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TECHNICAL NOTE—CALIBRATION OF A DEBT-SERVICE-TO-INCOME LIMIT IN ROMANIA—EVIDENCE FROM MICRODATA

This Technical Note on Calibration of a Debt-Service-to-Income Limit in Romania on Romania was prepared by a staff team of the International Monetary Fund. It is based on the information available at the time it was completed on May 18, 2018.

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TECHNICAL NOTE

CALIBRATION OF A DEBT-SERVICE-TO-INCOME LIMIT IN ROMANIA: EVIDENCE FROM MICRODATA

Prepared By
National Bank of Romania and Monetary and Capital Markets Department, IMF

This Technical Note was prepared in the context of a joint IMF-World Bank Financial Sector Assessment Program (FSAP) mission to Romania during October 31–November 21, 2017, and January 11–23, 2018 led by Erlend Nier, IMF and Laurent Gonnet, World Bank, and overseen by the Monetary and Capital Markets Department, IMF, and the Finance, Competitiveness and Innovation Global Practice, World Bank. The note contains the technical analysis and detailed information underpinning the FSAP assessment's findings and recommendations. Further information on the FSAP program can be found at http://www.imf.org/external/np/fsap/fssa.aspx.

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Glossary

DTI	Debt to Income
DSTI	Debt Service to Income
FSAP	Financial Sector Assessment Program
LTI	Loan to Income
LTV	Loan-to-Value
NBR	National Bank of Romania
NPL	Nonperforming Loan
PD	Probability of Default
RON	Romanian currency abbreviation

EXECUTIVE SUMMARY[1]

The recent pick-up in household credit in Romania has given rise to a need for revisiting the design of existing macroprudential tools addressing household vulnerabilities. After a period of contraction followed by lackluster growth in the aftermath of the financial crisis, household credit growth has risen rapidly starting in 2016. This trend has strengthened the need to revisit the design of macroprudential tools aimed at constraining excessive household borrowing, and in particular the existing stressed Debt Service to Income (DSTI) limit applicable to consumer loans.

The National Bank of Romania (NBR) is considering a redesign of its existing macroprudential tool related to household indebtedness, including expanding its scope to cover all household loans. Against the backdrop of rising vulnerabilities associated with household indebtedness, the NBR is considering a recalibration of the existing DSTI limit. Specifically, it proposes: (i) introducing an explicit maximum DSTI limit which applies to the stressed DSTI level (after imposing shocks on interest rate, FX and income), rather than relying on banks' internal limits; (ii) expanding the scope of the tool to cover all household loans (consumer and mortgage loans, including *Prima Casa* loans); and (iii) recalibration of the shocks for calculation of stressed DSTI applicable to consumer loans and introducing similar shocks applicable to mortgage loans.

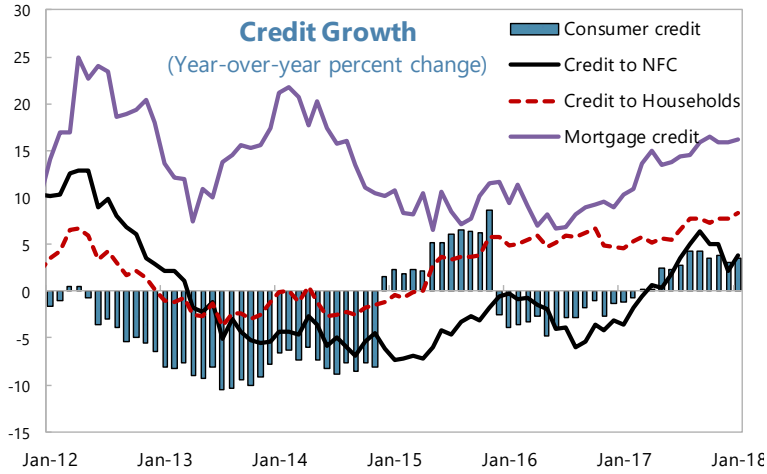
The analysis presented in this paper suggests that a stressed DSTI limit of 50 percent is the appropriate level for household loans. The analysis of loan-level data from the Central Credit Register suggests that the probability of default (PD) of a borrower is highly sensitive to any changes in DSTI at DSTI ratios around 50 percent, particularly for mortgage loans. Therefore, it is recommended to set the limit such that loans do not exceed this sensitivity threshold.

The impact analysis shows that imposing a 50 percent DSTI limit would lead to lower NPL ratios, while the impact on loan volumes would be limited. The analysis suggests that three-year ahead NPL ratios will be lower by 0.3 to 0.4 percentage points for mortgages and consumers, respectively, while (aggregate) loan levels would be 7–11 percent lower, depending on the share of loans that are exempted from the DSTI limit.

[1] This is a joint Technical Note by the International Monetary Fund and the National Bank of Romania. It has been prepared by Elena Banu and Radu Popa, NBR, and Maral Shamloo, Monetary and Capital Markets Department, IMF.

INTRODUCTION

1. The recent pick-up in household credit in Romania has given rise to a need for a reassessment of macroprudential tools addressing household vulnerabilities. After a period of contraction followed by lackluster growth in the aftermath of the financial crisis, household credit growth has picked up starting in 2015 (see text chart). This trend has strengthened the need to revisit the design of macroprudential tools aimed at containing household vulnerabilities, and in particular the existing stressed DSTI limit applicable to consumer loans.



Source: IMF staff calculations

2. The use of sectoral macroprudential tools is an effective way to address vulnerabilities arising from lending to households. Limits on Loan-to-Value (LTV) and DSTI ratios have gained prominence in addressing vulnerabilities associated with excessive credit to the household sector. These tools have been used in several countries and a range of empirical studies show that they are effective in impacting credit dynamics (Claessens et al., 2014, Kuttner and Shim, 2013, and IMF 2014). More importantly, loan restrictions, such as LTV and DSTI constraints, bolster resilience at the household level by capping borrowing to sustainable levels and reducing the likelihood of default, and can thereby indirectly increase the resilience of lenders.

3. Adopting (or tightening) macroprudential policies is most useful at a juncture that coincides with the build-up of vulnerabilities. Adopting macroprudential policies once risks begin to materialize is not only too late, but may precipitate or deepen the realization of losses. When adopted earlier in the cycle, while risks are still benign, macroprudential policies help to reign in the build-up of vulnerabilities. In this sense, the policy proposal is timely in the case of Romania as credit growth begins to strengthen and while default rates are still low.

4. DSTI caps complement other macroprudential tools as they directly target household vulnerabilities. While sectoral capital tools act on the supply side and promote the resilience of banks, DSTI (and LTV) caps enhance borrowers' resilience to interest rate and income shocks (or exchange rate shocks if borrowing is in FX) so that low DSTI lending is associated with lower default rates. For this reason, many countries are using a combination of both sets of tools. Furthermore, while limits on LTV ratios may become less binding and thus lose effectiveness with the increase of house prices (Kuttner and Shim, 2013), caps on DSTI ratios become more binding when house prices (and mortgage loans) grow faster than households' disposable income. As a result of this built-in automatic stabilizer, DSTI caps can smooth credit even without any time-varying element.

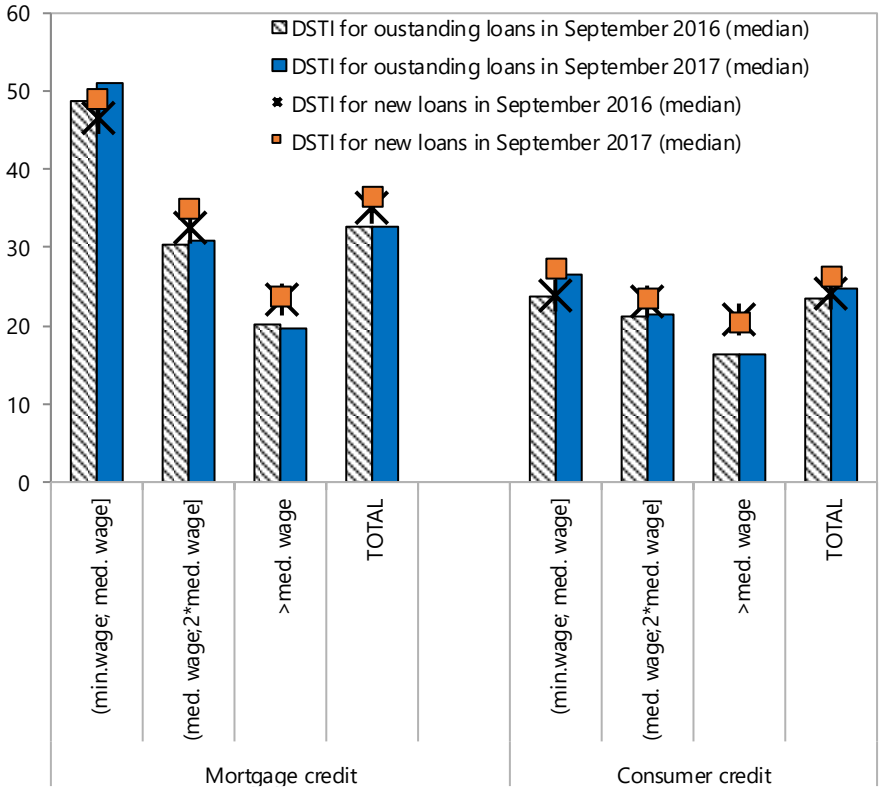
5. Appropriate calibration of macroprudential instruments is central in ensuring their effectiveness. Quantification of macroprudential tools using granular data provides the most analytically sound link between instrument setting and objectives. However, data limitations do not always allow for such an approach. For instance, data coverage may be too short and not include periods of financial distress within a given jurisdiction. In Romania, the existence of a comprehensive household credit register with detailed information on all loans extended by the banking sector to individuals, covering full macroeconomic cycles, provides a unique opportunity to use this information to help calibrate macroprudential tools appropriately.

