and Slovenia) and finds that the money demand depends significantly on the euro interest rate and on the exchange rate against the euro, which indicates possible instability of the money demand in these countries. The exchange rate elasticity, however, is low, which is, according to Fidrmuc, a good precondition for the eventual adoption of the euro by CEE countries.[10] The euro area interest rate significantly affected money demand in CEE countries, indicating that capital mobility plays an important role in this region. The coefficient estimated for the euro area interest rate exceeds by a large amount the coefficients of domestic rates. Hsieh and Hsing (2009) find that the demand for M2 in Hungary positively associates with the nominal effective exchange rate and negatively associates with the deposit rate, the euro area interest

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uncovered interest parity holds, and a variation of the expected exchange rate induces a variation of the domestic interest rate).

[9] In Leventakis's (1993) general model, one cannot isolate the separate effects of currency substitution and capital mobility on the money demand. But, if foreigners do not hold domestic currency assets, as, for example, in Cuddington (1983), it becomes possible to separate their effects.

[10] He also finds that the parameters of money demand in CEE countries closely approximates those in developed countries, which gives a good pre-condition for euro adoption.

rate, and the expected inflation rate from 1995-2005. They find an output elasticity near unity, while Fidrmuc (2009) finds lower output elasticity and a euro area interest rate coefficient higher than the domestic rate coefficient.

Elbourne and de Haan (2006) and Fidrmuc (2009) argue that a stable money demand and a transmission mechanism like that in the euro area will create good pre-conditions for the eventual introduction of the euro by new EU member states. Filosa (1995) and Dreger et al. (2007) also conclude that a stable money demand provides an important condition for using monetary aggregates in the conduct of monetary policy. Thus, these authors see that currency substitution indicates money demand instability. As such, a low exchange rate elasticity will, thus, provide a good pre-condition for the eventual adoption of the euro in CEE countries.

On the contrary, this point of view is problematic. In fact, currency substitution results from monetary integration. Miles (1978), McKinnon (1982), Bordo and Choudri (1982), Leventakis (1993), and Hueng (1998) remind us that if people's money holdings change with foreign monetary developments such as foreign interest and exchange rates, then the isolation mechanism of the floating exchange rate system will not work, thus providing the policymaker less control from stabilization policies. Currency substitution does reduce the stability of the money demand in each country, but this does not mean that the global money demand is less stable. In fact, while defining meaningful monetary aggregates, McKinnon (1982) suggests that currency substitution makes an appropriately defined global (monetary union) money supply rather than national money supplies more relevant for studying global (union) inflation. Thus, when currency substitution occurs, it then becomes more appropriate to conduct a global (union) monetary policy rather than a national monetary policy. From this point of view, currency substitution between CEE currencies and the euro gives a signal of monetary integration between the two areas and a good pre-condition for the eventual adoption of the euro by CEE countries.

Our research relies on both strands of literature described above. First, we propose a micro-founded money demand model, which separates the currency substitution effect from the sensitivity of money demand to exchange rates. To this end, we propose a money-in-utility model that as compared to other specifications of optimizing microeconomic models with money (e.g. cash-in-advance and shopping-time models), includes the advantage of a construct to address the issue of currency substitution and currency complementarity.[11] Second, we parameterize the model and empirically investigate the long-run money demand with an application to four CEE countries.

3. The micro-founded open-economy money demand model

The domestic agent living in an outlying country (i.e., CEE country) orders his preferences according to the lifetime utility function:

$$V_t = E_t\left[\sum_{i=0}^{\infty}\beta^i U\left(\frac{X_{t+i}}{P_{t+i}}, \frac{M_{t+i}}{P_{t+i}}, \frac{S_{t+i}M^*_{t+i}}{P_{t+i}}\right)\right], \tag{1}$$

where X_t is monetary consumption spending measured in terms of domestic money, P_t is the price index, M_t is domestic money holding, and M^*_t is foreign money holding. If one unit of foreign money equals S_t units of domestic money, then $S_tM^*_t$ equals the domestic money

[11] By using a money-in-utility specification, we follow an old tradition of monetary economics in that money directly enters the utility of consumption function. Using real balance in the utility function received strong criticism by earlier authors, because money in this model assumes no role in transactions. Nonetheless, Feenstra (1986) shows that this way of incorporating money in optimizing models is equivalent to assuming that money facilitates consumption transactions. He demonstrates a functional equivalence between entering real balances in the utility function and entering money into liquidity costs, which appear in the budget constraint. Therefore, we can derive the same money demand equation, for example, from a shopping-time model where the time spent in purchasing goods does not depend on the origin (foreign or domestic) of the good but where the two types of money (foreign or domestic) possess different transaction-facilitating properties. Nevertheless, only the money-in-utility specification includes explicit utility parameters, such as the elasticity of substitution between domestic and foreign money, which is a key parameter in our analysis.

value of the domestic agent's foreign money holding. The expectations operator $E_t[.]$ is conditional on the information available at time t.

The agent faces the following budget constraint:

$$M_{t-1}(1-\phi)+S_t M^*_{t-1}(1-\phi)+B_{t-1}(1+i_t)+S_t B^*_{t-1}(1+i^*_t)+Z_t = X_t + M_t + S_t M^*_t + B_t + S_t B^*_t,$$

where B_t and B^*_t are the monetary values (in terms of domestic and foreign money) of domestic and foreign bond holdings; Z_t is the lump-sum monetary transfer to the agent from the government; and i_{t+1} and i^*_{t+1} are the nominal domestic and foreign interest rates, respectively. Foreign bonds imperfectly substitute for domestic bonds because of exchange rate risk. Finally, as bonds are nominally risk-free, i_{t+1} and i^*_{t+1} are known at time t.

The parameter ϕ represents the cost the agent faces for holding money. We model this cost as a proportional cost to simplify the analysis. It stands for the charges related to the use of a bank account, the cost of a bankcard, the renting of a bank safe deposit box, and the cost of cash theft or loss. Standard money demand models neglect this (proportional) cost (i.e., $\phi = 0$), assuring a non-negative interest rate. Assuming a non-zero ϕ addresses in a simple way negative interest rates (see Benati et al. (2016)).

