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BORROWER BASED MEASURES ANALYSIS VIA A NEW AGENT BASED MODEL OF THE ITALIAN REAL ESTATE SECTOR

by Gennaro Catapano*

Abstract

This paper presents a new agent-based model (ABM) of the real estate and credit sectors. The main purpose of the model is the study of the effects of the introduction of a borrower-based macroprudential policy on the banking system, the households, and the real estate market. The paper describes a comprehensive set of simulated policy experiments that study the effects of the introduction of different loan-to-value (LTV) caps on newly issued mortgages. The analysis sheds light on the role played by the degree of heterogeneity in household indebtedness tolerance and its mean level. Moreover, it studies the impact of the phase-in period length and of the timing of the introduction of such measure. While generally effective at reducing credit risk and curbing both house prices and household indebtedness growth, these measures may also have transitory negative side effects on banks' balance sheets and real estate markets. The results suggest the scenarios, calibration, and timing under which the introduction of an LTV cap might have the most favorable set of outcomes.

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Contents

1 Introduction*

This paper presents a new agent-based model (ABM) of the real estate and credit sectors. The model is discrete-time dynamic and simulates a large number of households and a banking sector that intermediates real estate financing. This allows for a comprehensive treatment of the agents' heterogeneity. The main purpose of the model is to study the effects of the introduction of borrower-based macroprudential measures.

This model is an extension of the one presented in Catapano et al., 2021, which, in turn, was derived from the model developed by the Bank of England and the researchers at the Oxford University and published in Baptista et al., 2016.[1] This article is part of a recent stream of literature that is sustained by the effort of several researchers working in central banks (Baptista et al., 2016, Cokayne, 2019, Laliotis et al., 2019, Borsos et al., 2021, Catapano et al., 2021).

Compared to Catapano et al., 2021, and more in general to the related literature, the present work introduces several extensions and refinements. Some concern the households sector, among which: a more flexible and realistic idiosyncratic income shock and consumption function; the introduction of heterogeneous preferences on indebtedness tolerance, and on the preferred house-quality level. Others pertain to the banking system, such as: the introduction of a mortgage status (*performing*, *past-due*, and *non-performing*); a more realistic treatment of defaults and foreclosures; the introduction of some indirect measures of profitability.[2] Finally, a number of technical refinements allow for a finer calibration at a lower computational cost.

In order to study the behavior of the model, three sets of experiments have been performed concerning the introduction of a loan-to-value (LTV) cap on newly issued mortgages. A wide range of LTV cap levels has been tested, from the very mild 90% to the very severe 50%. Each set of experiments analyses the interaction between an aspect of the households' preferences on indebtedness tolerance and a particular characteristic of the policy intervention. These households' exogenous preferences are expressed in terms of individual upper limits to the mortgage LTV and *loan-service-to-income* (LSTI) that

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[1] An earlier version of the model can be found in Axtell et al., 2014.

[2] In particular, the return on mortgages (grouped by status), and the stock of the NPLs. These measures complement the flow of credit which was already present in Catapano et al., 2021.

are deemed tolerable in order to buy a residential property. They effectively determine the *steady-state* mortgage LTV and LSTI distributions.[3] The first set of experiments (section 4.3) studies the interaction between the degree of dispersion of these preferences (hence, their heterogeneity) among the households population and the level of the LTV cap being introduced. The second set (section 4.3) focuses on the interaction between the mean level of these preferences and the level of the LTV cap. Finally, the last set of experiments (4.4) analyses the interaction between the mean level of the preferences on indebtedness tolerance and the timing and phasing-in length of the introduction of the LTV caps.

The baseline experimental setting is calibrated on some empirical variables of the Italian housing markets (e.g. the rate of new defaults on mortgages or the number of transactions per month) and the many alternative scenarios depart from it in one or more directions.[4]

The results show that the effects of the introduction of an LTV cap are in line with the economic intuition. In general, the introduction of the LTV caps on newly issued mortgages tends to reduce the loan riskiness (favoring a reduction in the NPL stock and an increase in their recovery rate, potentially causing an increase in the bank's overall profitability) and household indebtedness. It also tends to reduce the price and, temporarily, the liquidity of residential properties while making it harder for some households to afford a house via mortgage financing.