6. An existing macroprudential instrument in Romania addresses over-indebtedness of households through restricting the maximum DSTI on consumer loans. The NBR Regulation No. 17/2012 stipulates that all consumer loans granted have to be consistent with the maximum level of DSTI ratio for the borrower established in the bank's internal regulations *after* considering an interest rate shock, an FX shock and an income shock of specified sizes. Currently, borrowers with a consumer loans have to be able to withstand: (i) a 35.5 percent depreciation if denominated in EUR, 40.9 percent if in U.S. dollars and 52.6 percent for loans in other FX; (ii) a 0.6 percentage point increase in interest rate; and (iii) a 6 percent reduction in income.

7. The NBR is considering an update to the existing macroprudential tool including expanding its scope to cover all household loans. Since the last calibration of the tool in 2012, household indebtedness has risen significantly and the median DSTI levels for low-income groups of debtors has increased (see Figure 1), giving rise to concerns regarding the sustainability of household indebtedness. Against this background, and in light of evolving macroeconomic conditions, the appropriateness of the size of the shocks specified in the existing stressed DSTI limit needs to be reassessed. Moreover, the existing stressed DSTI limit only applies to consumer loans and the effectiveness of the maximum LTV ratios on mortgages is undermined by the *Prima Casa* program that allows for borrowing with LTVs up to 95 percent. As such there is a need to address vulnerabilities arising from mortgage lending by expanding the scope of the stressed DSTI limit to cover mortgages.

8. This paper proposes a stressed DSTI limit of 50 percent based on the analysis of loan-level data which covers bank lending to households. Using detailed information on more than 220,000 mortgages and 170,000 consumer loans included in the Central Credit Register, the paper analyzes the determinants of default on household loans. The analysis shows that a borrower's probability of default is highly sensitive to any changes in the DSTI ratio when this indicator reaches the 50 percent mark. As such, it recommends calibrating the limit at 50 percent to ensure that a borrower's DSTI remains below this level even after shocks to interest rate, income and exchange rate are taken into account.

Figure 1. Romania: DSTI Distribution of Household Loans*



Sources: NBR, Credit Bureau, and the Ministry of Public Finance.

*The bars for mortgage credit capture DSTI corresponding to all debt associated with the debtor (including consumer loans); The bars for consumer credit show DSTI for borrowers with only consumer loans.

Box 1. The Use of DSTI Limit as a Macroprudential Tool: An International Perspective

A cap on DSTI has been implemented in several jurisdictions:

- The Monetary Authority of **Singapore** introduced, in 2013, a unified standard for calculation of the debt service ratio for property loans granted by financial institutions, the Total Debt Servicing Ratio (TDSR), and set a maximum threshold for that ratio. The TDSR was implemented against a backdrop of rising average loan maturities for housing loans, and uneven policies among banks when computing and evaluating DSTI ratios of mortgage loan applicants. From a macroprudential perspective, rising household debt and strong growth of housing loans were observed in an environment of low interest rates and search for yield. The choice of the instrument took account of existing regulatory requirements. In calculating the TDSR, all outstanding debt obligations are taken into account, including all property- and nonproperty-related loans (CGFS, 2016).

- **Poland** experienced a period of rapid growth in mortgage lending, with banks offering foreign-currency, high-LTV housing loans. This was followed by a surge in consumer lending. As a result, the microprudential regulator implemented a number of prudential measures, including caps on DSTI ratio. Specifically, these entailed a 50 percent cap on DSTI ratio in the case of borrowers with income below the average salary and a 65 percent cap for other borrowers. For FX mortgages, a 42 percent cap on DSTI was introduced. Later, these caps were replaced by banks' internal limits on DSTI. The assessment of the caps introduced in 2010 and 2011 seem to have been effective, particularly in ensuring that the DSTI ratio for highly indebted households (DSTI larger than 50 percent) grew more slowly compared to the entire population (NBP, 2015).

- **Netherlands** implemented a loan-to-income (LTI) ratio that applies to mortgage loans, and stipulates a cap on the percentage of income that households are permitted to spend on interest and repayments. This maximum percentage of financing burden, the income and the level of interest rates determine the maximum amount of mortgage loans that a household is allowed to take. The LTI has effectively become more binding in the recent years, despite the drop-in interest rates, primarily due to the rising burden of taxes and social security contributions.

- In the **United Kingdom** (**U.K.)**, the Financial Policy Committee (FPC) and the Prudential Regulation Authority (PRA) required regulated lenders to place limits on residential mortgage lending, in terms of LTI ratio cap and a stressed DSTI ratio. In particular, banks are limited in the issuance of loans with high loan to income ratios, defined as greater than 4.5. Banks are allowed to have a flow of 15 percent of new loans that do not meet the requirement. In this way, the U.K. is one of the few countries that does not prohibit but only constrains the provision of high DTI credit.

- In the **European Union**, Cyprus, Portugal, Slovakia and Slovenia also have in place DSTI limits related to real estate lending (ESRB, 2017).

POLICY PROPOSAL

9. The existing regulation regarding DSTI applies to consumer loans only. As discussed above, the existing NBR Regulation 17/2012 does not define a pre-set limit but relies on banks' internal limits for maximum DSTI. Furthermore, the shocks for stressing DSTI are only defined for consumer loans, although the regulation considers a borrower's total DSTI ratio, including that arising from mortgage loans.[2] Finally, given the current low interest rate levels the interest rate shock proposed in the current regulation is too small to provide meaningful resilience.

10. The new policy proposal would impose an explicit stressed DSTI limit for all household borrowing. The new proposal aims to expand the NBR Regulation No. 17/2012 in a few dimensions. First, it would specify the maximum level of DSTI applicable to household loans, rather than relying on banks' internal limits. The limit would apply to the stressed level of the DSTI, after imposition of shocks to interest rate, FX and income. Second, the explicit DSTI limit would apply to all household borrowing (mortgage loans, including *Prima Casa* loans and consumer loans). In other words, any new household lending will be limited by the *aggregate* stressed DSTI limit. Third, the shocks applicable to stressed DSTI for consumer loans are recalibrated and new shocks applicable to stressed DSTI for mortgages are introduced.

11. The proposal tightens the shocks for the purposes of calculating stressed DSTI. The stressed DSTI (which will have to be below the DSTI limit) is obtained by subjecting the actual DSTI at origination to an interest rate shock, an income shock, and an exchange rate shock. For consumer loans the FX shocks remain unchanged (35.5 percent for EUR, 40.9 percent for U.S. dollars and 52.6 percent for other FX), the interest rate shock is recalibrated to 2 percentage points (up from 0.6 percentage points under the current regulation) and the income shock is 10 percent (up from 6 percent under the current regulation). For mortgage loans the shocks are identical to those applicable to consumer loans for FX and interest rates; the proposed shock to income is 6 percent.

12. The DSTI limit considers a borrower's total debt-service obligations, including existing loans. Default decisions across debts are not independent. Being delinquent in one type of loan is a strong predictor of delinquency in other loans. In fact, supervisory treatment of NPLs often takes into account "contamination", i.e., a loan is classified as unlikely to be paid if the borrower has defaulted on other loans, even if the loan in question is still performing. For this reason, the DSTI limit regulation will consider a borrower's entire debt obligations for calculation of debt-service. We follow the same approach in our regression analysis. Since borrowers can be identified in the credit register, we construct our DSTI measure taking into account *all* of the borrower's debt obligations and not only that associated with a specific loan.

