Working Papers 2019 5

Modelling the Demand for Euro Banknotes

António Rua

BANCO DE PORTUGAL
EUROSYSTEM

Working Papers 2019 5

Modelling the Demand for Euro Banknotes

António Rua

FEBRUARY 2019

Please address correspondence to
Banco de Portugal, Economics and Research Department
Av. Almirante Reis, 71, 1150-012 Lisboa, Portugal
Tel.: +351 213 130 000, email: estudos@bportugal.pt

BANCO DE PORTUGAL
EUROSYSTEM

Lisbon, 2019 • www.bportugal.pt

Working Papers | Lisbon 2019 • **Banco de Portugal** Av. Almirante Reis, 71 | 1150-012 Lisboa • www.bportugal.pt •
Edition Economics and Research Department • **ISBN (online)** 978-989-678-649-6 • **ISSN (online)** 2182-0422

Modelling the Demand for Euro Banknotes

António Rua
Banco de Portugal
Nova SBE

February 2019

Abstract
Liquidity management is a key mission of a central bank. In particular, the adequate provision of banknotes requires the understanding of what drives currency demand in a continuously changing environment. The challenge is even bigger in the case of the European monetary union where the euro continues to develop into a well-established currency outside borders. The focus is on modelling euro banknotes demand namely by considering its denominational breakdown. Such an analysis allows to unveil the heterogeneous role played by the several drivers while providing a more in depth modelling of currency demand. The econometric approach pursued allows to take on board the interconnections across denominations both in the long- and short-run dynamics.

JEL: C32, E41, E50

Acknowledgements: The opinions expressed in the article are those of the author and do not necessarily coincide with those of Banco de Portugal or the Eurosystem. Any errors and omissions are the sole responsability of the author. The author would like to thank the participants of the Eurosystem research network on cash (Eureca) for helpful discussions and the ECB for providing data.

E-mail: antonio.rua@bportugal.pt

1. Introduction

Notwithstanding the evolving payment systems, cash still remains an essential part of everyday use (see, for example, Bagnall *et al.* (2016) and Esselink and Hernandez (2017)). In this respect, countries belonging to the euro area faced a major change at the time of the introduction of the euro with the undertaking to exchange the legacy currency notes and coins for their euro-denominated equivalents. In particular, the physical introduction of the euro on the 1st January 2002 meant the largest-ever currency changeover affecting more than 300 million people. The impact of the changeover to euro currency was also felt outside the euro area as legacy currencies were already being used throughout the world.

Banknotes in circulation appear under the autonomous factors on the Eurosystem balance sheet, as the central bank has no direct control over it. Being one of the largest autonomous factors, it becomes crucial to understand the drivers of banknotes demand for the ECB liquidity management. Although the central bank knows exactly the outstanding amount of banknotes in circulation, there is no way to know with certainty who holds it and why. Besides the usual motives for holding currency, such as for transactions purposes or as a store of value, in the case of the euro, it is even more challenging to model demand due to its international role. According to the ECB (2018), it is estimated that around 30 per cent of the currency in circulation was held outside the euro area at the end of 2017. Other major currencies, namely the US dollar, are also known to have a noteworthy circulation outside their national borders (see, for example, Porter and Judson (1996), Rogoff (1998) and Lambert and Stanton (2001)).

Furthermore, to assure that supply meets demand, the denominational breakdown of currency demand cannot be disregarded. For instance, Sargent and Velde (1999, 2002) analyze several past episodes where the supply of an inadequate mix of denominations had disruptive economic effects. In this respect, the factors driving demand may differ or have a heterogeneous effect across banknote denominations. For example, low-value denominations are usually more demanded for transaction purposes whereas large-value denominations are typically influenced by the store of value motive.

Recent research on modelling currency demand by considering some degree of denominational breakdown includes, for example, Doyle (2000), Judson and Porter (2004), Amromin and Chakravorti (2009), Nachane *et al.* (2013)

and Cusbert and Rohling (2013). In the case of the euro, there are only a few studies focusing on euro banknotes demand. Fischer *et al.* (2004) addresses euro currency demand resorting to euro legacy banknotes while considering a breakdown into large and small-value denominations. Bartzsch *et al.* (2015) consider the euro banknotes issued by the Deutsche Bundesbank while modelling the demand for small (€5, €10 and €20), medium (€50 and €100) and large (€200 and €500). Rua (2018) addresses the demand for euro currency issued by Banco de Portugal with all banknote denominations taken individually.

In contrast with previous literature, the focus is on the euro banknotes issued by the Eurosystem as a whole while considering the full denominational breakdown. Such an approach can potentially lead to a more in depth understanding of banknote demand for one of the most important currencies in the world.

Besides considering the classical motives for currency demand, such as for transaction purposes or as store of value (drawing on the seminal work by Baumol (1952) and Tobin (1956)), other potential determinants are assessed. For instance, the technological developments associated with financial innovation may influence currency demand (see Attanasio *et al.* (2002), Alvarez and Lippi (2009) and Lippi and Secchi (2009)). Uncertainty can also play a role as it may affect the demand for cash holdings. In this respect, we consider two types of measures, one reflecting financial volatility and one related to economic policy uncertainty (see Baker *et al.* (2016)). Furthermore, reflecting the international role of the euro, special attention is given to the demand from outside the euro area. In particular, it is proposed a novel foreign demand indicator for euro banknotes which is found to have a noteworthy empirical adherence.

From an econometric point of view, following the long standing approach for modelling money demand, an error correction model framework is pursued. However, given that one is interested in taking into account the possible interconnections among denominations, we resort to the Dynamic Seemingly Unrelated Regression (DSUR) estimator suggested by Mark *et al.* (2005) for the system estimation of the long-run relationships and to a SUR ECM for the short-run dynamics (see also Rua (2018)). The resulting model, coined as D€NOTES (Demand for Euro notes) model, is able to track quite well the developments regarding euro banknotes demand.

The paper is organised as follows. In section 2, the challenging nature of the demand for euro banknotes is addressed. The econometric approach pursued is presented in section 3 while the data and variables considered for modelling banknotes demand are described in section 4. In section 5, the empirical analysis is conducted and the results are discussed. Finally, section 6 concludes.

2. The challenging nature of the euro

Since the physical introduction of the euro in 2002, the total value of euro banknotes in circulation has been increasing over time (see Figure 1). In particular, it recorded an annual average growth above 8 per cent, reflecting to some extent the substantial growth observed in the years following the introduction of euro banknotes. Nevertheless, in the most recent period, it presented an annual average growth above 5 per cent over the last five years.