More specifically, the numerous experiments described in this paper suggest that the magnitude and duration of each of the effects (both on banks and households) and the possible presence of transitory dynamics (for example on housing liquidity) are context-depended. In particular, the experiments highlighted the main factors driving the results: the severity of the cap in relation to the prevailing mean LTV and LSTI (section 4.3); the dispersion in households' subjective indebtedness tolerance (section 4.2); the presence of an upward trend in household indebtedness (sections 4.3 and 4.4); the length of the phase-in period and timing of introduction (section 4.4).

The results show that particularly favorable consequences materialize when a relatively moderate LTV cap (from 90 to 70%) is introduced gradually (in the experiments using a 6-years phase-in period) in a scenario characterized by relatively high and growing

[3] In particular, the higher the heterogeneity (in the indebtedness tolerance) the more, *ceteris paribus*, disperse the mortgage LTV and LSTI distributions are.

[4] For example: higher mean and upward trend in LTV-LSTI for experiment sets "2" and "3".

household indebtedness (from a mean LTV of 70%). In this context, the macroprudential policy intervention effectively curbs the accumulation of risks (reducing the flow of new defaults) and the rise in house prices while minimizing the negative and transient effects of real estate liquidity and the NPL stock. Moreover, the experiments indicate that the best approach could be the preemptive introduction of a moderate LTV cap at the onset of an upward trend in prevailing LTV and LSTI (section 4.4). In this latter case, the policy intervention would prevent the build-up of risks and excessive indebtedness while having little or no impact on the real estate market in terms of liquidity or prices.

The article is organized as follows: the second section details the aim and scope of the present work; the third section describes the model, with a particular emphasis on the extensions introduced; the fourth section describes the general experimental setting; the fifth presents and comments the experimental results; finally the sixth section offers the concluding remarks.

2 The model

This section describes the model and it is articulated in three parts. The first one offers a high-level overview of the model's components and a description of their main interactions. In particular, the first subsection focuses on the logical macro-structures that are common to both the new model and its predecessor. The second subsection contains a detailed account of the structure of the model. There, a particular emphasis is placed on the differences with and the extensions of the model presented in Catapano et al., 2021, of which the one presented here is a direct evolution. In the final part, there's a description of the specific set of simplifications used to perform the experiments proposed in this article.

2.1 Model overview

The model describes a critical portion of an economy: the real estate (both rental and property) markets along with the sources of real estate financing (both banking and household income and wealth). It is a discrete-time model with four classes of agents: (i) households; (ii) a construction sector; (iii) a bank; (iv) a central bank/macroprudential authority. There are four asset classes: (i) currency; (ii) checking accounts; (iii) government bonds; (iv) houses. Houses can be rented and their property is exchanged on two double-auction markets. Finally, the rules of interaction among agents and the environment (markets, assets...) complete the model. Figure 1 shows a schematic of the macro-components of the model and of their interactions.

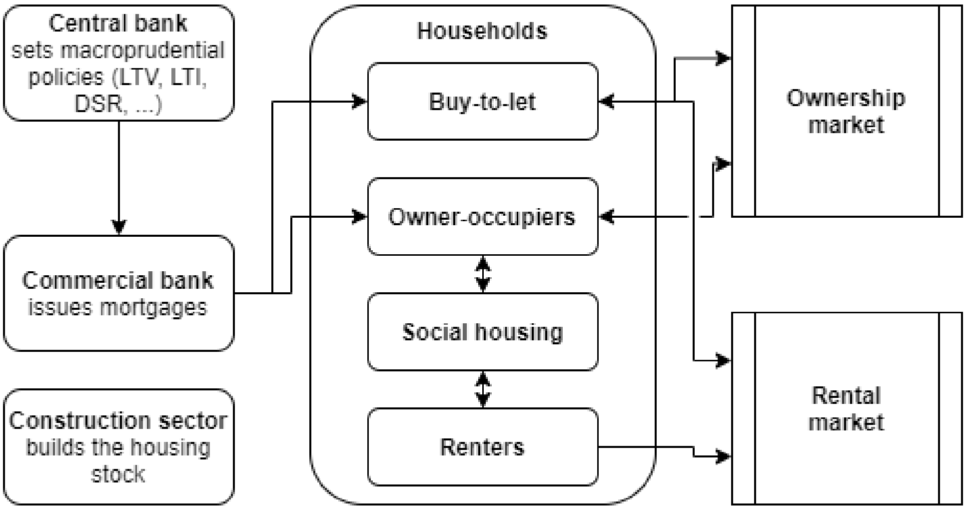

Fig. 1. Model components and their interactions.