13. In addition, the proposal includes certain exemptions from the DSTI cap to avoid large efficiency costs. Specifically, it proposes an exemption from the application of the interest rate shock for loans granted with fixed rate for an initial period of at least five years. In addition, in order to smooth the impact on credit provision, it proposes a blanket exemption from the DSTI cap and

[2] While the banks are obliged to establish internal limits for maximum stressed DSTI for both consumer and mortgage loans, the current regulation does not provide specific shock values for mortgage loans.

from stressing the DSTI for 15 percent of the quarterly flow of new loans granted by each bank (the value of a loan subject to exemption cannot exceed the RON equivalent amount of EUR 250,000). The application of such exemptions has become common and is in line with the approach taken in other jurisdictions, namely New Zealand, the U.K., and more recently Portugal. The aim is to reduce efficiency costs associated with imposing a loan cap. For instance, the exemption allows lending to take place in cases where a bank believes there are good reasons to lend to a borrower despite a high DSTI ratio (good collateral, good prospects for income, temporary reduction in income, etc.).

EMPIRICAL ANALYSIS

14. This paper uses debtor-level data to inform the calibration of the new DSTI limit. It does so by using data from the Central Credit Register on a large number of mortgage and unsecured consumer loans to establish a model of PDs based on a number of explanatory variables, including the DSTI level of the borrower (see Section C). The analysis shows that borrowers with DSTI levels close to 50 percent are highly sensitive to changes in their DSTI levels, particularly for mortgage loans. This result implies that even small shocks to the DSTI level are associated with large increases in the PD. As such, the proposal is to set the debtor's DSTI limit at 50 percent for all new borrowing (mortgage or consumer loans).

15. The rest of this section is organized as follows. Section A describes the data. Section B provides an overview of loan and borrower characteristics that are underlying this analysis. Section C and D introduce the baseline PD model and present the results, respectively. Section E translates the proposed shocks to stressed DSTI and what they imply for stressed PDs. Section F presents the augmented regression and argues that 50 percent is an appropriate level for the DSTI limit.

A. Data

16. Data from several databases are used to gather information on loans and debtors at micro level:

- **Most of the data is based on the information in the Central Credit Register,** covering all loans to borrowers with credit or commitments whose cumulated value is equal to or higher than the reporting threshold above RON 20, 000[3] on balance sheet of banks as of June 2016. The same loans are observed in June 2017 to register their performing status 1-year ahead. The Central Credit Register offers a wide variety of information regarding the type of loan. This information includes loan type (consumer secured or unsecured, mortgage regular or *Prima Casa*), currency of denomination, residual maturity, bank and county of residence.

[3] Equivalent of approximately EUR 4,400.

- **The interest rate, used for the computation of debt service, is extracted from the Monetary Balance Sheet.**[4] This is the average interest rate reported by each bank for various classes of loans, differentiated by loan category, maturity and currency. The monthly loan installment is computed using a constant annuity assumption, taking into account a loan's residual maturity and the interest rate.

- **Data on monthly income provided by the Ministry of Public Finance is then used to compute the DSTI ratio.** The latest available data on income are wages reported for the fiscal year of 2016. The debt-service is calculated using information from both Central Credit Register and Credit Bureau (which also covers some loans bellow RON 20,000), in order to ensure an accurate representation of individual indebtedness.

- **The information is consolidated by debtor using the national personal identification number.** The data on credit and income are used to compute the monthly annuity of each loan and then summed up for each debtor to obtain the total monthly debt service. Finally, the DSTI is computed by dividing the total monthly debt service by the monthly income. DSTI values above 300 percent and below 5 percent are winsorized at those respective values.

17. The initial selection covers around 356 thousand mortgage loans and 634 thousand unsecured consumer loans. In order to construct the dataset, we excluded all loans that are: (i) restructured and refinanced; (ii) converted from FX to RON; (iii) flagged "unlikely to pay" under the EBA definition of nonperformance; (iv) with overdue payments more than 90 days, or (v) with residual maturity less than 12 months (as these loans drop off the database in before June 2017). After applying these criteria, we are left with 334,000 mortgage loans and 480,000 unsecured consumer loans.

18. The final step in constructing the database consists of identifying the loans that are still on banks' balance sheets in June 2017. Those loans that have become nonperforming (registering more than 90 days past due for installment payments) are flagged. After merging the two datasets (the June 2016 and June 2017 observations), we are left with 228,000 mortgage loans and 174,000 unsecured consumer loans. The reason for the lower coverage rate in the case of unsecured consumer loans is due to a higher rate of prepayment of performing loans, as well as write-offs of nonperforming loans. 27,000 debtors are common to both databases.

[4] In the Monetary Balance Sheet, each bank reports average interest rate values, separately by maturity class, currency and type of loan, as well as other characteristic. We match these rates with our loan-level characteristics (bank, maturity, currency, type of loan). Therefore, loans of the same type (mortgage or consumer), granted by the same bank, in the same currency and falling into the same maturity class (5 to 10 years for instance), will have the same "average" interest rate, as reported by the respective banks.

B. Loan and Debtor Characteristics

19. Tables 1 and 2 and Figure 2 present summary characteristics of the loans and borrowers in our study.

- The average mortgage loan is around EUR 30,000, while the average amount outstanding for unsecured consumer loans is EUR 6,000.[5]
- Given the interest rate and the maturity differential, monthly installments for unsecured consumer loans are quite close to those for mortgage loans. As expected, interest rates for consumer loans are much higher compared to mortgage loans due to the higher riskiness of unsecured loans.
- Furthermore, due to stricter regulations implemented by the NBR in 2011 and a higher repayment rate of unsecured consumer loans, the share of unsecured consumer loans in foreign currency is close to zero, while foreign currency mortgage loans are mostly vintages issued before the regulation was implemented.
- Approximately 56 percent of mortgage loans are *Prima Case* loans, while 16 percent of debtors with unsecured consumer loans also have a mortgage loan.
- Debtors with mortgage loans are on average younger. Incomes levels are comparable across the two loan types. However, the NPL rate is much higher for unsecured consumer loans compared to mortgage loans.
- The median DSTI for a mortgage borrower is 33 percent, while for the unsecured consumer borrower this level rises to 39 percent (for those borrowers with *only* unsecured consumer loans the median is slightly lower at 38 percent).[6]

Table 1. Romania: Characteristics of a Typical Household Loan
(Median values)

	Mortgage	Unsecured Consumer Credit
Remaining on Balance-Sheet Amount (EUR)	30,559	6,000
Monthly Installment (EUR)	172	151
Interest Rate (percent)	3.6	9.4
Residual Maturity (years)	23.9	4.1

Source: NBR.

[5] These are based on the remaining on-balance sheet amounts of outstanding loans in our sample (at June 2016).

[6] To calculate medians, we considered the aggregate DSTI of a borrower associated with each loan. Thus, there is an overlap between borrowers in the two groups (e.g., roughly 15 percent of borrowers with a consumer loan have a mortgage also and 5 percent have a secured consumer loan).

Table 2. Romania: Characteristics of a Typical Debtor
(Median values)

	Mortgage	Unsecured Consumer Credit
Age	36	43
Income (EUR)	569	557
NPL Rate	0.2%	2.3%

Source: NBR.

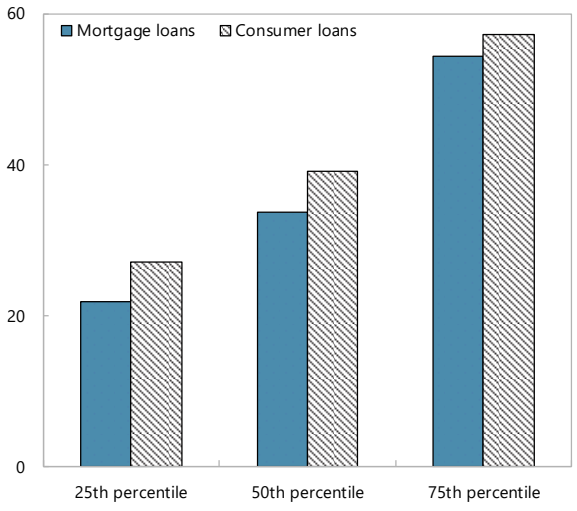
Table 3. Romania: Currency Split of Household Loans
(In percent)

	Mortgage loans	Unsecured Consumer Loans
Euro	50	2
CHF	2	0
RON	48	98

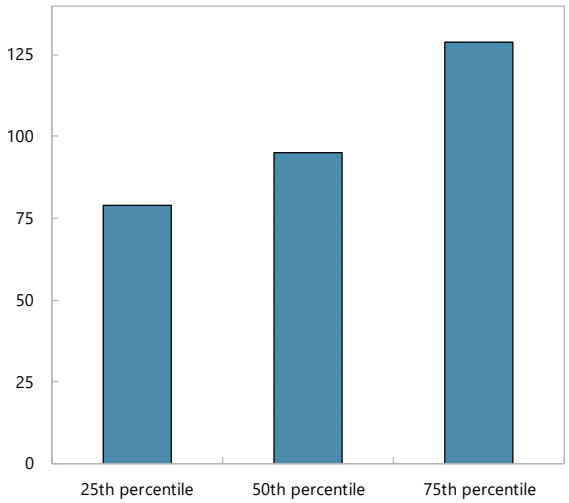
Source: NBR.