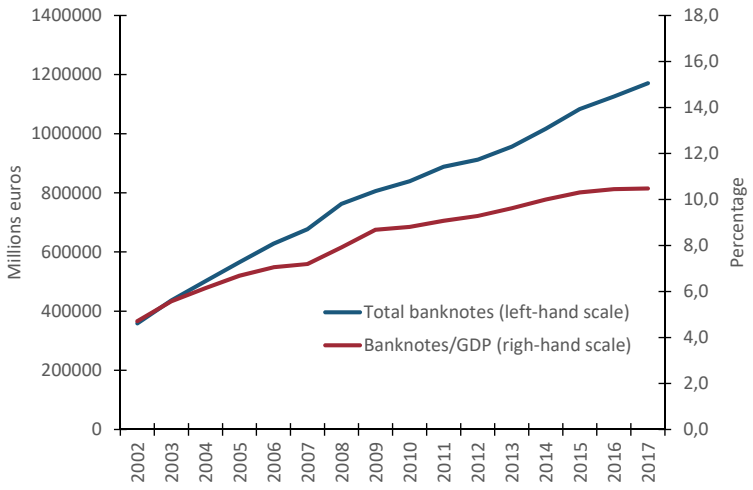


FIGURE 1: Total amount of euro banknotes in circulation

The ratio of banknotes in circulation to nominal GDP has also been increasing. Such a ratio went from less than 5 per cent at the end of 2002 to more than 10 per cent in 2017. This means that banknotes demand has been

growing faster than overall euro area economic activity suggesting that other factors have also been playing a role in driving demand.

In terms of denominational breakdown, the most circulated banknotes are the €50, €100 and €500 banknotes (see Figure 2). One should mention that the €500 denomination had the largest share, in terms of value in circulation, at the time of the Lehman Brothers crisis (35 per cent). Such a prominence has decreased markedly since 2016 with the announcement by the ECB to discontinue production of the €500 banknote. At the end of 2017, its share stood slightly above 20 per cent. In turn, the €50 banknote has been gaining importance and is by now the most circulated banknote accounting for more than 40 per cent of the total value of banknotes in circulation. The €100 banknote has attained the second highest share surpassing the €500 banknote at the end of 2017. The three lowest denominations (€5, €10 and €20) have been losing relevance over time totaling less than 10 per cent at the end of 2017.

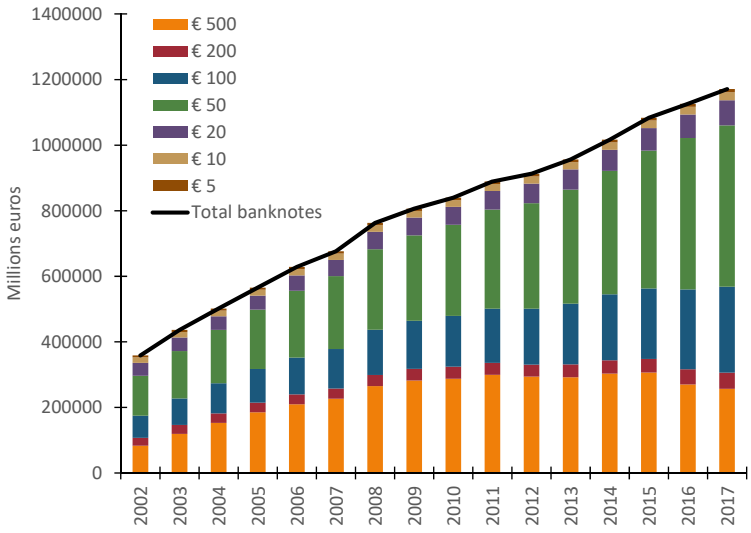


FIGURE 2: Breakdown by denomination of euro banknotes in circulation

Despite the on-going development of alternative means of payment, the demand for euro banknotes has continued to record a robust growth as

mentioned earlier. Certainly, the low interest rate environment has contributed to support such developments. But these factors are not the end of the story. In the case of the euro, the international demand for euro banknotes has to be taken on board in the analysis.

In fact, euro banknotes are also demanded from countries outside the euro area. Such a demand can be driven by transaction purposes, such as travel for leisure or business. There are also countries, such as Montenegro and Kosovo, that have adopted unilaterally the euro as *de facto* currency.[1] Furthermore, euro currency can also be held outside the euro area as a store of value. As it is well known, residents of many developing, emerging market and transition economies hold a noteworthy share of their financial assets in foreign currency and partly in the form of cash. Since its launch, the euro has been the second most widely held international reserve currency after the US dollar.

FIGURE 3: Cumulated net shipments of euro banknotes

1. Although the euro is not legal tender in those countries it is treated as such by the population.

Such an international role of the euro can be depicted with the net shipments of euro banknotes by euro area monetary and financial institutions (MFIs) to destinations outside the euro area (see Figure 3).[2] One can see that net shipments of euro banknotes have been recording an upward trend since the physical introduction of the euro in 2002, attaining around 15 per cent of the total amount of banknotes in circulation in 2017. One should mention that such a demand from abroad is heterogeneous across denominations (see Figure 4). In fact, the euro banknotes more demanded relatively to the total amount issued are the €200 and €100 banknotes. At the end of 2017, the cumulated net shipments of €200 banknotes relatively to the amount issued stood around 85 per cent whereas in the case of €100 banknotes it was close to 60 per cent.

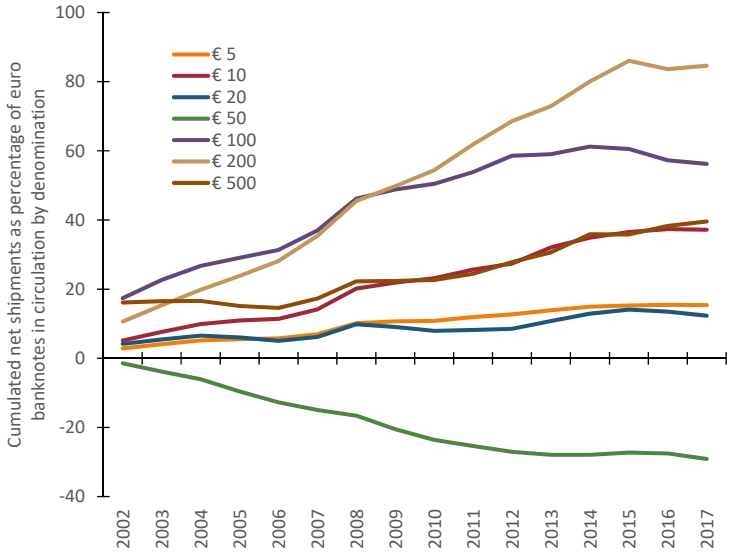


FIGURE 4: Breakdown by denomination of the cumulated net shipments

The information on banknotes shipments is the only direct data source on cross-border currency flows available in the euro area. However, as external

2. Net shipments are defined as shipments of euro banknotes by euro area MFIs to destinations outside the euro area minus the return of euro banknotes from countries outside the euro area to euro area MFIs.

demand is only partially captured by net shipments data, the above figures only provide a tentative insight on the importance of foreign demand. In fact, transfers of euro banknotes to and from the euro area can also occur through other channels, such as tourism, workers' remittances or informal economy.