The following is a more detailed description of the main characteristics of the model and of the modeling approach:

1. **Modeling approach**:
   (a) **Agent-based and simulation-based approaches**: the model design follows the agent-based approach. Moreover, since the model is analytically intractable, due to its complexity, the analysis is performed using Monte Carlo computer simulations.
   (b) **Dynamic, discrete-time**: the model is fully dynamic and has a discrete-time structure. The simulated time-step intends to represent a one-month length.
   (c) **Emergent market-dynamics**: the (potentially) stationary dynamics of (some of) the endogenous variables (e.g. house prices) are not the result of the imposition of an equilibrium condition (as e.g. in a Walrasian equilibrium). Instead, the micro-interactions among agents lead to the emergence of the aggregate (and possibly stationary) dynamics.

(d) **Bounded rationality, behavioral rules**: there's no assumption of perfectly optimizing behavior, nor of rational expectations. The agents (all classes, including the banks) behave according to behavioral rules (which will be described in detail in the following sections).

(e) **Emphasis on agents' heterogeneity**: as a large cohort of heterogeneous households (along with heterogeneous mortgage and rental contracts) is simulated, the emphasis of the analysis lies on the distributional characteristics of the cross-section.

2. **Economic sectors modeled**:

(a) **Households**: the model individually simulates a large set of heterogeneous households. Each household receives a dynamic, stochastic labor income that is taken from a parametric distribution (of exogenous income processes). The income is then consumed for both housing and non-housing-related expenses. Crucially households take housing decisions (e.g. setting a house-purchase budget).

(b) **Mortgage and banking sectors**: the banking sector offers interest-bearing checking accounts and credit for the purchase of residential properties. In particular, it is available a fixed-rate, fixed-length mortgage. This credit supply has to comply with the macroprudential regulation set forth by the macroprudential authority.

(c) **Real estate construction sector and housing stock**: a stylized construction sector builds a one-dimensionally-heterogeneous housing stock. After a transient phase, the housing stock is completely owned by households.

(d) **Real estate property and rental markets**: the supply and demand sides for the ownership of residential properties and for rental agreements meet and match on two double-auction markets.

(e) **Central bank/macroprudential authority**: a central bank/macroprudential authority sets the overarching limits for the credit supplied by the banking sector. In particular, the authority sets the base interest rate in the economy and may impose borrower-based macroprudential limits on mortgage supply.

3. **Model parameters**: The model uses a large quantity of input data, some pertain to exogenous variables and some others to behavioral parameters. Here we only highlight the broad categories and defer a detailed exposition to the appendix.

(a) **Exogenous variables**

i. Household income and wealth (cross-section and time-series).

ii. Mortgage and government bonds interest rates (time-series).
iii. Housing stock data: value distribution, quality distribution. This particular data is used as an initial condition; afterwards, the house prices are endogenously determined.

(b) **Behavior parameters**

i. Parameters that influence housing-related decisions made by households (e.g. the average time a household lives in the same dwelling or the average asking price reduction for an unsold property on the market).
ii. Households' idiosyncratic risk tolerance: a (cross-sectional) distribution of subjective LTV, LSTI, LTI limits to mortgage indebtedness.

4. **Model capabilities**:

(a) **Endogenous real-estate variables**: the model endogenously generates a set of time series (one series for each house-quality level) for house prices, the number of transactions per time-step (one month), and the average time necessary to sell a property.

(b) **Endogenous real-estate financing variables**: the model endogenously generates a set of data regarding house-purchase financing. In particular, the distributions of LTV, LSTI, and LTI are tracked over time. Moreover, the output includes time series for interest rate, the flow of defaults, loan stage classification (performing, past-due, non-performing), and some indirect profitability measures.

(c) **Macroprudential analysis**: the aim of the model is to assess the effects of the introduction or modification of a (or a set of) borrower-based macroprudential policy on residential real-estate markets conditions (e.g. liquidity, valuations), households' accessibility of home-ownership and credit risk.