Figure 2. Romania: DSTI and LTV Distribution of Household Loans
(in percent)

Distribution of DSTI.



Distribution of LTVs for mortgage loans.



Sources: NBR, Credit Bureau, and the Ministry of Public Finance.

C. Methodology

PD Model Overview[7]

20. In order to predict forward looking PDs, we adopt a two-step methodology, following Costeiu and Neagu (2013). In the first step, the PDs are modeled based on micro (borrower-level) data, with a bottom-up approach (estimated for the June 2016–June 2017 period). The micro-model indicates the likelihood that a borrower defaults on its loan given the borrower characteristics. In the second step, the mean of the PD distribution is forecasted using a forward-looking macroeconomic model, to obtain a forecast for average PDs in Q3 2018. The two models allow us to project the distribution of PDs (based on borrower level characteristics) around a forecasted mean (which depends on the macroeconomic environment). We discuss each of these steps below.

21. The bottom-up PD model is estimated such that the one-year ahead PD is explained by a number of debtor-level characteristics. The framework is based on micro data. As discussed above, debtor characteristics are observed as of June 2016 and the default state of their loans is observed one year later, in June 2017. In order to estimate the PD model, we employ a standard logistic regression where the dependent variable is the state of default and the explanatory variables are chosen from a large set of loan and debtor characteristics. Because mortgage and unsecured consumer loans have substantially different features, we develop two separate PD models for each loan type.

22. A default is defined as a loan which is 90 days or more overdue on its payment, with "1" indicating default and "0" a non-default. The model estimates the probability of default ($\pi(x)$), directly. The logit transformation of probability of default assumes it is a linear function of the regressors:

$$f(x) = \ln\left[\frac{\pi(x)}{1-\pi(x)}\right] \qquad \textit{Equation 1}$$
$$= \beta_0 + \beta_1 * age + \beta_2 * residual\ maturity + \beta_3 * FX\ dummy + \beta_4 * DSTI + \beta_5 * other\ loan\ specific\ variables + \beta_6 * bank\ fixed\ effects + \beta_7 * year\ of\ originiation\ fixed\ effects + \beta_8 * development\ region\ fixed\ effects$$

The conditional distribution of the default state follows a binomial distribution with conditional mean $\pi(x)$. The error term in this case has a mean of zero and variance $[\pi(x)(1-\pi(x))]$.

23. A univariate analysis is employed to choose explanatory variables with high discriminatory power for the dependent variable (Appendix I). This analysis indicated that for both unsecured consumer and mortgage models the following variables were significant: debtor

[7] Our work is closely related to Mihai et al. (2018).

age, loan residual maturity, DSTI and FX *dummy*. For mortgage loans Prima Casa *dummy* is also relevant and for unsecured consumer loans a *dummy* to capture the different behavior of debtors who also had mortgage loan was included. Moreover, we included *dummy* variables for income groups and years of origination, as well as bank fixed effects. When a debtor has loans from multiple banks, we consider the bank with the highest loan as the originating bank.

Macro-Model Overview

24. While the micro-level PD model captures differences in PDs across borrowers well, it is a poor tool for projecting PDs over time. The regression model based on the micro-level data provides information on the cross-sectional distribution of PDs based on borrower-level characteristics. However, it is not the appropriate tool for projecting future (average) PDs. There are several reasons for this. No macroeconomic parameters enter the logistic regression, since it is estimated at a point in time and not based on time-series information. In general, no-time varying explanatory variables for the average PD (the intercept) are captured. In order to overcome these drawbacks, a macroeconomic model is employed in order to adjust the intercept in the logistic regression, based on the macroeconomic environment. Note that this adjustment preserves the variance of the distribution of PDs projected by the micro-model, but the mean of the distribution shifts based on the macroeconomic environment.

25. The macroeconomic model is a one-factor Merton model which links macroeconomic variables to the average sectoral PD (Appendix II). The aggregate household sector's default threshold depends on the macroeconomic environment. The model can be used to forecast the future default rate based on projections of macroeconomic indicators.

26. The macroeconomic model indicates that annual GDP growth and the (annualized) quarterly change in real effective exchange rate (REER) have the greatest explanatory powers. Two macroeconomic models, one for mortgage loans and another for unsecured consumer loans, are developed where the dependent variable is the respective one-year ahead observed default rate for the aggregate household sector[8] and the independent variables include macroeconomic variables such as GDP growth, REER and unemployment rate. The model is estimated based on quarterly data covering the period Q1 2004 through Q3 2017. The one year ahead projection (Q3 2018) are based on the NBR projections for macroeconomic variables. Based on the forecast, we obtain an estimated PD of 2.7 percent for consumer loans and 0.56 percent for mortgage loans for Q3 2018.

27. The PD values obtained with the logistic regression are adjusted to the levels estimated by the macroeconomic model. This follows the approach proposed by King and Zeng (2002). The exact procedure is the following. The intercept of the micro-level PD model is adjusted such that the mean of the estimated PD, $\pi(x)$, converges to π_d:

[8] The aggregate PD is calculated by dividing the numbers of debtors who are nonperforming at time t (but who were performing at t-1), by the total number of performing debtors at t-1.

$$ln\left(\frac{\pi(x)}{1-\pi(x)}\right) = \alpha + X\beta + ln\left(\frac{\frac{\pi_d}{1-\pi_d}}{\frac{p}{1-p}}\right) + \epsilon$$

where π_d is obtained from the macro model and p is the share of defaulted borrowers in the sample.

D. Results

28. The results from the logistic regression indicated that the DSTI, residual maturity and the income bracket are significant variables for both types of loans (Table 4).[9] The following observations are noteworthy:

- DSTI level is statistically significant in both models, supporting the idea that indebtedness is an important component of a borrower's resilience. An increase of 10 percentage points in DSTI raises the PD by 6 percent for mortgage loans and by 3 percent for unsecured consumer loans.

- All else equal, debtors with income below the average wage are 50 percent more likely to default on a housing loan and 100 percent more likely to default on an unsecured consumer loans compared to those with income between the average wage and the double average wage. On the other hand, debtors with income more than twice the average wage have a PD that is 30 percent lower for mortgage loans and 45 percent lower for unsecured consumer loans. Thus, we observe that the income group has a higher impact on unsecured consumer loans compared to mortgage loans.

- All else equal, Prima Casa mortgage loans have a PD that is lower by 80 percent compared to standard housing loans. One possible explanation for this finding relates to the conditions to qualify for a Prima Casa loan, awarded to first-time buyers. There is evidence that first time buyers are less likely to default (see Kelly, et. al). Furthermore, since first-time buyers are often owner-occupiers, the probability of default could also be lower compared to properties purchased for investment purposes.

- For unsecured consumer loans, the PD of debtors who also have a mortgage is 75 percent lower than that posted by debtors with a consumer loan only. While this group has a higher DSTI on average, they tend to be richer compared to the entire sample.

- Increasing the residual maturity by one year leads to a 20 percent increase in the PD of unsecured consumer loans and 4 percent increase for mortgage loans.

- There is evidence that lending standards have tightened over time. Mortgage loans originated before 2007 have a significantly higher PD compared to those originated at 2015, all else being

[9] A table with coefficients on all estimated variables is included in Appendix II.

equal. Lending standards have continued to tighten since 2007 (see Appendix III). Similar results apply to consumer loans.[10]

Table 4. Romania: Marginal Effects for Mortgage and Consumer PD Models*

	Mortgage loans	Unsecured Consumer loans
Age	0.000%	-0.11%***
Residual maturity	0.03%***	0.58%***
DSTI[1]	0.04%***	0.09%***
Below average wage (dummy)	0.28%***	2.06%***
Greater 2x average wage (dummy)	-0.22%***	-1.39%***
FX (dummy)	0.090%	N/A
First Home dummy	-0.88%***	N/A
Other mortgage credit	N/A	-2.28%***
Adjusted R squared	0,21	0,13
Number of observations	228 123	174 475
p-values in parentheses: * p < 0.10, ** p < 0.05, *** p < 0.01		

Sources: NBR, Credit Bureau, and the Ministry of Public Finance.

***** Values represent percentage point changes in PD as a result of a 1-unit change in the explanatory variable

(1) Marginal effect calculated for 10 percentage points change in explanatory variable.

Bank, year of origination and regional fixed effects were estimated, but not reported

29. The regression model captures the cross-sectional variation of the data closely. Figure 3 shows the empirical PD as represented by fraction of borrowers defaulted by income category for mortgage and consumer loans, as of June 2017. For each income category, we have plotted the average PD. It also shows the average of predicted PDs, from the bottom-up model (Equation 1). As the graph shows the model predictions are very close for PDs for all income levels, both for mortgage and consumer loans.