Hence, obtaining a precise estimate of the amount of banknotes held outside borders is not an easy task and different approaches may lead to different estimates (see, for example, Bartzsch *et al.* (2011, 2013a, 2013b)). The ECB (2017) argues that a lower bound estimate could be obtained through the net shipments data whereas an upper bound could be based on the ratio of coins to banknotes. By taking the average of the lower and upper bound estimates (25 and 35 per cent, respectively) as done by the ECB (2017), it is concluded that around 30 per cent of euro banknotes are held outside the euro area.

3. Econometric approach

The literature on modelling money demand functions has drawn historically on the ECM approach initially advocated by Engle and Granger (1987). Such a modelling strategy basically encompasses two stages. In the first stage, the long-run relationship among the variables of interest is estimated while in the second stage, given the estimated cointegrating equation, the short-run behaviour is modelled.

Although the least squares estimator is a consistent estimator of the long-run relationship, it has been found that it can be severely biased in small samples and it is not efficient (see Stock (1987) and Phillips (1991)). Hence, Phillips and Loretan (1991) and Stock and Watson (1993) propose estimating by least squares the cointegrating regression augmented with leads and lags of the first-differenced regressors. Such an estimator has been termed as Dynamic OLS (DOLS) and is consistent, asymptotically normally distributed and efficient under certain assumptions.

The DOLS estimator has been recently extended to the case of a system of cointegrating equations by Mark *et al.* (2005). The resulting Dynamic Seemingly Unrelated Regression (DSUR) estimator enhances efficiency over single equation estimation methods namely in a context of heterogeneous cointegrating vectors and when equilibrium errors are correlated across cointegrating regressions. Such an approach seems particularly appropriate for

the estimation of banknote demand with denominational breakdown (see also Rua (2018)).

More formally, let us consider N cointegrating regressions where each equation $i = 1, ..., N$ for $t = 1, ..., T$ has a triangular representation

$$y_{it} = x'_{it}\beta_i + u_{it} \tag{1}$$

$$\Delta x_{it} = e_{it} \tag{2}$$

where x_{it} and e_{it} are $k \times 1$ dimensional vectors. Note that if there is correlation between the equilibrium error of equation i, i.e. u_{it}, and leads or lags of the first-differenced regressors from any of the equations in the system then an endogeneity problem arises. Thus, Mark *et al.* (2005) suggest considering not only leads and lags of Δx_{it}, as is the case in a single-equation context, but leads and lags of Δx_{1t} through Δx_{Nt}.

The projection of u_{it} onto z'_t, that is

$$u_{it} = z'_t\delta_i + \varepsilon_{it} \tag{3}$$

where $z'_t = (z'_{1t}, ..., z'_{Nt})$ with $z'_{it} = \left(\Delta x'_{i,t-p}, ..., \Delta x'_{i,t+p}\right)$ for a finite number of p leads and lags, yields a projection error ε_{it} that is, by construction, orthogonal to all leads and lags of Δx_{it}, $i = 1, ..., N$. By substituting (3) into (1) one obtains the following equation

$$y_{it} = x'_{it}\beta_i + z'_t\delta_i + \varepsilon_{it} \tag{4}$$

and by stacking the resulting N equations, the system can be written as

$$Y_t = \begin{bmatrix} X_t \\ Z_t \end{bmatrix}' \begin{bmatrix} \beta \\ \delta \end{bmatrix} + \varepsilon_t \tag{5}$$

with $Y_t = (y_{1t}, ..., y_{Nt})'$, $X_t = diag\,(x_{1t}, ..., x_{Nt})$, $Z_t = (I_N \otimes z_t)$, $\beta = (\beta_1, ..., \beta_N)'$, $\delta = (\delta_1, ..., \delta_N)'$ and $\varepsilon_t = (\varepsilon_{1t}, ..., \varepsilon_{Nt})'$.

The DSUR estimator is given by

$$\begin{bmatrix} \beta^{DSUR} \\ \delta^{DSUR} \end{bmatrix} = \left(\sum_{t=1+p}^{T-p} \begin{bmatrix} X_t \\ Z_t \end{bmatrix} \Omega_{\varepsilon\varepsilon}^{-1} \begin{bmatrix} X_t & Z_t \end{bmatrix} \right)^{-1} \left(\sum_{t=1+p}^{T-p} \begin{bmatrix} X_t \\ Z_t \end{bmatrix} \Omega_{\varepsilon\varepsilon}^{-1} Y_t \right) \tag{6}$$

where $\Omega_{\varepsilon\varepsilon}$ is the long-run covariance matrix of ε_t. In practice, as suggested by Mark *et al.* (2005), the estimation can be conducted by firstly purging

endogeneity by least squares and then estimating β^{DSUR} by running SUR on the resulting least squares residuals.

Given a DSUR estimate of β_i for equation i, that is $\widehat{\beta}_i^{DSUR}$, the second stage of the modelling approach consists on fitting an ECM for each y_{it}

$$\Delta y_{it} = \varphi_{i0} + \sum_{j=1} \varphi_{ij} \Delta y_{i,t-j} + \sum_{h=0} x'_{i,t-h} \theta_{ih} + \gamma_i \left(y_{i,t-1} - x'_{i,t-1} \widehat{\beta}_i^{DSUR} \right) + \xi_{it} \tag{7}$$

By stacking equation (7) for $i = 1, ..., N$, one can apply the standard SUR estimator to the corresponding system. Hence, not only the long-run cross sectional dependence among the cointegration relationships is captured through the DSUR estimator, as the interconnections among the short-run dynamics are taken into account.