We calculate real consumption spending from the budget constraint as follows:

$$\begin{aligned} \frac{X_t}{P_t} = {} & \frac{M_{t-1}}{P_{t-1}}\frac{P_{t-1}}{P_t}(1-\phi)+\frac{S_t M^*_{t-1}}{P_{t-1}}\frac{P_{t-1}}{P_t}(1-\phi)+\frac{B_{t-1}}{P_{t-1}}\frac{P_{t-1}}{P_t}(1+i_t)+\frac{S_t B^*_{t-1}}{P_{t-1}}\frac{P_{t-1}}{P_t}(1+i^*_t)+\frac{Z_t}{P_t} \\ & -\frac{M_t}{P_t}-\frac{S_t M^*_t}{P_t}-\frac{B_t}{P_t}-\frac{S_t B^*_t}{P_t} \end{aligned} \quad . \quad (2)$$

The agent maximizes equation (1) with respect to $\frac{M_t}{P_t}, \frac{S_t M^*_t}{P_t}, \frac{B_t}{P_t}$ and $\frac{S_t B^*_t}{P_t}$ subject to equation (2). Let U_H denote the partial derivative of U with respect to H. The first-order conditions are as follows:

$$E_t\left[\frac{\partial V_t}{\partial \frac{M_t}{P_t}}\right]=0 \Leftrightarrow E_t\left[-U_{\frac{X_t}{P_t}}+\beta U_{\frac{X_{t+1}}{P_{t+1}}}\frac{P_t}{P_{t+1}}(1-\phi)+U_{\frac{M_t}{P_t}}\right]=0 \tag{3}$$

$$E_t\left[\frac{\partial V_t}{\partial \frac{S_t M_t^*}{P_t}}\right]=0 \Leftrightarrow E_t\left[-U_{\frac{X_t}{P_t}}+\beta U_{\frac{X_{t+1}}{P_{t+1}}}\frac{S_{t+1}}{S_t}\frac{P_t}{P_{t+1}}(1-\phi)+U_{\frac{S_t M_t^*}{P_t}}\right]=0\,; \tag{4}$$

$$E_t\left[\frac{\partial V_t}{\partial \frac{B_t}{P_t}}\right]=0 \Leftrightarrow E_t\left[-U_{\frac{X_t}{P_t}}+\beta U_{\frac{X_{t+1}}{P_{t+1}}}\frac{P_t}{P_{t+1}}(1+i_{t+1})\right]=0\,;\text{ and} \tag{5}$$

$$E_t\left[\frac{\partial V_t}{\partial \frac{S_t B_t^*}{P_t}}\right]=0 \Leftrightarrow E_t\left[-U_{\frac{X_t}{P_t}}+\beta U_{\frac{X_{t+1}}{P_{t+1}}}\frac{S_{t+1}}{S_t}\frac{P_t}{P_{t+1}}(1+i^*_{t+1})\right]=0\,. \tag{6}$$

Equations (4), (5), and (6) describe direct and indirect currency substitution. First, consider equation (4). This equation generates the optimal foreign money holding. It assumes that direct currency substitution exists. On the contrary, imagine that the agent cannot substitute foreign and domestic currencies. Then the agent cannot choose his level of foreign money holding, which is fixed: $\frac{S_t M_t^*}{P_t}=\frac{S_t M_{t-1}^*}{P_t}$, or in a more general way, $\frac{S_t M_t^*}{P_t}=\frac{S_t\left(M_{t-1}^*+em_t^*\right)}{P_t}$, where em_t^* is exogenous. In any case, if no currency substitution exists, the agent cannot decide the level of $\frac{S_t M_t^*}{P_t}$ and he cannot optimize his utility function with respect to it. Therefore, equation (4) does not hold if currency substitution does not exist. Equation (4), then, is a consequence of currency substitution.[12]

Next, consider equation (6). This equation produces the optimal foreign bond holding. It assumes capital mobility. If international capital flows do not occur, then the agent cannot choose his foreign bond holding, which is fixed. In the extreme case: $\frac{S_t B_t^*}{P_t} = \frac{S_t B_{t-1}^*}{P_t}$, or in a more general way, $\frac{S_t B_t^*}{P_t} = \frac{S_t \left(M_{t-1}^* + eb_t\right)}{P_t}$, where eb_t is exogenous. If capital mobility does not exist, then the agent cannot determine $\frac{S_t B_t^*}{P_t}$ and equation (6) does not hold. Equation (6) then is a consequence of capital mobility.

Finally, consider equation (5). This equation determines the optimal domestic bond holding. Indirect currency substitution assumes that the agent can freely choose domestic bond holding. If the agent cannot determine $\frac{B_t}{P_t}$, then equation (5) does not hold.

Now, suppose the absence of currency substitution, direct or indirect, which corresponds to the hypothesis of exogeneity of $\frac{S_t M_t^*}{P_t}$, $\frac{S_t B_t^*}{P_t}$, and $\frac{B_t}{P_t}$, and equations (4), (5), and (6) do not hold. The agent only determines the optimal domestic money holding, hinging on equation (3), the only equation that holds. Equation (3) shows a relationship between the current and one-period ahead marginal utility of consumption, foreign and domestic real cash balances, and the inflation rate. As the various marginal utilities depend on $\frac{X_t}{P_t}$, $\frac{M_t}{P_t}$ and $\frac{S_t M_t^*}{P_t}$, equation (3) indicates that the domestic money demand $\frac{M_t}{P_t}$ depends

[12] The ownership of foreign money by residents does not prove (direct) currency substitution. Rather, the responsiveness of foreign money demand to the exchange rate or to the foreign interest rate provides clear evidence of currency substitution.

on $\frac{X_t}{P_t}$, $\frac{S_t M_t^*}{P_t}$, $\frac{X_{t+1}}{P_{t+1}}$, $\frac{M_{t+1}}{P_{t+1}}$, $\frac{S_{t+1} M_{t+1}^*}{P_{t+1}}$ and $\frac{P_t}{P_{t+1}}$. For this somewhat complex formulation of the open-economy money demand, we observe that the one-period ahead exchange rate S_{t+1} enters the money demand function. Thus, even after removing any possibility of currency substitution, the money demand depends on the exchange rate, a result that contrasts with the whole literature devoted to currency substitution.

The intuition behind this result is simple. In effect, the variation of the exchange rate influences the liquidity services provided by foreign money holding. Even if the agent will not replace domestic money with foreign money (or with domestic or foreign bonds) in response to changes in their relative rate of return, the agent can switch between consumption and domestic money holding to respond to liquidity shocks caused by the exchange rate change. Therefore, the agent responds to the exchange rate change by modifying domestic money holding. Consequently, in any case, we conclude that a non-zero exchange rate elasticity results from direct or indirect currency substitution.[13]

Thus, if we remove any possibility of currency substitution, equation (3) shows that the domestic money demand depends on the exchange rate and the inflation rate. The money demand, however, does not depend on the domestic and foreign interest rates. If we assume, which seems realistic, that the agent controls domestic bond holdings, then equation (5) holds too. Multiplying equation (3) by $(1+i_{t+1})/(1-\phi)$ and subtracting equation (5) gives:

$$-U_{\frac{X_t}{P_t}}\left(i_{t+1}+\phi\right)+U_{\frac{M_t}{P_t}}\left(1+i_{t+1}\right)=0. \qquad (7)$$

[13] In fact, the consumption – money substitution effect that we describe is possibly more important than the currency substitution effect, depending on the value of the liquidity elasticity defined hereafter.