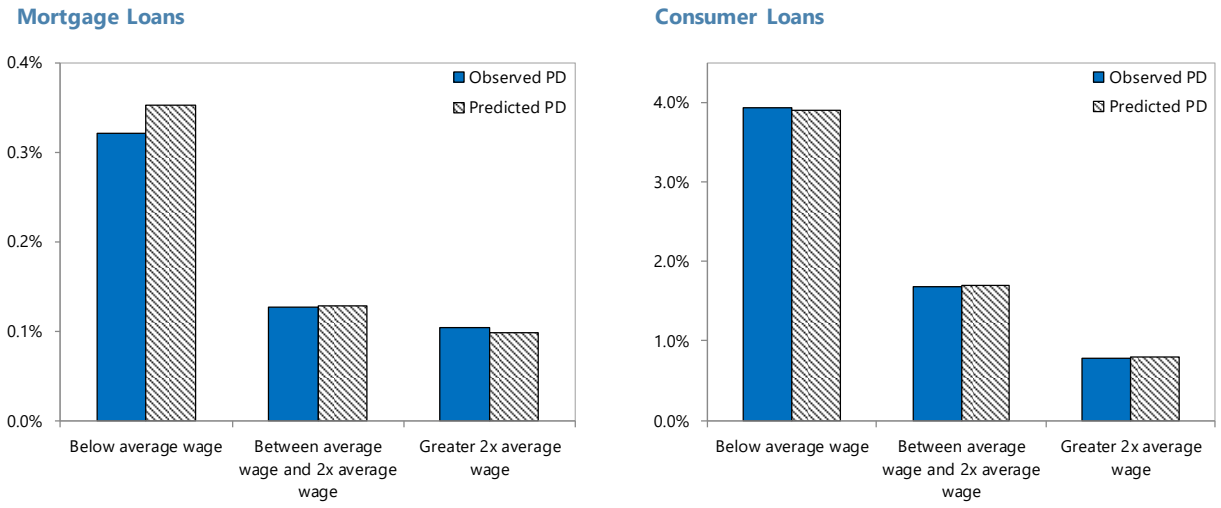
30. Note that given the recent balance sheet clean-up in Romania, the average default rates were relatively low in 2017. The implicit assumption for basing the calibration of the DSTI limit on data from a "good year" is that the cross-sectional relationship between likelihood of default and borrower characteristics remain stable throughout the cycle. In other words, while the average PD would vary throughout the cycle, the coefficients of the bottom-up regression (Equation 1) are independent of the average PD.

31. The macro model suggests that average PDs will increase slightly in Q3 2018 relative to Q3 2017 for mortgage loans. Figure 4 shows the evolution of the average PD for mortgage and consumer loans. The estimated PDs show the macroeconomic model's 1-year ahead projection, which capture the dynamics of aggregate PDs well throughout the cycle. The projections indicate a slight uptick for mortgage PDs while consumer PDs are expected to remain more or less constant.

[10] Consumer loans originated in 2011 have lower likelihood of default as they have a low residual maturity.

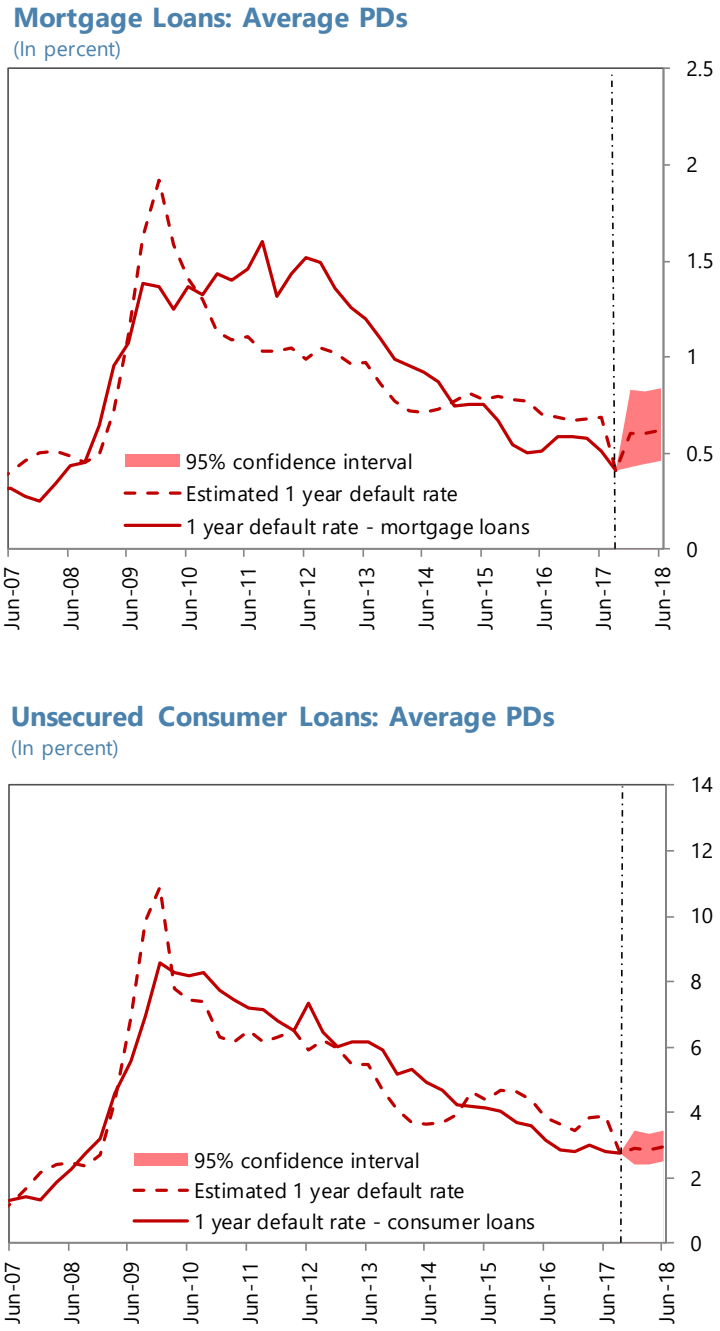
32. Income distribution has an important effect on predicted PDs (Figure 5). The PD values from the baseline model (as of Q3 2018) show that the skewness of the distribution of PDs for borrowers with income greater than double the average wage is significantly more left skewed compared to those with wages below average wage.

Figure 3. Romania: PD of Household Loans: Estimated and Actual



Sources: NBR, Credit Bureau, and the Ministry of Public Finance.

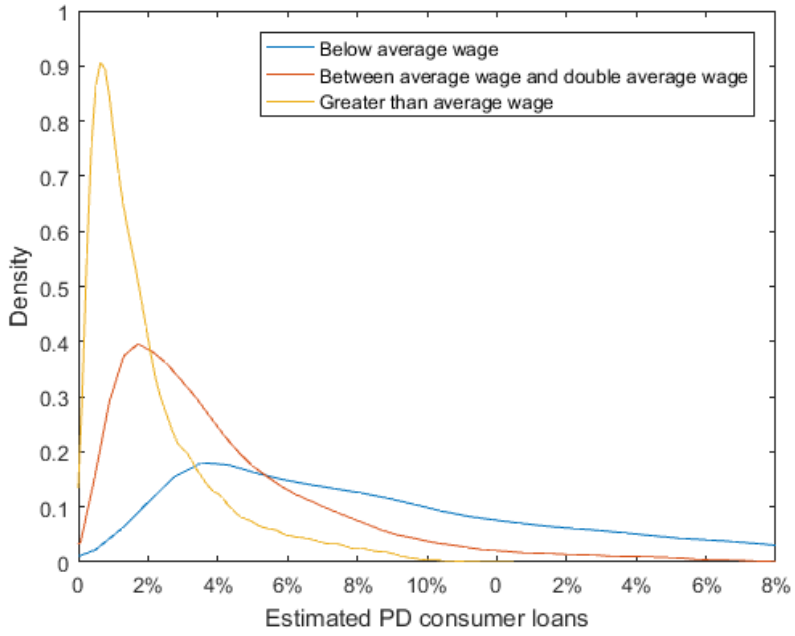
Figure 4. Romania: Evolution of Household Loan PDs: Macro-Model Projections vs. Historical



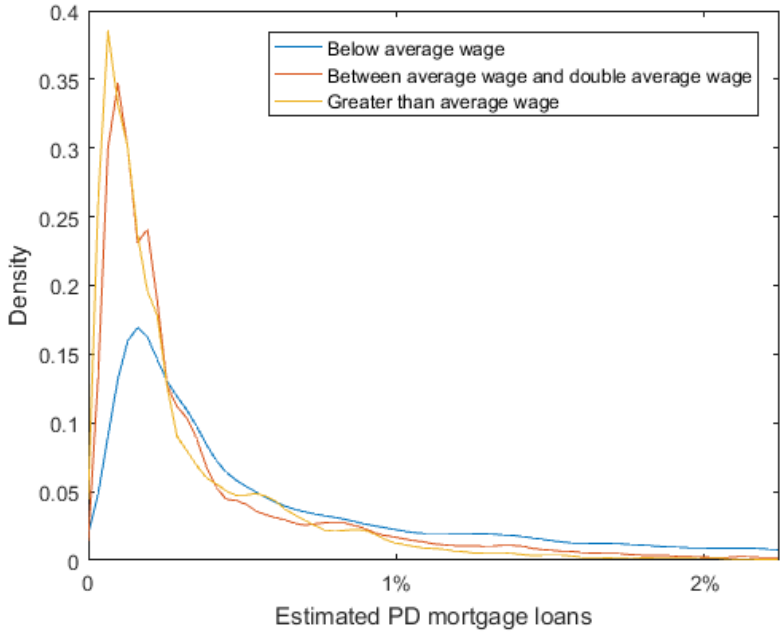
Sources: NBR, Credit Bureau, and the Ministry of Public Finance.