4. Data

The data concerning the euro banknote circulation corresponds to the net cumulated issuance by the Eurosystem as a whole since 2002. As mentioned earlier, a breakdown by denomination is considered namely, €5, €10, €20, €50, €100, €200 and €500 banknotes. The data is provided by the ECB. The quarterly data has been seasonally adjusted using JDEMETRA+ which is the official software provided by the Eurostat for seasonal adjustment. As usual in money demand literature, we focus on real currency holdings by deflating the net cumulated issuance with the euro area GDP deflator.

Several potential determinants of banknotes demand are considered. The typical motive for demanding currency is for transaction purposes. To capture the transactions motive, we consider real quarterly GDP for the euro area which is a broad measure of economic activity.[3]

Another well-established motive for holding cash is its store of value function. Naturally, it will be negatively affected by the opportunity cost of holding it. As proxy of such an opportunity cost, we consider both short- and long-term interest rates corresponding to the 3-month Euribor and 10-year Treasury bond yield, respectively.

3. The results are qualitatively similar if one considers private consumption as the relevant transactions variable.

To assess the potential effect of the financial innovation process on banknote demand, we consider the number of ATMs and POS terminals in the euro area. On the one hand, the widespread availability of ATMs throughout the territory may incentive the use of banknotes, in particular those denominations that are loaded in the terminals. On the other hand, the increasingly number of POS terminals may spur the use of credit and debit cards as an alternative mean of payment putting pressure on the use of cash. As the data is only available on annual basis, it was converted to the quarterly frequency using a Chow-Lin type disaggregation method with AR(1) errors.

As the euro is one of the most important currencies in the world, euro banknotes are also held outside the euro area for transaction purposes and as a store of value. To capture external demand, we construct a foreign demand indicator as the weighted average of real GDP of the main countries of destination of euro banknotes, where the weights are the relative importance of each destination country in terms of shipments. In particular, we cover nine countries namely United Kingdom, Russia, Switzerland, China, Brazil, USA, South Korea, Canada and Sweden, which account for around 70 per cent of the shipments in 2017.

Besides the above measure, we consider the exchange rate since the relative strength of the currency may influence the demand from abroad (see Fischer *et al.* (2004) and Bartzsch *et al.* (2015)). In particular, it is considered the real effective exchange rate of the euro against a group of nineteen trading partners based on GDP deflators, where an increase of the index corresponds to an appreciation of the euro.[4]

As uncertainty may also impact on the desired level of cash holdings, we consider two variables. The first is the VSTOXX which corresponds to the 30-day implied volatility of the EURO STOXX 50 and reflects the volatility of equity markets. The second variable considered is the Economic Policy Uncertainty which is designed to measure policy-related economic uncertainty as proposed by Baker *et al.* (2016). In particular, an index for the euro area is obtained by aggregating the indexes for the main countries namely Germany, France, Italy and Spain using GDP nominal weights. One should note that although both measures intend to capture uncertainty, the two measures differ

4. One should mention that the results are robust to the group of countries or deflators (such as CPI, PPI or unit labour costs) considered for the effective exchange rate.

conceptually in several ways namely in the topical scope (for a more thorough discussion see Baker *et al.* (2016). In fact, the correlation between the two variables is 0.25.

Finally, as the situation in the labour market may influence cash demand, it has also been considered the unemployment rate for the euro area (as in Fischer *et al.* (2004) and Bartzsch *et al.* (2015)).

As usual, we consider all variables in logs with the exception of interest rates and unemployment rate. The sample period runs from the physical introduction of the euro in 2002 up to the last quarter of 2017.

5. Empirical analysis

5.1. Unit roots

Firstly, we assess the non-stationarity of the variables above described. In Table 1, we report the modified Dickey-Fuller test statistic (DF-GLS) and the point-optimal test statistic (P) as proposed by Elliott, Rothenberg and Stock (1996). The null hypothesis postulates the presence of a unit root. To complement these tests we also conducted the well-known KPSS test which considers as the null the stationarity of the series. Based on the unit root test results, one can conclude that all series have a unit root with the exception of the uncertainty variables (EPU and VSTOXX) and unemployment rate which are stationary.

Variable	Notation	DF-GLS	P-statistic	KPSS
500 euro banknotes	€500	0.20	1296.68	0.74*
200 euro banknotes	€200	1.48	204.26	1.01*
100 euro banknotes	€100	2.33	1442.80	1.02*
50 euro banknotes	€50	1.68	3137.21	1.02*
20 euro banknotes	€20	-0.15	284.28	1.00*
10 euro banknotes	€10	-0.67	23.14	0.92*
5 euro banknotes	€5	-0.46	979.40	0.97*
Real Gross Domestic Product	RGDP	0.19	33.37	0.83*
Short-term interest rate	STIR	-1.37	7.37	0.73*
Long-term interest rate	LTIR	0.07	52.93	0.77*
ATM terminals	ATM	-0.75	72.75	0.82*
POS terminals	POS	-0.17	150.18	0.97*
Foreign Demand indicator	FD	0.65	373.41	0.97*
Real Effective Exchange Rate	REER	-1.31	10.55	0.66*
Unemployment Rate	UR	-1.98*	3.02*	0.42
Economic Policy Uncertainty	EPU	-2.69*	2.23*	0.36
EURO STOXX 50 Volatility	VSTOXX	-2.31*	2.99*	0.13

TABLE 1. Unit root test statistics

Note: * denotes rejection of the null hypothesis at the usual 5 per cent significance level.

5.2. DSUR

As discussed earlier, the first stage of the pursued modelling strategy consists on the estimation of the system of long-run equations for banknote demand by denomination. In particular, we use the feasible two-step DSUR estimator of Mark *et al.* (2005) and set $p = 1$ following the usual practice with relatively small samples.[5] The estimation results are presented in Table 2.

Before proceeding with the analysis of Table 2 one should mention the following. Firstly, the usefulness of the DSUR estimator in the current context is empirically supported by the presence of a non-negligible cross-section dependence among cointegrating equations. In fact, both the LM test of Breusch and Pagan (1980) and the CD test developed by Pesaran (2004, 2015) lead to the rejection of the null hypothesis of no cross-section dependence among the residuals of the long-run banknote demand by denomination.[6] Secondly,

5. Nevertheless, we find that the results are qualitatively similar regardless the choice of the number of leads and lags.