No more role exists for risky variables in equation (7), in particular, the inflation rate. Equation (7) shows that domestic money demand depends on $\frac{X_t}{P_t}$, $\frac{S_t M_t^*}{P_t}$, and the domestic interest rate i_{t+1}.

We can write the money demand function in many ways. We can use equation (3) to express money demand as a complex function involving the exchange rate and the inflation rate, or we can use a mix of equations (3) and (5) to express money demand in a way that excludes these two variables. If we add the hypothesis that the agent controls foreign bond holdings, which assumes capital mobility, equation (6) also holds. Multiply equation (6) by $i_{t+1} + \phi$ and then subtracting equation (7) gives:

$$U_{\frac{M_t}{P_t}}(1+i_{t+1}) - E_t\left[\beta U_{\frac{X_t}{P_{t+1}}} \frac{S_{t+1}}{S_t}\frac{P_t}{P_{t+1}}(1+i_{t+1}^*)(i_{t+1}+\phi)\right] = 0$$

This equation leads to a complex, intractable formulation of the domestic money demand depending on all variables considered in the model, the exchange rate, the inflation rate, and the foreign and domestic interest rates.

Finally, we add the assumption of direct currency substitution, which means that equation (4) holds. Then multiplying equation (4) by $(1+i_{t+1}^*)/(1-\phi)$ and subtracting equation (6) gives:

$$-U_{\frac{X_t}{P_t}}(i_{t+1}^* + \phi) + U_{\frac{S_t M_t^*}{P_t}}(1+i_{t+1}^*) = 0 \quad . \tag{8}$$

Both equations (7) and (8) depend on known (non-random) terms that express the domestic money demand as a function of domestic and foreign interest rates (but independent of the exchange rate and the inflation rate).

To conclude, a non-zero exchange rate elasticity does not prove that currency substitution exists. Indeed, a consumption–money substitution effect also influences the money demand and, thus, the sensitivity of money demand to international variables does not depend solely on currency substitution. Moreover, even if currency substitution exists, we can still express the money demand as a function independent of the exchange rate.

Finally, we cannot test the assumption of currency substitution in a model that depends crucially on this hypothesis. If equations (3) to (6) hold, then we assume indirect and direct currency substitution, which is a core hypothesis of the model and which we cannot test. Fortunately, this assumption is not as strict as it seems, as the micro-founded model permits a flexible degree of substitution, which could be higher or lower, consistent with a high degree of currency substitution or with currency complementarity. We investigate the degree of currency substitution between the euro and the currencies of CEE countries and estimate the intensity of the parameters that explain the sensitivity of money demand to international economic variables.

4. A parameterization of the utility function

Following Miles (1978), we parameterize our model by specifying that the domestic and foreign currency enter a CES liquidity production function L_t/P_t and that the produced liquidity and real consumption also enter a CES utility function. Thus,

$$U = \left\{ \theta \left(\frac{X_t}{P_t} \right)^{\eta} + (1-\theta) \left(\frac{L_t}{P_t} \right)^{\eta} \right\}^{\frac{1}{\eta}} \text{ with } \eta = \frac{\zeta - 1}{\zeta}, \tag{9}$$

where $\zeta = 1/(1-\eta)$ is the elasticity of substitution between consumption and liquidity, and

$$\frac{L_t}{P_t} = \left\{ \delta \left(\frac{M_t}{P_t} \right)^{\gamma} + (1-\delta) \left(\frac{S_t M_t^*}{P_t} \right)^{\gamma} \right\}^{\frac{1}{\gamma}} \quad \text{with } \gamma = \frac{\sigma - 1}{\sigma}, \tag{10}$$

where $\sigma = 1/(1-\gamma)$ is the elasticity of substitution between domestic and foreign money in the liquidity production function.

For a zero elasticity of substitution $\sigma\ (\zeta)$, the CES function becomes the Leontief function, which indicates that domestic and foreign money (or consumption and liquidity) are perfect complements. For a unitary elasticity of substitution, the CES function becomes a Cobb-Douglas function.

When the elasticity of substitution $\sigma\ (\zeta)$ increases, it is easier to replace one currency with another (or to replace consumption with liquidity). In the extreme perfect substitution case, the elasticity of substitution goes to infinity. A value of $\sigma > 1\ (\zeta > 1)$ indicates substitutability between domestic and foreign moneys (between consumption and liquidity), while a value $\sigma < 1$ (ζ<1) indicates complementarity between them. If we confirm the assumption of CEE countries' monetary integration with the euro area, then these currencies must exhibit high substitutability with the euro. Therefore, we must pay attention to the σ (ζ) estimates.

The term $\left\{\delta\left(\frac{M_t}{P_t}\right)^{\gamma} + (1-\delta)\left(\frac{S_t M_t^*}{P_t}\right)^{\gamma}\right\}^{\frac{1}{\gamma}}$ represents the liquidity production function with inputs of domestic and foreign money holdings and share parameter δ. The condition $\delta > 0.5$ ($\delta < 0.5$) means that the domestic money is more (less) liquid than the euro in the eyes of CEE countries' representative agent. The CES liquidity production function and real consumption are next combined according to a CES utility function,[14] where θ is the share parameter. We restrict the parameters of the utility and liquidity production functions so that $0 < \theta < 1$, $0 < \delta < 1$, $0 \leq \sigma < +\infty$ and $0 \leq \zeta < +\infty$.

[14] The generalized utility function $\frac{1}{1-\alpha}U^{1-\alpha}$ leads to the same money demand function as the CES utility function, which does not depend on the risk aversion parameter α. Therefore, we ignore risk aversion, as it does not affect the money demand equation.