Figure 5. Romania: Distribution of PDs According to Income Group

Estimated PDs for unsecured consumer loans (projected as of Q3 2018), by income group



Estimated PDs for mortgage loans (projected as of Q3 2018), by income group



Sources: NBR, Credit Bureau, and the Ministry of Public Finance.

E. Stressed DSTI and Probability of Default

33. We evaluate the impact of shocks to interest rate, exchange rate and income on PDs through their impact on DSTI, using the regression coefficients obtained above. As discussed above, the policy proposal envisages that the following shocks be incorporated for calculating the stressed DSTI: FX shocks (35.5 percent for EUR, 40.9 percent for U.S. dollars, and 52.6 percent for other FX) for unsecured consumer and mortgage loans; interest rate shock of 2 percentage points for both types of loans and an income shock is 10 percent for consumer loans and 6 percent for mortgages. We apply the proposed shocks[11] and calculate the stressed DSTI as a result. We then use the PD model of the previous section to evaluate the impact on average PDs.

34. The shocks are applied at debtor-level and the DSTI ratios are recalculated according to the following formula:[12]

$$DSTI_{shocked} = f_{d\ shock} \cdot \frac{(1 + shock_{FX})}{(1 - shock_{income})} \cdot \frac{S}{V}$$

where $f_{d\ shock}$ is the annuity factor modified to incorporate the interest rate (IR) shock:

$$f_{d\ shock} = \frac{(r + IR\ shock)}{(1 - (1 + r + IR\ shock)^{-n})}$$

and n is the residual maturity, r is the initial interest rate, S is the credit amount, V is the monthly income and $shock_{FX}$, $shock_{income}$ are the shocks for FX and income shocks.

The new DSTI levels are then incorporated in the PD model to assess how the average estimated default rate changes. The calibration of shocks proposed will have a significant impact on projected PDs as of Q3 2018 compared to the case where DSTI levels are not stressed. Specifically, the analysis suggests:

- For unsecured consumer loans, if debtors are confronted with a 2-percentage point increase in the interest rate, a 35 percent shock to the exchange rate, and a 10 percent decrease in income, then the median DSTI increased by 8 percentage points, implying that average PD increases by 4 percent.
- For mortgage loans, applying the same shocks for interest rate and FX loans and a 6 percent decrease in income, implies that the median DSTI increases by 15 percentage points, translating to a 25 percent increase in average PD. This is due to the higher sensitivity of mortgage loans due to their longer maturities and larger exposures.

[11] For the FX shock, we apply a 35 percent depreciation for all currencies. While the proposal envisages differentiated shocks by currency when a loan is granted, for simplification we applied a 35 percent depreciation for all FX denominated loans, irrespective of the currency. The FX loans are at any rate predominantly denominated in euros (95 percent).

[12] We are interested solely in the impact of debtor-specific shocks on PDs, so we do not introduce shocks in the macroeconomic model used in the calibration.

F. Setting a DSTI Limit

35. In order to calibrate the regulatory limit on DSTI we investigate the sensitivity of probability of default to changes in DSTI. The idea is to identify a level of the DSTI limit that is effective in reducing meaningfully the likelihood of default, without imposing unnecessarily strict constraints on borrowers. Recall that the stressed DSTI of a loan (after incorporation of the shocks on interest rate, income and exchange rate) needs to be below the DSTI limit.

36. We investigate whether PDs are more sensitive to changes in DSTI at higher level of indebtedness. To do so, we add to the baseline model interaction terms between DSTI and a *dummy* variable based on the DSTI interval. In other words, we run the following regression model:

$$f(x) = \ln\left[\frac{\pi(x)}{1-\pi(x)}\right] = \beta_0 + \beta_1 * age + \beta_2 * residual\ maturity + \beta_3 * FX\ dummy$$
$$+\beta_4 * DSTI + \beta_5 * other\ loan\ specific\ variables$$
$$+\beta_6 * bank\ fixed\ effects + \beta_7 * year\ of\ originiation\ fixed\ effects$$
$$+\beta_8 * development\ region\ fixed\ effects$$
$$+\sum_{i=1}^{8} \gamma_i * DSTI * d_i$$

where d_i indicate whether a loan belongs to the i^{th} DSTI bracket.

37. We set DSTI intervals so that there is a fairly even distribution of debtors over the intervals. Specifically, the baseline case are loans with DSTI lower than 20 percent. We include *dummies* for intervals of DSTI up to 30, 40, 50, 60, 70, 100, 200, and greater than 200 percent and evaluate the interactions of these *dummy* variables with the DSTI level. The coefficients γ_i can therefore be interpreted as the *additional* impact of an increase in DSTI for loans belonging to bracket *i* relative to the baseline case (DSTI lower than 20 percent).

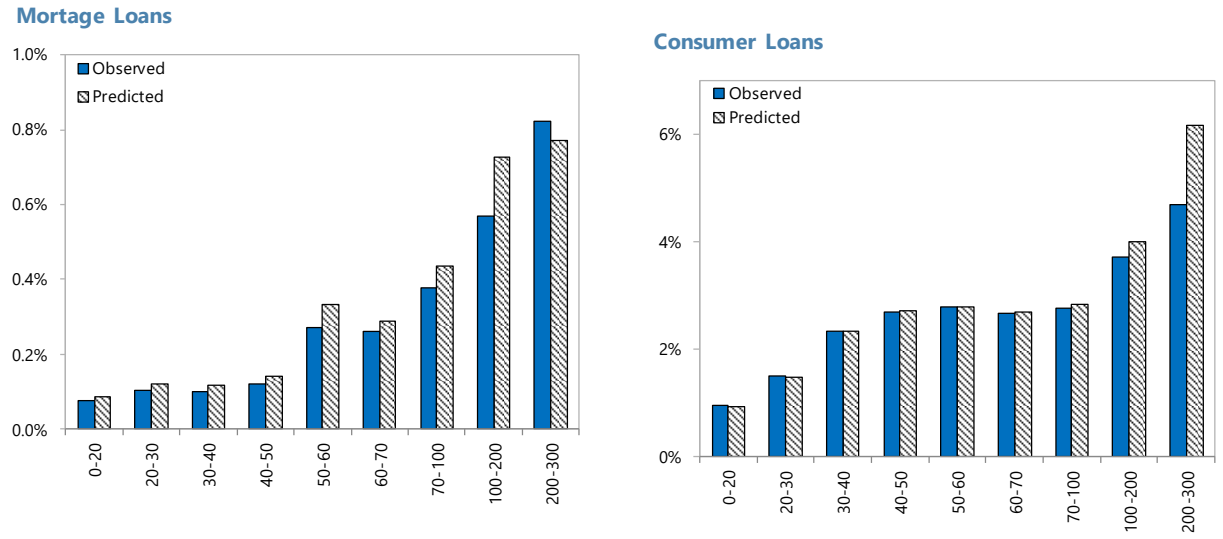
38. The results indicate that there is indeed a degree of non-linearity in the way DSTI impacts debtors' loan performance (Table 5). All interactions terms are statistically significant and the coefficients have economically meaningful magnitudes for both types of loans. Our base group was represented by debtors with a DSTI below 20 percent, therefore the DSTI coefficient is negative and the coefficients associated with the higher DSTI limits are positive, as increasing indebtedness generates more risk. In the case of consumer loans, the coefficients increase significantly above the 30 percent threshold, while for mortgage loans this occurs above the 50 percent threshold.

39. Results indicate that the highest positive impact of a DSTI is registered around the 50 percent threshold, which forms the basis of our recommendation to set the DSTI limit at

50 percent. This result is particularly strong in the case of mortgage loans, while for consumer loans the limit could be set even lower, somewhere between 30 percent and 50 percent.[13]

40. DSTI level is a significant determinant for the PD of a household loan. Figure 6 shows the average default frequencies for mortgage and consumer loans in different DSTI buckets as of June 2017 (solid blue bards). The PD for mortgages increases significantly with DSTI above 50 percent. The increase in PD for consumer loans occurs earlier (close to 30 percent). The model projections for PDs by DSTI group (as of Q2 2017) is very much in line with observed default frequencies.