6. The LM statistic is 225.62 ($p - value = 0.000$) and the CD statistic is 3.15 ($p - value = 0.001$).

Regressors	Dependent variable y_t						
	€500	€200	€100	€50	€20	€10	€5
$RGDP_t$	5.582		3.415	5.274	2.302	1.313	1.301
	[0.558]		[0.119]	[0.169]	[0.079]	[0.033]	[0.060]
$STIR_t$	−0.105	−0.018	−0.083	−0.109	−0.048	−0.013	−0.031
	[0.033]	[0.009]	[0.003]	[0.007]	[0.003]	[0.001]	[0.003]
ATM_t				0.189	0.039		
				[0.058]	[0.019]		
FD_t		1.025	1.041				
		[0.054]	[0.055]				
$REER_t$	1.855	0.229	0.401				
	[0.486]	[0.091]	[0.036]				

TABLE 2. DSUR estimation results

Note: Standard deviations are reported within brackets.

the existence of cointegration cannot be rejected for any of the estimated equations.[7]

The results presented in Table 2 highlight the heterogeneity across euro banknote denominations in terms of the long-run demand determinants. The transactions motive, as captured by real GDP in the euro area, is relevant for all denominations but €200 banknotes. Such a result reflects the fact that €200 banknotes are basically driven by demand from abroad since most of the €200 banknotes issued have been shipped to outside the euro area as documented above.

We also find that the opportunity cost for holding cash impacts negatively on the demand for all banknote denominations. Moreover, drawing on the size of the estimated coefficient for the short-term interest rate, it seems that the demand for larger denominations is more affected than small denominations (in line with the findings by, for example, Amromin and Chakravorti (2009) for a panel of countries).

Regarding financial innovation, we find that the number of ATMs has a positive effect on the long-run demand of €50 and €20 banknotes. This result

7. In particular, it was conducted the residual-based cointegration test suggested by Shin (1994) which allows to test the cointegration hypothesis directly since the null corresponds to the existence of cointegration against the alternative of no cointegration. The corresponding test statistics for each denomination are: $C_{€500} = 0.150$; $C_{€200} = 0.110$; $C_{€100} = 0.063$; $C_{€50} = 0.091$; $C_{€20} = 0.112$; $C_{€10} = 0.042$; $C_{€5} = 0.100$.

reflects the fact that in most countries those denominations account for the majority of the euro banknotes loaded in the ATMs.[8]

Concerning demand from outside the euro area, we find that the proposed indicator for foreign demand is a relevant driver for the long-run demand of €200 and €100 banknotes. In fact, as discussed above, the €200 and €100 denominations are the most demanded banknotes from abroad relatively to the corresponding issuance.

In the case of the real effective exchange rate, we find that the appreciation of the euro, which has associated a higher attractiveness for residents outside the euro area, leads to an increase of demand. In particular, it influences the long-run demand of the largest banknote denominations, €500, €200 and €100 which are more prone to be used as a store of value (as also found by Fischer and Seitz (2004) for euro legacy currencies).

5.3. SUR ECM

After having estimated the system of cointegrating relationships allowing to capture interactions in the long-run, the second stage comprises the modelling of the short-run dynamics. As outlined in section 3, a system of ECM equations, resorting to the SUR estimator, is estimated to take also into account the interconnections in the short-run between banknotes demand by denomination.

The estimation results are reported in Table 3. Again, one should mention that the use of the SUR estimator is warranted by the presence of non-negligible cross-section dependence among the residuals of the ECM equations.[9]

Besides the statistical significance of lagged terms of the dependent variable (ranging from one up to two lags), one can see that GDP changes impact positively the short-run behaviour of several banknote denominations namely €200, €100 and €10 banknotes. In turn, changes in the opportunity cost, as captured by the short-term interest rate, have a negative effect on the evolution of the demand of €200, €20 and €10 banknotes.

Concerning the variables related with external demand, the foreign demand indicator has a positive and contemporaneous effect on the €500 banknotes

8. For the Portuguese case, Rua (2018) also finds that the number of ATMs impacts positively the banknote denominations that are loaded in the ATMs.

9. The LM statistic is 288.95 ($p-value=0.000$) and the CD statistic is 14.06 ($p-value=0.000$).

demand whereas an appreciation of the real effective exchange leads to a increase of the demand for €200, €100 and €50 banknotes.

Regarding uncertainty, one should mention that both measures appear as statistically significant for the €50 banknote denomination, which is currently the dominant euro banknote in circulation. Although both measures present a lead of one period, the EPU presents a negative coefficient whereas the VSTOXX has associated a positive effect. This implies that heightened uncertainty related with economic policy leads to a refraining of banknotes demand. Such a finding may reflect that fact that a rise of economic policy uncertainty has a negative impact on economic activity by inducing, for example, economic agents to postpone spending decisions which translates into a lower banknote demand. In contrast, higher financial uncertainty, as measured by the implied volatility on equity prices, leads to an increase of banknotes demand. In this case, higher financial volatility may lead to an increase of currency demand due to precautionary motives, such as diminished trust in financial intermediaries, or as a safe haven asset.

We also find that the unemployment rate plays a role in the short-run dynamics of the €50, €20 and €10 banknotes demand. Since the unemployment rate appears statistically significant with two consecutive terms (UR_t and UR_{t-1} in the case of the €50 and UR_{t-2} and UR_{t-3} for €20 and €10 denominations) and with similar size coefficients but opposite signs, then it implicitly means that what influences banknotes demand are the unemployment rate changes. For instance, a deterioration of the labour market through the increase of the unemployment rate leads to a decrease of the demand for those denominations.

Concerning the speed of adjustment towards the long-run relationship, it is sizeable for several denominations. As expected, the coefficient associated with the error correction term is negative and statistically significant at the usual five per cent significance level.[10] We also find that two episodes have been important for banknotes demand behaviour over the time period considered. The first is associated with the Lehman Brothers collapse in mid-September 2008 which led to an abnormal surge of cash demand. Such an event is captured by a time dummy variable for the fourth quarter of 2008 (denoted as D2008Q4) which

10. In the case of the €100 banknotes, the coefficient is statistically significant with a ten per cent significance level.