Calculating the partial derivatives $U_{\frac{X_t}{P_t}}, U_{\frac{M_t}{P_t}}$, and $U_{\frac{S_t M_t^*}{P_t}}$ and inserting them successively into equations (7) and (8) gives:

$$\frac{1-\theta}{\theta}\left(\frac{L_t}{P_t}\right)^{\eta-\gamma}\left(\frac{X_t}{P_t}\right)^{1-\eta}=\frac{1}{\delta}\frac{i_{t+1}+\phi}{1+i_{t+1}}\left(\frac{M_t}{P_t}\right)^{1-\gamma}, \tag{11}$$

and

$$\frac{1-\theta}{\theta}\left(\frac{L_t}{P_t}\right)^{\eta-\gamma}\left(\frac{X_t}{P_t}\right)^{1-\eta}=\frac{1}{1-\delta}\frac{i^*_{t+1}+\phi}{1+i^*_{t+1}}\left(\frac{S_t M^*_t}{P_t}\right)^{1-\gamma}. \tag{12}$$

Equating the right-hand side terms of equations (11) and (12) leads to:

$$\frac{S_t M^*_t}{P_t}=\left[\frac{1-\delta}{\delta}\left(\frac{i_{t+1}+\phi}{1+i_{t+1}}\Big/\frac{i^*_{t+1}+\phi}{1+i^*_{t+1}}\right)\right]^{\sigma}\frac{M_t}{P_t}. \tag{13}$$

We denote $oc_{t+1}=\frac{i_{t+1}+\phi}{1+i_{t+1}}$ and $oc^*_{t+1}=\frac{i^*_{t+1}+\phi}{1+i^*_{t+1}}$ as the opportunity costs of holding domestic and foreign moneys, respectively. If $\phi=0$, then these opportunity costs equal the discounted interest rates.[15]

We rewrite equation (13) in natural logarithms as follows:

$$\ln\left(\frac{M_t}{S_t M^*_t}\right)=\sigma\ln\left(\frac{\delta}{1-\delta}\right)+\sigma\left(\ln oc^*_{t+1}-\ln oc_{t+1}\right) \tag{14}$$

Equation (14) matches the relationship between domestic and foreign money demand derived by Miles (1978), except that equation (14) replaces $1+i_{t+1}$ and $1+i^*_{t+1}$ in Miles (1978) with oc_{t+1} and oc^*_{t+1}. By integrating the liquidity production function and real consumption in a CES function, we demonstrate that the Bordo-Choudri (1982) criticism of Miles's (1978) money demand equation is not relevant, as the equation does not reflect the omission of

[15] The empirical money demand literature depicts the interest rate as the opportunity cost of money holding, which assumes that $\phi=0$, and uses it as a regressor in the money demand equation. But, as the interest rate is perceived one period later, we must discount it to the present, and the discounted interest rate enters the money demand regression.

consumption or income. When we compare domestic and foreign money demand, we do not need to add a scale variable such as consumption or income. We only need the share parameter and the elasticity of substitution to explain the shift in domestic relative to foreign money demand.

If $\ln\left(M_t / S_t M_t^*\right)$ and $\ln oc_{t+1}^* - \ln oc_{t+1}$ are nonstationary, I(1), then equation (14) may describe a cointegrating relationship.[16] In the long run, equation (14) holds exactly, and so, it appears as a long-run money demand equation. In the short run, however, because adjustment takes time, a temporary disequilibrium ε_t exists such that the relationship is:

$$\ln\left(\frac{M_t}{S_t M_t^*}\right) = \kappa_0 + \kappa_1\left(\ln oc_{t+1}^* - \ln oc_{t+1}\right), \tag{15}$$

where the elements κ_0 and κ_1 of the cointegrating vector relate to the structural parameters by $\kappa_0 = \sigma \ln[\delta/(1-\delta)]$ and $\kappa_1 = \sigma$.

The relative money demand function in equation (15) is not the only result of the model. Our model can also produce a money demand equation that depends on a scale variable (consumption or income), more consistent with the standard empirical money demand equations estimated in the literature.

Returning to equation (11) expressed as:

$$\frac{M_t}{P_t} = \left\{\delta\left(\frac{1-\theta}{\theta}\right)\frac{1+i_{t+1}}{i_{t+1}+\phi}\right\}^{\frac{1}{1-\eta}} \left\{\delta + (1-\delta)\left(\frac{S_t M_t^*}{P_t} \Big/ \frac{M_t}{P_t}\right)^{\gamma}\right\}^{\frac{\eta-\gamma}{(1-\eta)\gamma}} \left(\frac{X_t}{P_t}\right), \tag{16}$$

and substitute equation (13) into equation (16) to get:

$$\frac{M_t}{P_t} = \left(\frac{1-\theta}{\theta}\right)^{\zeta} oc_{t+1}^{-\zeta} \delta^{\frac{\sigma(\zeta-1)}{\sigma-1}} \left\{1+\psi\left(\frac{oc_{t+1}}{oc_{t+1}^*}\right)^{\sigma-1}\right\}^{\frac{\zeta-\sigma}{\sigma-1}} \left(\frac{X_t}{P_t}\right) \text{ with } \psi = \left(\frac{1-\delta}{\delta}\right)^{\sigma}. \tag{17}$$

[16] Standard unit-root tests and panel unit-root tests confirm that the variables involved in equation (17) are I(1) processes (see Dreger et al. (2007), Fidrmuc (2009), Hsieh and Hsing (2009)).

Since the country in question is an outlying country, its currency offers no liquidity services to foreign agents. In this case, we assume that the money of the foreign country (i.e., the euro) is an international money that offers liquidity services to the agent of the outlying country, but not the reverse. The foreign agent does not demand money from the outlying country, and the total demand for money of this country simply equals M_t/P_t.

Taking the logarithm of equation (17) gives:

$$\ln\left(\frac{M_t}{P_t}\right)=\zeta\ln\left(\frac{1-\theta}{\theta}\right)+\frac{\sigma(\zeta-1)}{\sigma-1}\ln\delta-\zeta\ln oc_{t+1}+\left(\frac{\zeta-\sigma}{\sigma-1}\right)\ln\left\{1+\psi\left(\frac{oc_{t+1}}{oc^*_{t+1}}\right)^{\sigma-1}\right\}+\ln\left(\frac{X_t}{P_t}\right). \quad (18)$$

We observe that the money demand in equation (18) conforms to the standard result of a unitary output elasticity. The model involves a complex nonlinear equation in which two different effects of the opportunity cost on money demand exist. The first effect captures how the opportunity cost influences the holding of domestic money. The second effect captures how the ratio between the opportunity costs influences the relative holding of domestic and foreign moneys. In what follows, we restrict our analysis to a simplified linearized version like those in empirical money demand studies.[17]

If we assume that $\ln oc^*_{t+1}-\ln oc_{t+1}$ varies in the neighborhood of a constant s, which we consider as a long-run spread, then the Taylor expansion of the fourth term on the right-hand side of equation (18) yields:

$$\begin{aligned}\ln\left(\frac{M_t}{P_t}\right)&=\zeta\ln\left(\frac{1-\theta}{\theta}\right)+\left(\frac{\zeta-\sigma}{\sigma-1}\right)\left[\ln\{1+\psi\exp[(\sigma-1)s]\}-\frac{s\psi(\sigma-1)\exp[(\sigma-1)s]}{1+\psi\exp[(\sigma-1)s]}\right]\\&+\frac{\sigma(\zeta-1)}{\sigma-1}\ln\delta-\zeta\ln oc_{t+1}+\frac{\psi(\sigma-\zeta)\exp[(\sigma-1)s]}{1+\psi\exp[(\sigma-1)s]}\left(\ln oc^*_{t+1}-\ln oc_{t+1}\right)+\ln\left(\frac{X_t}{P_t}\right)\end{aligned} \quad (19)$$