Figure 6. Romania: PD of Household Loans by DSTI: Estimated and Actual



Sources: NBR, Credit Bureau, and the Ministry of Public Finance.

[13] As explained earlier, the DSTI is calculated taking into account the entire debt-service of a borrower, including other loans.

Table 5. Romania: Coefficients for DSTI Interactions		
	Mortgage Loans	Unsecured Consumer Loans
Age	-0.016***	-0.046***
Residual maturity	0.002***	0.009***
DTI	-0.095***	-0.027***
DTI interaction [20, 30)	0.057***	0.021***
DTI interaction [30, 40)	0.066***	0.031***
DTI interaction [40, 50)	0.074***	0.033***
DTI interaction [50, 60)	0.093***	0.032***
DTI interaction [60, 70)	0.089***	0.03***
DTI interaction [70, 100)	0.096***	0.03***
DTI interaction [100,200)	0.098***	0.031***
DTI interaction [200, max)	0.096***	0.03***
Below average wage (dummy)	0.124	0.675***
Greater 2x average wage (dummy)	-0.393***	-0.559***
FX (dummy)	0.046	-
First Home (dummy)	-1.614***	-
Other mortgage credit (dummy)	-	-1.606***
Adjusted R squared	0.216	0.145
Number of observations	221,957	171,161

Sources: NBR and IMF staff calculations.

Notes: p-values in parentheses: * p < 0.10, ** p < 0.05, *** p < 0.01.
Bank, regional and year of origination fixed effects were estimated, but not reported.

IMPACT ANALYSIS: CONSEQUENCES OF A DSTI LIMIT

41. This section considers the consequences of imposing a DSTI limit on average PDs, NPL ratios and loan volumes. Our counterfactual analyses offer an estimate of long-term benefits of putting in place a macroprudential limit on borrower DSTI as well as its cost in terms of lower credit provision.

42. The micro-level PD model is used to predict PDs for loans with lower DSTI levels (Table 6). We construct a hypothetical portfolio where the debtors with DSTI over a particular threshold would have been limited at the respective maximum value. For instance, for a DSTI limit of 50 percent, all borrowers with a DSTI greater than 50 percent are replaced with borrowers with a DSTI of 50 percent. We then calculate the fitted value of the PD based on the regression model parameters for these borrowers, given their characteristics and their new, lower, DSTI. The average

PD of the portfolio is then projected forward using the macro-model. A comparison between average PD projected for 2018 based on the original portfolio and the hypothetical portfolio with the DSTI limit (Table 6) shows that the resulting differences are significant in relative terms, as the one-year average estimated PD of the mortgage and unsecured consumer loan portfolios decreases by approximately 0.25 percentage points for the case of a maximum DSTI threshold of 50 percent.

Table 6. Romania: Average PD (%) and the Maximum DSTI Limit

DSTI limit	40%	45%	50%	55%	60%
			Mortgage Loans		
W/O DSTI limit			0.72		
W/ DSTI limit	0.46	0.47	0.48	0.48	0.49
			Unsecured Consumer Loans		
W/O DSTI limit			3.14		
W/ DSTI limit	2.82	2.85	2.87	2.89	2.91

Sources: NBR, Credit Bureau, and the Ministry of Public Finance.

43. We further compute the impact of various DSTI thresholds on NPL ratios as of June 2017 (Table 7). Each column shows the counterfactual NPL if a maximum DSTI limit had been introduced since the origination of the current stock of loans. This is the NPL ratio that would have prevailed, had all loans in the sample been restricted to DSTIs indicated by the cap. The analysis is based on two assumptions: (i) the NPL rate for debtors at a DSTI level above the relevant limit remains constant through time (for instance for a 50 percent threshold, the debtors with DSTI over 50 percent are assigned the default rate for borrowers with DSTI between 45 and 50 percent) and (ii) borrowers with DSTI over a certain limit would have been granted loans within the DSTI limit, so the aggregate credit volume is lower.

44. The analysis suggests a large impact on NPL ratios over time. For a DSTI limit of 50 percent, the NPL ratio would have fallen from 2.92 percent to 1.44 percent in the case of mortgage loans, and from 7.76 percent to 3.13 percent for consumer loans. Note that the analysis is conducted on the stock of loans, i.e., assumes that the DSTI limit would have applied to all existing loans. The analysis demonstrates the powerful impact that the DSTI limit can have over time as more and more loans are issued subject to this prudential rule.

45. We also calculate the forward-looking impact on asset quality of introducing a limit on DSTI ratios. The calculation is based on the following assumptions: First, issuance of new loans and amortization will remain at the level observed between September 2016 and September 2017. Second, we assumed existing NPL loans remain on the banks' balance sheet, i.e., no NPL workouts. Third, we assume new flows into NPL are calculated using the 3-year extrapolation of the 1-year PD using a survivorship assumption (see equations below). Finally, we assume the NPL rate is calculated using only loans that are 90 days past due, volumes of loans that are categorized as unlikely to pay will remain constant.

Table 7. Romania: The Impact of Imposing a Maximum DSTI Limit					
DSTI limit	40%	45%	50%	55%	60%
			Mortgage Loans		
NPL ratio: Sept. 2017 (%)*			2.92		
Counterfactual NPL ratio: limit on DSTI (%)	1.01	1.05	1.44	1.50	1.37
			Unsecured Consumer Loans		
NPL ratio: Sept. 2017 (%)*			7.76		
Counterfactual NPL ratio: limit on DSTI (%)	2.64	2.86	3.13	3.38	3.41

Sources: NBR, Credit Bureau, and the Ministry of Public Finance.

Note: The NPL ratio is computed in this case only for debtors for whom we have available information on income. This coverage ratio is 76 percent in the case of mortgage loans and 69 percent in the case of unsecured consumer loans.

46. Specifically, the process is described by the formulas below:

$$NPL\ ratio_t = \frac{NPL_t}{total\ \ loans_t} \qquad \textit{Equation 2}$$

For k = 1 to 3,

$$total\ \ loans_{t,t+k} = total\ loans_t \cdot [(1-rr)^k + (1+rnl)^k - 1] \qquad \textit{Equation 3}$$

Similarly, for k = 1 to 3

$$NPL_{t,t+k} = NPL_t \qquad \textit{Equation 4}$$

$$+(total\ \ loans_t \cdot (1-rr)^k - NPL_t) \cdot (1-(1-PD_{old})^k)$$

$$+total\ \ loans_t \cdot ((1+rnl)^k - 1) \cdot (1-(1-PD_{new})^k)$$

where rr and rnl are the reimbursement rate and the rate of new lending respectively, over a period of 1 year, t is current time, k is the number of years over which we do the analysis (we show the results below for k=3 years), PD_{old} represents the 1 year PD without a change in DSTIs (which is associated with old credit) and PD_{new} represents the 1 year PD after imposing a DSTI limit (which is associated with new credit).[14]

47. The impact of the DSTI limit on NPLs is tangible even after three years. Table 8 presents the results of the analysis above, i.e., the NPL ratio in three years if no DSTI limit is established and the counterfactual NPL levels for different DSTI limits. Note that in contrast to Table 7, the analysis presented in Table 8 assumes that only the new flow of credit is affected by the DSTI limit

[14] More specifically, PD-old is the mean estimated PD from the baseline model, while PD new is the mean PD estimated on the portfolio where all debtors with a DSTI above the threshold are assumed to have the PD associated with the threshold.

(Equations 2–4). This is why the impact is significantly smaller compared to those in Table 7. However, the long-term impact of the DSTI limit can be significantly larger as the exercise in Table 7 demonstrates.

Table 8. Romania: The Impact of Imposing a Maximum DSTI Limit on the Future NPL Ratio

DSTI limit	40%	45%	50%	55%	60%
			Mortgage Loans		
NPL ratio in 3 years (%) No change in policy			4.44		
NPL ratio in 3 years (%) Limit on DSTI	4.13	4.14	4.15	4.16	4.16
			Unsecured Consumer Loans		
NPL ratio in 3 years (%) No change in policy			12.57		
NPL ratio in 3 years (%) Limit on DSTI	12.04	12.09	12.13	12.16	12.19

Sources: NBR, Credit Bureau, and the Ministry of Public Finance.

48. Imposing a DSTI limit would lead to a drop in NPL ratios in the next three years (Table 8). Under the assumption that credit growth remains the same and PD dynamics is governed by the baseline model, our estimate shows that imposing a maximum DSTI limit of 50 percent would mean that the NPL ratio would be smaller by 0.3 percentage points in the case of mortgage loans and by 0.4 percentage points in the case of unsecured consumer loans in three years compared to their level today.