Regressors	Dependent variable Δy_t						
	€500	€200	€100	€50	€20	€10	€5
Constant	−3.896	−0.019	−1.452	−3.045	−3.927	−4.746	−1.207
	[0.891]	[0.006]	[0.858]	[1.012]	[0.951]	[0.826]	[0.592]
Δy_{t-1}	0.608	0.396	0.426	0.075	−0.188	−0.139	−0.367
	[0.041]	[0.072]	[0.050]	[0.053]	[0.063]	[0.064]	[0.071]
Δy_{t-2}			0.106	0.259	−0.125		
			[0.033]	[0.047]	[0.035]		
$\Delta RGDP_t$		0.821	0.362			0.564	
		[0.240	[0.114]			[0.163]	
$\Delta STIR_t$		−0.013				−0.010	
		[0.004]				[0.003]	
$\Delta STIR_{t-1}$					−0.006		
					[0.002]		
$\Delta STIR_{t-2}$					−0.007	−0.008	
					[0.003]	[0.003]	
ΔFD_t	0.687						
	[0.159]						
$\Delta REER_{t-2}$		0.153	0.165	0.142			
		[0.045]	[0.029]	[0.030]			
EPU_{t-1}				−0.009			
				[0.002]			
$VSTOXX_{t-1}$				0.008			
				[0.002]			
UR_t				−0.010			
				[0.003]			
UR_{t-1}				0.011			
				[0.004]			
UR_{t-2}					−0.018	−0.012	
					[0.005]	[0.006]	
UR_{t-3}					0.018	0.013	
					[0.005]	[0.006]	
$\text{Coint}_{t-1}^{DSUR}$	−0.047	−0.120	−0.029	−0.043	−0.141	−0.339	−0.082
	[0.011]	[0.033]	[0.017]	[0.014]	[0.034]	[0.059]	[0.040]
D2008Q4	0.108	0.041	0.059	0.036	0.023		
	[0.009]	[0.008]	[0.005]	[0.006]	[0.005]		
D2016Q2	−0.041	0.021	0.013				
	[0.007]	[0.006]	[0.004]				
SD2016Q3	−0.022	0.014					
	[0.006]	[0.003]					
R^2	0.95	0.71	0.85	0.60	0.37	0.33	0.30

TABLE 3. SUR ECM estimation results

Note: $\text{Coint}_{i,t-1}^{DSUR} = y_{i,t-1} - x'_{i,t-1}\widehat{\beta}_i^{DSUR}$. Standard deviations are reported within brackets.

turns out to be significant for all denominations with the exception of the low-value ones. Interestingly, it is for highest denomination that it is recorded the highest impact. The second episode is related with the ECB announcement, in May 2016, of the end of issuance of the €500 banknote. Such an announcement had an immediate impact on the banknotes demand. Specifically, the demand for the €500 denomination was quite negatively affected accompanied by a stronger demand of the other high value denominations, €200 and €100 banknotes. This has been captured by a time dummy for the second quarter of 2016 (D2016Q2). However, as this substitution effect persisted, albeit less markedly, a step dummy starting in the third quarter of 2016 has also been included (SD2016Q3). Drawing on the coefficient estimates for these dummies, one can conclude that such announcement did not led merely to a re-composition of banknotes in circulation as the net impact on the total banknotes demand was negative.[11]

In terms of the fit of the estimated system, a relatively high R^2 is achieved for the higher value denominations whereas for low value denominations the dynamics are much more harder to model. In particular, for the denominations from €50 up to €500 the R^2 ranges from 0.60 up to 0.95 while for the denominations from €5 up to €20 the R^2 is below 0.40. Since low value denominations account for a relatively small share of banknotes in circulation, it does not impede capturing the overall behaviour of banknotes demand quite well. In fact, by aggregating the fitted values for the different denominations, one obtains a very high correlation of 0.93 with the observed overall banknotes demand.

6. Conclusions

As liquidity management is a core function of a central bank, it is crucial to understand the forces behind currency demand. Although there is a huge body of literature on money demand, the work addressing a narrow money aggregate such as currency is relatively limited. Such work is even scarcer for the euro despite being one of the most important currencies in the world.

11. In particular, it is estimated a net impact on the rate of change of -0.75 p.p. in the second quarter of 2016 and -0.5 p.p. for the subsequent quarters.

Besides focusing on the euro, this paper intends to contribute to the literature in several other dimensions. Instead of targeting overall banknotes demand, the denominational breakdown is considered. In contrast with most of the previous literature, all existing banknote denominations (*i.e.* €500, €200, €100, €50, €20, €10, €5) are considered. Moreover, the econometric approach pursued allows one to take into account the interactions among the demand for different denominations both in the long- and short-run. We also go beyond the classical motives for demanding currency, such as for transactions purposes or as a store of value. For instance, for a major currency like the euro, a particularly important driver is the demand from abroad. In this respect, it is proposed a novel foreign demand indicator to capture the influence of external demand. The pool of determinants was also extended by including uncertainty measures covering both financial and economic policy uncertainty.

Drawing on the empirical results, one can conclude that the transactions motive and the store of value function are relevant across banknote denominations. Concerning the influence of external demand, it is found that it basically affects the high value denominations with the proposed foreign demand indicator showing significant explanatory power. Financial technological developments, such as the availability of ATMs supports the use of banknotes namely those denominations that are loaded in such terminals. Uncertainty seems to influence the demand for the dominant banknote, with the sign of the impact depending on the type of uncertainty. Financial uncertainty has a positive effect whereas economic policy uncertainty has a negative one. It is also found that the announcement by the ECB of the end of issuance of the highest value denomination, *i.e.* the €500 banknote, had a negative impact on the overall demand for euro banknotes. By taking on board the heterogeneity across denominations regarding the underlying factors driving demand, an enhanced understanding of the demand for euro currency could be achieved and a notable fit could be obtained for the overall banknotes demand.

References

Alvarez, F. and Lippi, F. (2009) "Financial Innovation and the Transactions Demand for Cash", *Econometrica*, 77(2), 363-402.

Amromin, G. and Chakravorti, S. (2009) "Whither loose change? The diminishing demand for small denomination currency", *Journal of Money, Credit and Banking*, 41, 315-335.

Attanasio, O., Guiso, L. and Jappelli, T. (2002) "The Demand for Money, Financial Innovation, and the Welfare Cost of Inflation: An Analysis with Household Data", *Journal of Political Economy*, 110, 317-351.

Bagnall, J., Bounie, D., Huynh, K., Kosse, A., Schmidt, T., Schuh, S. and Stix, H. (2016) "Consumer Cash Usage: A Cross-Country Comparison with Payment Diary Survey Data", *International Journal of Central Banking*, vol. 12 no. 4, 1-61.