If $\ln(M_t/P_t)$, $\ln oc_{t+1}$, $\ln oc^*_{t+1}-\ln oc_{t+1}$ and $\ln(X_t/P_t)$ are I(1), then equation (19) describes a second possible cointegrating relationship. In the long run, this money demand

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[17] Hueng (2000) made the same choice when confronted with a nonlinear money demand function.

equation holds exactly, but in the short run, the money demand depends also on a stationary disequilibrium η_t:

$$\ln\left(\frac{M_t}{P_t}\right) = \omega_0 + \omega_1 \ln oc_{t+1} + \omega_2\left(\ln oc^*_{t+1} - \ln oc_{t+1}\right) + \omega_3 \ln\left(\frac{X_t}{P_t}\right) + \eta_t, \tag{20}$$

where the elements of the cointegrating vector relate to the structural parameters by

$$\omega_0 = \zeta \ln\left(\frac{1-\theta}{\theta}\right) + \frac{\sigma(\zeta-1)}{\sigma-1}\ln\delta + \left(\frac{\zeta-\sigma}{\sigma-1}\right)\left[\ln\{1+\psi\exp[(\sigma-1)s]\} - \frac{s\psi(\sigma-1)\exp[(\sigma-1)s]}{1+\psi\exp[(\sigma-1)s]}\right],$$

$$\omega_1 = -\zeta,\ \omega_2 = \frac{\psi(\sigma-\zeta)\exp[(\sigma-1)s]}{1+\psi\exp[(\sigma-1)s]},\ \text{and}\ \omega_3 = 1.$$

The parameter ω_1 is equal to the elasticity of substitution between consumption and liquidity $(-\zeta)$. In a pure domestic model where foreign money does not provide liquidity services to the domestic agents (if $\omega_2 = 0$), the parameter ω_1 is the interest rate elasticity. In the general model where foreign money matters, this elasticity is (ω_1-ω_2). The parameter ω_2 is the foreign interest rate elasticity. Its sign depends on the difference between the two elasticities of substitution ζ and σ. Negative (positive) value of ω_2 indicates that substitutability between foreign and domestic moneys is less (higher) than substitutability between consumption and liquidity. If the parameter ω_1 (equal to -ζ) takes low values (which is the case in the reported results), a negative value of ω_2 is then a sign of complementarity between foreign and domestic moneys.

The money demand equations (15) and (20) follow in the line of Meltzer (1963) or fit the category of Baumol-Tobin models (i.e., inventory-theoretic models, Baumol 1952 and Tobin 1956), which consider as explanatory variables the log of the opportunity cost, and not the opportunity cost itself, as in Cagan's (1956) approach.

Cagan's (1956) semi-log form is a commonly used specification for empirical analysis of money demand in which the opportunity cost generally becomes the interest rate.

The existence of low, or even negative, interest rates makes it difficult or impossible to use a log-log money demand specification when $\phi = 0$. But, for a high enough value of ϕ, or for much higher interest rates, the log-log money demand specification offers an interesting alternative.[18]

5. An application to CEE countries

We apply the model described in the previous sections to CEE countries, where an international currency (the euro) offers liquidity services to domestic agents. Most CEE countries exhibit a high ratio of foreign currency deposits to total deposits, where most foreign currency deposits are euros.

We use monthly statistics for the Czech Republic, Hungary, Poland and Romania to test the two long-run money demand equations -- equations (15) and (20) – using monthly data from January 1999 to November 2015. The data come from the International Financial Statistics (IFS) database, the Eurostat database, the OECD database, and statistics provided by the national central banks.

In equation (15), the ratio of domestic to foreign currency deposits proxies for the money demand in our model, as the structure of money in circulation (cash) is unknown. For equation (20), we use M2 to compute real money demand, as researchers commonly use broad money to estimate money demand in CEE countries. For robustness, we also employ M1 in equation (20) to measure real money demand. We use the money market rate, the consumer price index, and household consumption expenditure as determinants of money demand.[19] A complete data description appears in the Appendix.

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[18] Lucas (2000) compares the two types of money demand and expresses a preference for the log-log form (for additional arguments for the log-log specification see, also, Benati et al, (2016) and Miller, et al. (forthcoming)). In contrast, Ireland (2009) argues for the semi-log form. The debate on the best choice of the form for the money demand equation continues.

[19] Because our model relies on monetary consumption spending, we retain household consumption expenditure for the scale variable in equation (20). This variable is available on a quarterly basis only, and we use a cubic spline function to generate the monthly frequency. In line with previous empirical estimations, however, we also

For the opportunity cost ϕ, we do not distinguish between money in circulation and deposits. Thus, the proportional cost is identical for all money substitutes. In addition, we assume that the value of ϕ is sufficiently small (see previous studies). In this context, we set for monthly data a value of 0.00082953, which corresponds to an annual loss rate (negative return) of 1% for narrow money[20] (see Lucas and Nicolini (2015) and Benati et al. (2016)). As explained by Benati et al. (2016), a non-zero (strictly positive) value for ϕ proves necessary when considering a log-log money demand, especially if the model applies to data containing periods of nearly zero interest rates.

We estimate the cointegration equations (15) and (20) by the DOLS method of Saikkonen (1991) and Stock and Watson (1993) and by the FMOLS method of Phillips and Hansen (1990). Both procedures produce asymptotically unbiased estimators even in the absence of strong exogeneity of the regressors.

Both methods are also consistent with the triangular representation of Phillips (1988, 1991) of cointegrated I(1) processes. This representation is valid for any cointegrating rank, but, given the existence of two long-run relationships characterizing our model, we assume that a cointegrating rank of 2. Consider a n-vector $Y_t = \left(y_{1t} \;\; y_{2t} \;\; Y_{3t}^{'}\right)$, where y_{1t} and y_{2t} are one-dimensional I(1) processes and Y_{3t} is a (n-2)-dimensional I(1) process. Assume that Y_t is cointegrated with rank 2. The triangular representation is a system consisting of two cointegrating regressions:

$$\begin{cases} y_{1t} = \mu_1 + a_1 Y_{3t} + z_{1t} \\ y_{2t} = \mu_2 + a_2 Y_{3t} + z_{2t} \end{cases}, \tag{21}$$

use as an alternative the monthly industrial production index for the scale variable. We seasonally adjusted both variables, using the Census X13.