49. The impact of the DSTI limit on loan volumes is estimated to be a reduction of roughly 7 percent (Table 9). A DSTI limit would nevertheless imply a reduction in the flow of new loans. In order to smooth the impact, the proposal of imposing a DSTI limit is accompanied by an exemption: banks would be allowed to grant loans without applying the shocks or being bound by the limit for the DSTI, for up to 15 percent of their previous year's flow of new loans. We calculate the impact on the new flows with and without this exemption. If a DSTI limit of 50 percent is stipulated the annual flow of new loans will drop by 11 percent. If the 15 percent exemption is included, the reduction will be of only 7 percent. Note that we have assumed the adjustment would take place at the intensive margin, i.e., loans would be extended only up to the maximum DSTI limit.

Table 9. Romania: Decline in Annual Flow of New Loans if a Maximum DSTI Limit Imposed
(In percent)

DSTI limit	40%	45%	50%	55%	60%
	Adjustment of New Total Loans				
w/o 15 percent exemption	17	13	11	9	7
w/ 15 percent exemption	12	9	7	5	4
	Adjustment of New Mortgage Loans				
w/o 15 percent exemption	18	15	12	9	8
w/ 15 percent exemption	14	11	8	6	4
	Adjustment of new Unsecured Consumer loans				
w/o 15 percent exemption	15	12	10	9	7
w/ 15 percent exemption	10	8	6	4	3

Sources: NBR, Credit Bureau, and the Ministry of Public Finance.

CONCLUSIONS

50. The aggregate DSTI of a debtor is an important determinant of its probability of default. Observed default frequencies by DSTI bracket as well estimated sensitivities of PDs to DSTI levels show that DSTI ratio is an important determining factor in the ability of a debtor to service their debt. As such, macroprudential limits on maximum DSTI ratio for households can be a potent tool for limiting household vulnerabilities and ensuring sound lending practices.

51. A macroprudential limit on DSTI ratio should incorporate plausible income shocks as income levels are also an important determinant of default likelihood. Data shows that borrowers with income levels above the average wage are significantly less likely to default on their loans. Therefore, the DSTI limit proposed is calibrated such that a borrower can continue to service its debt even after having faced a (reasonably calibrated) negative income shock. The same principle is true for exchange rate (in the case of FX denominated loans) and interest rates shocks.

52. The macroprudential limit on DSTI is expected to contribute significantly to lower household NPLs in the long-run. Counterfactual analysis shows that had the proposed DSTI limit been applied to all current loans, household NPL ratios would have been roughly a half of their current levels. These figures point to the potency of the DSTI limit in the long-run to limit household vulnerabilities.

53. At the same time, application of the new DSTI limit to the flow of new credit ensures that the cost in terms of reduced credit will be limited. The proposed DSTI limit would only apply to the flow of new loans. The proposal also envisages that up to 15 percent of (previous year's flow of) new credit for each bank would be exempt from the DSTI limit. As a result, the analysis suggests that credit to households would be lower by a modest 7–11 percent compared to a scenario without a limit on DSTI ratio for the aggregate household debt.

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Appendix I. PD Model: Choice of Explanatory Variables

The choice of explanatory variables was motivated by the results of a univariate analysis which looked into the ability of each variable to discriminate between good and bad debtors. We ran a series of tests to evaluate if the characteristics of defaulters and non-defaulters are drawn from significantly different continuous distributions (we used the Kolmogorov-Smirnov test) and if the log odds of the default flag are monotonically and linearly related to a particular covariate. Moreover, we were interested in the discriminatory power of each single variable, so we ran separate univariate logistic regressions and excluded variables with a ROC of less than 50 percent. The set of variables which passed these preliminary evaluations were further tested for multicolinearity and only the covariates with a correlation of less than 75 percent were kept in the final model specifications.

To estimate the logistic regression, we run a multivariate backward selection logistic model and use a bootstrapping exercise with 100 iterations. For each bootstrapping simulation, we sample 20 percent defaulting debtors and 80 percent non-defaulting debtors from the dataset. Because we have a low number of defaults, we decide to use all the nonperforming debtors and sample the performing debtors proportionally.

Appendix II. Macroeconomic Model

The macroeconomic model for projection of aggregate PDs is a one-factor Merton type model with a default barrier depending on the macroeconomic environment. The model assumes a homogenous portfolio of agents in the economy. A random process with a standard normal distribution is assumed for the standardized logarithmic return on assets of an agent. The discrete normal logarithmic return satisfies the following equation for each firm in the economy:

$$R_{it} = \sqrt{\rho}F_t + \sqrt{1-\rho}U_{it} \qquad \textit{Equation 5}$$

where R_{it} denotes the logarithmic asset return for economic agent i in the economy at time t; F_t stands for the logarithmic asset return of the economy at time t, which is assumed to be a random variable with a standard normal distribution; U_{it} represents the agent-specific asset return, which is assumed to be random with a standard normal distribution; The coefficient ρ expresses the correlation between the returns on assets of any two debtors. The variable F_t represents the part of the asset return which is not specific to the economic agent and could be attributed to the general macroeconomic conditions. F_t and U_{it} are assumed to be uncorrelated.

In order to model aggregate credit risk by incorporating different macroeconomic indicators, we assume that the value of the default threshold *T* depends on the state of the economy. This is modeled by using a linear combination of macroeconomic variables (x_{it}) to represent the value of the default threshold *T*. The final representation of the macroeconomic, one-factor credit risk model used in this model is as follows:

$$p_{it} = P(R_{it} < T) = P\left(\sqrt{\rho}F_t + \sqrt{1-\rho}U_{it} < \beta_0 + \sum_{j=1}^{N}\beta_j x_{jt}\right) = \varphi\left(\beta_0 + \sum_{j=1}^{N}\beta_j x_{jt}\right)$$

where φ denotes the cumulative distribution function of the standard normal distribution that represents the impact of a change in the macroeconomic indicators, β_0 is a constant and β_j are the coefficients of the macroeconomic variables x_{jt}.

Assuming a homogeneous portfolio of agents in the economy whose asset returns follow process (Equation 5), the default rate in the economy will converge based on the law of large numbers to a sectoral default probability p_t specified as below:

$$p_t = \varphi\left(\beta_0 + \sum_{j=1}^{N}\beta_j x_{jt}\right)$$

Appendix III. PD Model: Full Table of Results

Mortgage Loans

	Coefficient	t stat
Intercept	-2.545	-8.46
Age	0.004	0.72
Residual maturity	0.004	7.00
DSTI	0.006	10.20
Below average wage (dummy)	0.434	5.09
Greater 2x average wage (dummy)	-0.369	-4.24
FX (dummy)	0.151	1.41
First Home dummy	-1.588	-17.51
Originated before 2007	1.248	7.01
Originated 2007	0.910	5.45
Originated 2008	1.348	8.78
Originated 2009	0.643	3.57
Originated 2010	0.674	3.68
Originated 2011	0.446	2.76
Originated 2012	0.126	0.87
Originated 2013	0.321	2.24
Originated 2014	0.103	0.78
Bank dummy 2	-0.530	-5.33
Bank dummy 3	-1.258	-8.32
Bank dummy 4	-1.057	-6.86
Bank dummy 5	-0.324	-2.52
Bank dummy 6	-0.909	-6.06
Bank dummy 7	-0.626	-4.25
Bank dummy 8	-1.136	-6.89
Bank dummy 9	-0.168	-0.81
Bank dummy 10	0.418	1.98
Bank dummy 0	-0.237	-1.59
Regional dummy 2	-0.305	-2.52
Regional dummy 3	-0.300	-2.40
Regional dummy 4	-0.237	-2.29
Regional dummy 5	0.106	0.93
Regional dummy 6	0.096	0.79
Regional dummy 7	0.178	1.28
Regional dummy 8	0.240	1.90

Source: NBR and IMF staff calculations.

Consumer Loans

	Coefficient	t stat
Intercept	-0.726	-8.55
Age	-0.041	-50.44
Residual maturity	0.017	12.71
DSTI	0.003	14.57
Below average wage (dummy)	0.769	33.59
Greater 2x average wage (dummy)	-0.651	-23.52
Other mortgage credit	-1.431	-42.20
Originated before 2011	0.045	0.74
Originated 2011	-0.527	-8.32
Originated 2012	0.544	4.91
Originated 2013	0.353	5.20
Originated 2014	0.059	1.49
Bank dummy 2	0.165	6.00
Bank dummy 3	-0.188	-5.70
Bank dummy 4	0.736	21.93
Bank dummy 5	-0.782	-22.76
Bank dummy 6	0.538	8.89
Bank dummy 7	-0.324	-5.64
Bank dummy 8	-1.269	-13.97
Bank dummy 9	0.375	5.04
Bank dummy 10	0.715	10.57
Bank dummy 0	0.044	0.95
Regional dummy 2	-0.335	-10.86
Regional dummy 3	-0.614	-16.84
Regional dummy 4	-0.302	-10.63
Regional dummy 5	-0.249	-8.59
Regional dummy 6	-0.320	-9.74
Regional dummy 7	-0.507	-11.98
Regional dummy 8	-0.165	-4.04

Source: NBR and IMF staff calculations.