Baker, S., Bloom, N. and Davis, S. (2016) "Measuring Economic Policy Uncertainty", *Quarterly Journal of Economics*, 131(4), 1593-1636.

Bartzsch, N., Rösl, G. and Seitz, F. (2011) "Foreign demand for euro banknotes issued in Germany: Estimation using indirect approaches", Deutsche Bundesbank Discussion Paper, Series 1, 21/2011.

Bartzsch, N., Rösl, G. and Seitz, F. (2013a) "Estimating the foreign circulation of banknotes", *Economics Letters*, 119(2), 165-167.

Bartzsch, N., Rösl, G. and Seitz, F. (2013b) "Currency movements within and outside a currency union: The case of Germany and the euro area", *The Quarterly Review of Economics and Finance*, 53(4), 393-401.

Bartzsch, N., Seitz, F. and Setzer, R. (2015) "The demand for euro banknotes in Germany: Structural modelling and forecasting", MPRA Paper 64949, University Library of Munich, Germany.

Baumol, W. J. (1952) "The Transactions Demand for Cash: An Inventory Theoretic Approach", *Quarterly Journal of Economics*, 66(4), 545-556.

Breusch, T. S. and Pagan, A. R. (1980) "The Lagrange multiplier test and its applications to model specification in econometrics", *Review of Economic Studies*, 47, 239-253.

Cusbert, T. and Rohling, T. (2013) "Currency demand during the global financial crisis: Evidence from Australia", Reserve Bank of Australia, Research Discussion Paper 2013-01.

Doyle, B. M. (2000) "'Here, Dollars, Dollars ...' – Estimating currency demand and worldwide currency substitution", Board of Governors of the Federal Reserve System, International Finance Discussion Papers 657.

ECB (2017) "Estimation of euro currency in circulation ouside the euro area", European Central Bank.

ECB (2018) "Trends and developments in the use of euro cash over the past ten years", Economic Bulletin Issue 6/2018, European Central Bank.

Elliott, G., Rothenberg, T. J. and Stock, J. H. (1996) "Efficient Tests for an Autoregressive Unit Root", *Econometrica*, 64(4), 813-836.

Engle, R. and Granger, C. (1987) "Co-Integration and Error Correction: Representation, Estimation, and Testing", *Econometrica*, 55(2), 251-276.

Esselink, H. and Hernandez, L. (2017) "The use of cash by households in the euro area", ECB Occasional Paper no. 201, European Central Bank.

Fischer, B., Köhler, P. and Seitz, F. (2004) "The demand for euro area currencies: Past, present and future", ECB Working Paper 330, European Central Bank.

Judson, R. and Porter, R. (2004) "Currency demand by federal reserve cash office: what do we know?", *Journal of Economics and Business*, 56(4), 273-285.

Lambert, M., Stanton, K.D. (2001) "Opportunities and Challenges of the U.S. Dollar as an Increasingly Global Currency: A Federal Reserve Perspective", Federal Reserve Bulletin, 87(9), 567-575.

Lippi, F. and Secchi, A. (2009) "Technological Change and the Household's Demand for Currency", *Journal of Monetary Economics*, 56(2), 222-230.

Mark, N., Ogaki, M. and Sul, D. (2005) "Dynamic Seemingly Unrelated Cointegrating Regressions", *Review of Economic Studies*, 72(3), 797-820.

Nachane, D., Chakraborty, A., Mitra, A. and Bordoloi, S. (2013) "Modelling currency demand in India: An empirical study", Reserve Bank of India Discussion Paper 39.

Pesaran, M. H. (2004) "General diagnostic tests for cross section dependence in panels", CESifo Working Papers No.1233.

Pesaran, M. H. (2015) "Testing Weak Cross-Sectional Dependence in Large Panels", *Econometric Reviews*, 34, 1089-1117.

Phillips, P. C. B. (1991) "Optimal Inference in Cointegrated Systems", *Econometrica*, 59, 283-306.

Phillips, P. C. B. and Loretan, M. (1991) "Estimating Long-Run Economic Equilibria", *The Review of Economic Studies*, 58(3), 407-436.

Porter, R. and Judson, R. (1996) "The Location of U.S. Currency: How Much is Abroad?", Federal Reserve Bulletin, 82(10), 883-903.

Rogoff, K. (1998) "Blessing or Curse? Foreign and Underground Demand for Euro Notes", *Economic Policy*, 26, 263-303.

Rua, A. (2018) "Modelling currency demand in a small open economy within a monetary union", *Economic Modelling*, 74, 88-96.

Sargent, T. and Velde, F. (1999) "The Big Problem of Small Change", *Journal of Money, Credit and Banking*, 31(2), 137-161.

Sargent, T. and Velde, F. (2002) The big problem of small change, Princeton University Press.

Shin, Y. (1994) "A residual-based test of the null of cointegration against the alternative of no cointegration", *Econometric Theory*, 10(1), 91-115.

Stock, J. (1987) "Asymptotic Properties of Least Squares Estimation of Cointegrating Vectors", *Econometrica*, 55, 1035-1056.

Stock, J. and Watson, M. (1993) "A Simple Estimator of Cointegrating Vectors in Higher Order Integrated Systems", *Econometrica*, 61, 783-820.

Tobin, J. (1956) "The Interest Elasticity of the Transactions Demand for Cash", *Review of Economics and Statistics*, 38(3), 241-247.

Working Papers

2017

1|17 The diffusion of knowledge via managers' mobility
Giordano Mion | Luca David Opromolla | Alessandro Sforza

2|17 Upward nominal wage rigidity
Paulo Guimarães | Fernando Martins | Pedro Portugal

3|17 Zooming the ins and outs of the U.S. unemployment
Pedro Portugal | António Rua

4|17 Labor market imperfections and the firm's wage setting policy
Sónia Félix | Pedro Portugal

5|17 International banking and cross-border effects of regulation: lessons from Portugal
Diana Bonfim | Sónia Costa

6|17 Disentangling the channels from birthdate to educational attainment
Luís Martins | Manuel Coutinho Pereira

7|17 Who's who in global value chains? A weighted network approach
João Amador | Sónia Cabral | Rossana Mastrandrea | Franco Ruzzenenti

8|17 Lending relationships and the real economy: evidence in the context of the euro area sovereign debt crisis
Luciana Barbosa

9|17 Impact of uncertainty measures on the Portuguese economy
Cristina Manteu | Sara Serra

10|17 Modelling currency demand in a small open economy within a monetary union
António Rua