[20] For cash, the value of ϕ may increase to 2%. This is the estimate by Alvarez and Lippi (2009) of the probability of cash theft in Italy, for example. A value of 1%, however, seems *a priori* more appropriate to describe the loss of cash and costs associated with owning a bank account.

and a (n-2)-dimensional I(1) process:

$$\Delta Y_{3t} = \mu_3 + Z_{3t}, \qquad (22)$$

where Y_{3t} is not cointegrated and $\left(z_{1t} \;\; z_{2t} \;\; Z_{3t}^{'}\right)$ is a zero-mean stationary process.

This triangular representation presents y_{1t} and y_{2t} as the "dependent" variables, but in fact, it does not require that they are the only endogenous variables, as the hypothesis of strong exogeneity of the (n-2)-dimensional regressor Y_{3t} is not required. Note that this representation assumes that only one "dependent" variable exists in each of the cointegrating regressions and that an equation for each "dependent" variable also exists. Equations (15) and (20) prove consistent with this triangular representation with $y_{1t} = \ln\left(M_t / S_t M_t^*\right)$, $y_{2t} = \ln\left(M_t / P_t\right)$ and $Y_{3t} = \left(\ln oc_{t+1},\ \ln oc_{t+1}^* - \ln oc_{t+1},\ \ln\left(X_t / P_t\right)\right)'$. The DOLS and FMOLS estimators of system (21) are asymptotically equivalent to the Johansen's maximum likelihood estimation method (Johansen (1988)), based on the vector error-correction model. They deliver standard statistics (e.g., t- and Wald-statistics) that are asymptotically normally distributed.

Before estimating the long-run relationship, however, we want to ensure that our series are I(1). Therefore, in the first step, we apply ADF and PP unit-root tests, including a constant term. Table 1 presents the results and show that our variables are I(1). Therefore, we proceed with the cointegration analysis for both equations (15) and (20).

For each equation, we test the existence of a long-run relationship based on Hansen's (1992) instability test, relying on the L_c statistic. The null hypothesis of this test is the presence of cointegration. For the DOLS-type estimations, we choose the number of leads and lags using the Akaike information criteria, while for the FMOLS (with Bartlett kernel), we use a Newey-West automatic bandwidth rule. We test different hypotheses on the parameters based on the Wald t-statistic.

The results for each equation (15) and (20) appear in Tables 2, 3, and 4. First, looking at equation (15), we notice that in almost all cases the results of the cointegration test differ between the DOLS and FMOLS estimations. Cointegration exists for the DOLS estimation only. Hungary represents an exception, as the L_c statistic shows the existence of a long-run relationship for both the DOLS and FMOLS estimations. Now, if we accept the hypothesis of cointegration, both methods show that the elasticity of substitution is low, less than 1, and positive (except for Poland). In addition, the Wald t-statistic shows that $\kappa_1 \neq 1$. We see that according to this criterion, less monetary integration of CEE countries with the euro area occurs as the value of the elasticity between the currencies estimated by κ_1 indicates currency complementary rather than currency substitution. This affirmation, however, is true to a smaller extent for Romania, where many current transactions use euros.[21]

The results for the second cointegrating relationship in equation (20) appear in Table 3. A first set considers real household consumption as the scale variable, while a second set considers real industrial production as the scale variable.

Several conclusions emerge from these findings. First, the coefficients' sign and significance level report, in general, a strong correspondence between the DOLS and FMOLS estimates. We can validate the cointegration relationship in all cases only for the DOLS approach. The FMOLS estimations exhibit slightly weaker findings, as we reject the null hypothesis of cointegration in 2 of the 8 cases.

Second, the interest elasticity ω_1 shows the expected sign when consumption is the scale variable, and it is significant, except for Poland. When we use real industrial production as scale variable, the sign of the interest elasticity shows mixed evidence. Its low value, however, indicates that consumption and liquidity are complements, not substitutes. The

[21] According to the National Bank of Romania statistics (monthly bulletins), the ratio of foreign currency to total deposits over 1999-2015 exceeds 50%, decreasing from 70% at the beginning of the 2000s, to 34% in the present.

negative sign of the spread's coefficient ω_2 implies that $\sigma < \zeta$, which reflects the low value of σ, in agreement with the estimates of equation (20). Third, the coefficient ω_3 is positive, as expected, in all the cases, both for household consumption and industrial production. According to the Wald test, however, the consumption and output elasticities significantly differ from 1 and in 14 out of 16 cases the coefficients exceed unity. We, thus, reject the hypothesis of a unitary elasticity.

If we compare CEE countries, the Hungarian and Romanian money demands respond more to the opportunity cost based on the internal discounted interest rate, while the Czech money demand responds more to the opportunity cost spread. In addition, real output exhibits greater importance for Romanian money demand than for the Czech, Polish, and Hungarian money demands. All in all, the small elasticity of substitution may imply less monetary integration for CEE countries than reported in previous studies (e.g., Fidrmuc (2009)).

We check the robustness of these findings by using M1 instead of M2 for the money demand in equation (20). Table 4 presents the results. As in the previous case, several similarities exist between the DOLS and FMOLS estimates. For both the DOLS and FMOLS approaches, Hansen's (1992) instability test shows the existence of a cointegrating relationship for all countries. At the same time, ω_1 exhibits the expected sign and is significant in all cases, except for Romania. The spread between the opportunity costs (ω_2) negatively affects money demand, indicating that $\sigma < \zeta$, with two exceptions, Poland and Romania for the DOLS estimation. The results for M1 and M2 are robust when we look to the scale variable (the sign of ω_3 is positive and significant) for both DOLS and FMOLS estimators.

In sum, our empirical estimates fit the theoretical assumptions synthetized in equations (15) and (20). The employed tests confirm, in general, the long-run relationship, explaining the money demand in CEE countries. Consequently, money demand in CEE countries depends on the opportunity cost of holding money (i.e., the discounted money market rate), the spread between the opportunity costs, and especially the scale variable (i.e., consumption or output).

6. Conclusions

We investigate the money demand in CEE countries starting from a theoretical model with micro-foundations, which, as a novel result, incorporates both the currency substitution and money demand sensitivity to exchange rate effects. This model establishes a channel for an exchange rate effect on money demand, even absent currency substitution. We apply this model to CEE countries, where the euro offers liquidity services to domestic agents, while money of CEE countries does not offer liquidity service to residents of the euro area.

The model parameterization shows that CEE money demand includes two complementary cointegrating relationships, an original result of our model. The empirical findings revealed by Hansen's (1992) instability test, on the one hand, and the DOLS and FMOLS estimators, on the other hand, document two cointegrating relationships in which real CEE money demand depends on the opportunity costs of holding money as well as real consumption or real output. A consensus exists between the DOLS and FMOLS results, and the findings are robust to the use of M2 or M1 for assessing the money demand in equation (20). In general, CEE countries' agents perceive that domestic currency is more liquid than the euro and a low level of substitution exists between domestic currencies and the euro. Previous empirical studies on CEE countries' money demand test the money demand sensitivity to international factors and report, in general, a high substitution level. Our micro-founded model shows a lower level of substitution and occasionally complementarity, not substitutability, between CEE currencies and the euro. Therefore, we view the high degree of substitution between CEE currencies and the euro reported in prior studies with caution, because these studies do not consider exchange rate effects on money demand in the absence of currency substitution. Also, they do not consider the possible complementary between CEE currencies and the euro.

Our empirical results, however, do not represent incontestable proof of two long-run money demand relationships, as the results prove less robust for the FMOLS estimator. Nevertheless, the empirical findings clearly show a reduced degree of substitution. Thus, the monetary integration of CEE countries with the euro area seems less complete for the moment. This result, however, depends on stronger confidence in CEE domestic currencies and by the increased liquidity service they provide. Moreover, other criteria such as the adoption of EU regulations and other aspects of financial integration show that CEE countries are more and more prepared for euro adoption.

The policy implications of our study are twofold. First, we show that the monetary authorities in CEE countries should consider in the money demand estimation not only the opportunity costs of holding the money and consumption or output, but also the effect of the exchange rate, which occurs even absent strong currency substitution. Second, we posit that the degree of substitution between CEE currencies and the euro should not imply *per se* reduced financial integration. Actual macroeconomic policies increase the confidence of CEE agents in domestic currencies, helping to explain our empirical findings. Efforts must continue toward higher monetary integration with Euro area, however.

Acknowledgements

This work was supported by a grant of the Romanian National Authority for Scientific Research and Innovation, CNCS – UEFISCDI, project number PN-II-RU-TE-2014-4-1760.

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Table 1. Unit-root tests

Variables	Tests	Czech Rep.	Hungary	Poland	Romania
$\ln\left(\frac{M_t}{S_t M_t^*}\right)$	ADF	-1.788***	-1.460***	-0.808***	-0.954***
	PP	-1.674***	-1.593***	-0.769***	-0.960***
$\ln oc_{t+1}^* - \ln oc_{t+1}$	ADF	-2.669**	-1.785***	-1.371***	-2.020***
	PP	-2.661**	-2.350***	-1.573***	-2.058***
$\ln\left(\frac{M2_t}{P_t}\right)$	ADF	-0.012***	-1.189***	1.065***	-1.795***
	PP	0.048***	-1.294***	0.752***	-0.602***
$\ln\left(\frac{M1_t}{P_t}\right)$	ADF	-1.370***	-1.365***	-0.408***	-1.650***
	PP	-1.453***	-1.162***	-0.048***	-0.685***
$\ln oc_{t+1}$	ADF	-1.181***	-0.367***	-0.852***	-0.552***
	PP	-1.269***	-0.302***	-1.016***	-0.191***
$\ln\left(\frac{XC_t}{P_t}\right)$	ADF	-2.505***	-2.202***	-0.078***	-1.070***
	PP	-2.281***	-2.573***	-0.414***	-1.470***
$\ln\left(\frac{XIP_t}{P_t}\right)$	ADF	-1.316***	-2.039***	-1.058***	-0.692***
	PP	-1.838***	-2.246***	-1.523***	-0.504***

*Notes: (i) the null hypothesis is the presence of unit root and ***, **, and * mean significant at the 1%, 5%, and10% levels, respectively. (ii)* $\ln\left(\frac{M1_t}{P_t}\right)$ *and* $\ln\left(\frac{M2_t}{P_t}\right)$ *are the two forms of* $\ln\left(\frac{M_t}{P_t}\right)$ *used in equation (20), considering the monetary aggregate M2 and M1, while* $\ln\left(\frac{XC_t}{P_t}\right)$ *and* $\ln\left(\frac{XIP_t}{P_t}\right)$ *are the two forms of* $\ln\left(\frac{X_t}{P_t}\right)$ *used in equation (20), considering the household consumption expenditure (C)* and *the industrial production index (IP).*

Table 2. Cointegration test and estimates for equation (15)

$\ln\left(\frac{M_t}{S_t M_t^*}\right)$	**Czech Rep.**		**Hungary**		**Poland**		**Romania**	
	DOLS	FMOLS	DOLS	FMOLS	DOLS	FMOLS	DOLS	FMOLS
κ_0	2.20***	2.17***	1.56***	1.43***	1.56***	1.69***	1.21***	0.93***
κ_1	0.48***	0.38**	0.27***	0.15	-0.37**	-0.24	0.52***	0.32***
R^2	0.30	0.16	0.25	0.06	0.29	0.08	0.74	0.48
L_c statistic	0.00	1.28	0.00	0.35	0.00	1.83	0.00	0.66
	(>0.2)	(0.00)	(>0.2)	(0.10)	(>0.2)	(0.00)	(>0.2)	(0.01)
Wald t-statistic	2.83	3.92	6.00	8.72	7.58	7.36	6.18	10.5
$\kappa_1 = 1$	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)

*Notes: (i) ***, **, and * mean significant at the 1%, 5% and 10% significance levels, respectively; (ii) p-value in brackets; (iii)* κ_0 *is the intercept of equation (15);* κ_1 *is the coefficient of* $\ln oc_{t+1}^* - \ln oc_{t+1}$.

Table 3. Cointegration test and estimates for equation (20)