11|17 Boom, slump, sudden stops, recovery, and policy options. Portugal and the Euro
Olivier Blanchard | Pedro Portugal

12|17 Inefficiency distribution of the European Banking System
João Oliveira

13|17 Banks' liquidity management and systemic risk
Luca G. Deidda | Ettore Panetti

14|17 Entrepreneurial risk and diversification through trade
Federico Esposito

15|17 The portuguese post-2008 period: a narrative from an estimated DSGE model
Paulo Júlio | José R. Maria

16|17 A theory of government bailouts in a heterogeneous banking system
Filomena Garcia | Ettore Panetti

17|17 Goods and factor market integration: a quantitative assessment of the EU enlargement
FLorenzo Caliendo | Luca David Opromolla | Fernando Parro | Alessandro Sforza

2018

1|18 Calibration and the estimation of macro-economic models
Nikolay Iskrev

2|18 Are asset price data informative about news shocks? A DSGE perspective
Nikolay Iskrev

3|18 Sub-optimality of the friedman rule with distorting taxes
Bernardino Adão | André C. Silva

4|18 The effect of firm cash holdings on monetary policy
Bernardino Adão | André C. Silva

5|18 The returns to schooling unveiled
Ana Rute Cardoso | Paulo Guimarães | Pedro Portugal | Hugo Reis

6|18 Real effects of financial distress: the role of heterogeneity
Francisco Buera | Sudipto Karmakar

7|18 Did recent reforms facilitate EU labour market adjustment? Firm level evidence
Mario Izquierdo | Theodora Kosma | Ana Lamo | Fernando Martins | Simon Savsek

8|18 Flexible wage components as a source of wage adaptability to shocks: evidence from European firms, 2010–2013
Jan Babecký | Clémence Berson | Ludmila Fadejeva | Ana Lamo | Petra Marotzke | Fernando Martins | Pawel Strzelecki

9|18 The effects of official and unofficial information on tax compliance
Filomena Garcia | Luca David Opromolla Andrea Vezulli | Rafael Marques

10|18 International trade in services: evidence for portuguese firms
João Amador | Sónia Cabral | Birgitte Ringstad

11|18 Fear the walking dead: zombie firms, spillovers and exit barriers
Ana Fontoura Gouveia | Christian Osterhold

12|18 Collateral Damage? Labour Market Effects of Competing with China – at Home and Abroad
Sónia Cabral | Pedro S. Martins | João Pereira dos Santos | Mariana Tavares

13|18 An integrated financial amplifier: The role of defaulted loans and occasionally binding constraints in output fluctuations
Paulo Júlio | José R. Maria

14|18 Structural Changes in the Duration of Bull Markets and Business Cycle Dynamics
João Cruz | João Nicolau | Paulo M.M. Rodrigues

15|18 Cross-border spillovers of monetary policy: what changes during a financial crisis?
Luciana Barbosa | Diana Bonfim | Sónia Costa | Mary Everett

16|18 When losses turn into loans: the cost of undercapitalized banks
Laura Blattner | Luísa Farinha | Francisca Rebelo

17|18 Testing the fractionally integrated hypothesis using M estimation: With an application to stock market volatility
Matei Demetrescu | Paulo M. M. Rodrigues | Antonio Rubia

18|18 Every cloud has a silver lining: Micro-level evidence on the cleansing effects of the Portuguese financial crisis
Daniel A. Dias | Carlos Robalo Marques

19|18 To ask or not to ask? Collateral versus screening in lending relationships
Hans Degryse | Artashes Karapetyan | Sudipto Karmakar

20|18 Thirty years of economic growth in Africa
João Amador | António R. dos Santos

21|18 CEO performance in severe crises: the role of newcomers
Sharmin Sazedj | João Amador | José Tavares

22|18 A general equilibrium theory of occupational choice under optimistic beliefs about entrepreneurial ability
Michele Dell'Era | Luca David Opromolla | Luís Santos-Pinto

23|18 Exploring the implications of different loan-to-value macroprudential policy designs
Rita Basto | Sandra Gomes | Diana Lima

24|18 Bank shocks and firm performance: new evidence from the sovereign debt crisis
Luísa Farinha | Marina-Eliza Spaliara | Serafem Tsoukas

25|18 Bank credit allocation and productivity: stylised facts for Portugal
Nuno Azevedo | Márcio Mateus | Álvaro Pina

26|18 Does domestic demand matter for firms' exports?
Paulo Soares Esteves | Miguel Portela | António Rua

27|18 Credit Subsidies
Isabel Correia | Fiorella De Fiore | Pedro Teles | Oreste Tristani

2019

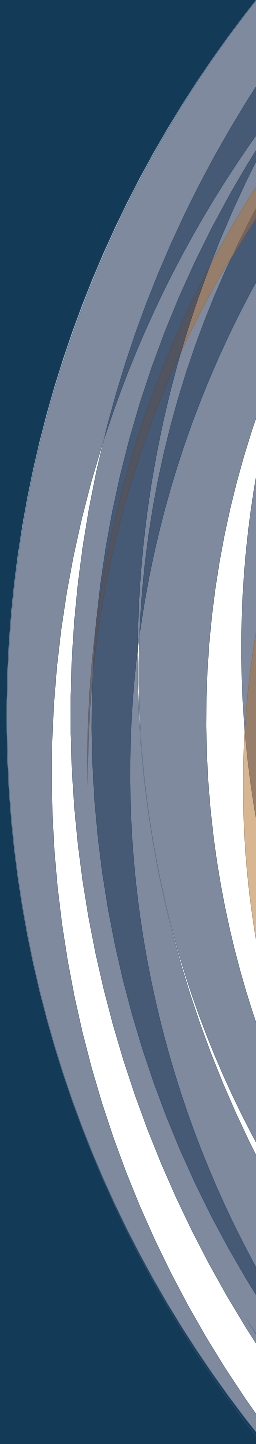
1|19 The transmission of unconventional monetary policy to bank credit supply: evidence from the TLTRO
António Afonso | Joana Sousa-Leite

2|19 How responsive are wages to demand within the firm? Evidence from idiosyncratic export demand shocks
Andrew Garin | Filipe Silvério

3|19 Vocational high school graduate wage gap: the role of cognitive skills and firms
Joop Hartog | Pedro Raposo | Hugo Reis

4|19 What is the Impact of Increased Business Competition?
Sónia Félix | Chiara Maggi

5|19 Modelling the Demand for Euro Banknotes
António Rua



www.bportugal.pt