$\ln\left(\frac{M2_t}{P_t}\right)$	**Czech Rep.**		**Hungary**		**Poland**		**Romania**	
Consumption	DOLS	FMOLS	DOLS	FMOLS	DOLS	FMOLS	DOLS	FMOLS
ω_0	-7.68***	-2.30	1.92*	-0.02	-7.92***	-5.65***	-1.44***	-3.80***
ω_1	0.07*	-0.08**	-0.23***	-0.19***	0.21***	0.04	-0.20***	-0.13***
ω_2	-0.90***	-0.23***	-0.02	-0.10***	-0.01	-0.05**	-0.03*	-0.17***
ω_3	2.45***	1.61***	0.89***	1.11***	2.72***	2.23***	1.39***	1.83***
R^2	0.98	0.88	0.98	0.80	0.99	0.98	0.99	0.98
L_c statistic	0.00 (>0.2)	1.01 (0.02)	0.00 (>0.2)	0.68 (0.09)	0.00 (>0.2)	2.02 (0.00)	0.00 (>0.2)	0.93 (0.03)
Wald t-statistic $\omega_1 = -1$	27.3 (0.00)	21.5 (0.00)	34.2 (0.00)	29.0 (0.00)	24.0 (0.00)	28.6 (0.00)	46.9 (0.00)	32.3 (0.00)
Wald t-statistic $\omega_3 = 1$	5.36 (0.00)	2.66 (0.00)	0.95 (0.34)	0.76 (0.44)	11.2 (0.00)	10.1 (0.00)	5.64 (0.00)	10.4 (0.00)
Industrial production	DOLS	FMOLS	DOLS	FMOLS	DOLS	FMOLS	DOLS	FMOLS
ω_0	4.37***	4.77***	6.07***	7.43***	3.29***	3.23***	-3.46	-4.51**
ω_1	0.07*	-0.02	0.31***	0.02	0.15**	-0.02	0.09	0.06
ω_2	-0.46***	-0.30***	-0.01	-0.05*	-0.09***	-0.13***	0.22**	-0.00
ω_3	1.31***	1.11***	1.57***	0.96***	1.39***	1.16***	2.53***	2.63***
R^2	0.97	0.90	0.98	0.85	0.99	0.95	0.93	0.89
L_c statistic	0.00 (>0.2)	0.54 (0.18)	0.00 (>0.2)	0.56 (0.16)	0.00 (>0.2)	1.20 (<0.01)	0.00 (>0.2)	0.89 (0.03)
*Wald t-statistic $\omega_3 = 1$	1.98 (0.05)	1.18 (0.23)	5.84 (0.00)	-0.37 (0.71)	2.88 (0.00)	1.70 (0.09)	2.29 (0.02)	2.95 (0.00)

*Notes: (i) ***, **, and * mean significant at the 1%, 5%, and 10% significance levels, respectively; (ii) p-value in brackets; (iii) ω_0 is the intercept of equation (20); (iv) ω_1 is the coefficient of $\ln oc_{t+1}$, ω_2 is the coefficient of $\ln oc^*_{t+1} - \ln oc_{t+1}$, and ω_3 is the coefficients of $\ln\left(\frac{XC_t}{P_t}\right)$ or $\ln\left(\frac{XIP_t}{P_t}\right)$; (v) M2 aggregate is considered.*

Table 4. Cointegration test and estimates for equation (20) – robustness check based on M1

$\ln\left(\frac{M1_t}{P_t}\right)$	**Czech Rep.**		**Hungary**		**Poland**		**Romania**	
Consumption	DOLS	FMOLS	DOLS	FMOLS	DOLS	FMOLS	DOLS	FMOLS
ω_0	-12.0***	-11.2***	2.69***	-0.60	-11.3***	-3.80***	-9.50***	-11.8***
ω_1	-0.31***	-0.34***	-0.50***	-0.36***	-0.09**	-0.13***	-0.06	0.00
ω_2	-0.43*	-0.15***	0.08***	-0.04	0.10***	-0.17***	0.00	-0.12
ω_3	2.68***	2.55***	0.61***	1.01	2.92***	1.83***	2.82***	3.26***
R^2	0.99	0.96	0.98	0.87	0.99	0.98	0.99	0.96
L_c statistic	0.00 (>0.2)	0.95 (0.02)	0.00 (>0.2)	0.55 (0.17)	0.00 (>0.2)	0.93 (0.02)	0.00 (>0.2)	0.55 (0.17)
Wald t-statistic $\omega_3 = 1$	4.75 (0.00)	7.05 (0.00)	4.14 (0.00)	0.07 (0.93)	12.3 (0.00)	10.4 (0.00)	3.40 (0.00)	9.49 (0.00)
Industrial production	DOLS	FMOLS	DOLS	FMOLS	DOLS	FMOLS	DOLS	FMOLS
ω_0	0.00	0.30	4.85***	6.25***	0.22	0.33	-14.4***	-14.8***
ω_1	0.19***	0.27***	0.05	0.16***	0.11*	0.15***	-0.66**	-0.47*
ω_2	0.30***	0.22***	-0.12***	0.00	-0.02	0.02	-0.63***	-0.20
ω_3	1.83***	1.68***	1.30***	0.86***	1.63***	1.53***	5.47***	5.18***
R^2	0.99	0.97	0.97	0.91	0.99	0.97	0.93	0.87
L_c statistic	0.00 (>0.2)	0.40 (>0.2)	0.00 (>0.2)	0.67 (0.10)	0.00 (>0.2)	0.80 (0.05)	0.00 (>0.2)	0.61 (0.13)
Wald t-statistic $\omega_3 = 1$	12.26 (0.00)	9.06 (0.00)	2.51 (0.01)	-1.69 (0.09)	5.70 (0.00)	5.40 (0.00)	4.10 (0.00)	4.32 (0.00)

*Notes: (i) ***, **, and * mean significant at the 1%, 5%, and 10% significance levels, respectively; (ii) p-value in brackets; (iii)* ω_0 *is the intercept of equation (20); (iv)* ω_1 *is the coefficient of* $\ln oc_{t+1}$ *n,* ω_2 *is the coefficient of* $\ln oc^*_{t+1} - \ln oc_{t+1}$*, and* ω_3 *is the coefficients of* $\ln\left(\frac{XC_t}{P_t}\right)$ *or* $\ln\left(\frac{XIP_t}{P_t}\right)$.

Appendix - Data description

Variables	Database	Explanations
M2	IFS (IMF)	Monetary aggregate M2 in millions of national currencies. As data are not available for all the countries over the entire time-span 1999:M1-2015M11, the series was completed as follows: OECD statistics for the Czech Republic (1999-2001) and for Hungary (1999-2004); national bank statistics for Romania (1999-2001).
M1	IFS (IMF)	Monetary aggregate M1 in millions of national currencies. As data are not available for all the countries over the entire time-span 1999:M1-2015M11, the series was completed as follows: OECD statistics for the Czech Republic (1999-2001); national bank statistics for Romania (1999-2001).
Interest rate	IFS (IMF)	The money market rate from the International Financial Statistics. For Hungary and the euro area, Eurostat data (day-to-day).
Domestic deposits to foreign deposits ratio	National Banks	For the Czech Republic, banking clients' deposits in foreign currency to total deposits. For Hungary, Poland, and Romania, aggregated balance sheet data of credit institutions.
Prices	IFS (IMF)	Consumer Price Index (2010=100).
Consumption	IFS (IMF)	Household consumption expenditure (quarterly data transformed in monthly data using a cubic spline function).
Output	IFS (IMF)	Industrial Production Index (2010=100).

Note: The industrial production is extracted from the IFS (IMF) database in real terms and, therefore, it does not require deflation. To keep the harmonization in terms of scale variable notation throughout the paper, however, we have in the result tables $\ln\left(\frac{XIP_t}{P_t}\right)$.