2.2 Model structure

Household cross-sectional income dynamics

As in Catapano et al. 2021, the household labor income (stochastic) processes are exogenous. Since in this model the overall labor income structure is substantially different from the one used by its predecessor, this subsection describes it in detail. Given N, the number of households, and T, the number of time steps, the model uses an exogenous matrix of random variables Υ as an input:

$$\Upsilon = \begin{bmatrix} \upsilon_{00} & \dots & \upsilon_{0T} \\ \vdots & \ddots & \vdots \\ \upsilon_{j0} \dots & \upsilon_{jt} & \dots \upsilon_{jT} \\ \vdots & \ddots & \vdots \\ \upsilon_{N0} & \dots & \upsilon_{NT} \end{bmatrix},$$

where $\upsilon_j t$ represents a labor income level, indexed by the cross-sectional unit j and the time period t. Obviously, Υ can also be represented as a sequence of cross-sectional vectors:

$$\Upsilon = \left[\Upsilon_0, \dots \Upsilon_t, \dots \Upsilon_T\right] = \left[\begin{bmatrix} \upsilon_{00} \\ \vdots \\ \upsilon_{j0} \\ \vdots \\ \upsilon_{N0} \end{bmatrix}, \dots \begin{bmatrix} \upsilon_{0t} \\ \vdots \\ \upsilon_{jt} \\ \vdots \\ \upsilon_{Nt} \end{bmatrix}, \dots \begin{bmatrix} \upsilon_{0T} \\ \vdots \\ \upsilon_{jT} \\ \vdots \\ \upsilon_{NT} \end{bmatrix}\right],$$

hence, Υ_t represents the labor income distribution at time t. The model does not require to impose any restriction on the matrix Υ (for example $\Upsilon_t = \Upsilon_{\neq t}$ or follow a more complex sequence of interrelated vectors). The quantile κ_{jt} of the Υ_t cross-section is computed for each income level υ_{jt}.

At time $t = 0$, the income levels in Υ_0 are randomly assigned to the households. Once a particular income level υ_{j0} has been assigned to household i, the household labor income y_{it} follows the corresponding temporal trajectory $Y_i = \{y_{i0} = \upsilon_{j0}, y_{i1} = \upsilon_{j1}, y_{i2} = \upsilon_{j2}, ..., y_{iT} = \upsilon_{jT}\}$. The model allows for the presence of an idiosyncratic labor income shock that alters the income trajectory Y_i (by changing the associated income levels υ_{jt}) while keeping the overall time-t labor income distribution Υ_t unchanged. The income shock has the following structure:

1. Each income quantile κ has an associated random variable X_κ with the following probability distribution:

$$
\begin{aligned}
P(X_\kappa = -2) &= p_{\kappa,-2},\\
P(X_\kappa = -1) &= p_{\kappa,-1},\\
P(X_\kappa = \ \ 0) &= p_{\kappa,0},\\
P(X_\kappa = \ \ 1) &= p_{\kappa,+1},\\
P(X_\kappa = \ \ 2) &= p_{\kappa,+2},
\end{aligned}
$$

where $p_{\kappa,x}$ denotes the probability that a household with a labor income level associated with quantile κ might switch to an income level associated with x quantiles above or below it (e.g. $p_{\kappa,-2}$ is the probability that an income associated to quantile κ might get switched to one associated to two quantiles below it).

2. At each time period $\hat{t}$, an household i^+ is randomly selected. A realization x_{κ^+} is drawn from X_{κ^+}, where κ^+ is the household's labor income quantile. If $x_{\kappa^+} = 0$, household i^+ income trajectory Y_{i^+}, remains unchanged. Otherwise, another household, household $i^\star$ is randomly selected among those with a labor income within quantile $\kappa^\star = \kappa^+ + x_{\kappa^+}$. Households i^+ and $i^\star$ exchange their labor income trajectories (Y_{i^+} and $Y_{i^\star}$) for any $t > \hat{t}$.
3. This procedure is repeated at each time-step $\hat{t}$, in a sequential fashion, for $N/2$ households.

These cross-sectional income dynamics allow keeping the Υ_t distributions of income unchanged (and without any need to impose any structure on Υ) while admitting a dynamic stochastic labor income trajectory of individual households.

Households consumption

As in the previous iteration of the model (in Catapano et al., 2021), households aim to maintain a (-n individual and exogenous) target bank balance. The model presented here introduces a new source of monthly expenditure, namely: the necessary consumption. The total monthly non-housing related household consumption is determined by the following expression:

$$
C_{it} = \begin{cases} B_{it}, & \text{if } B_{it} \leq C_N, \\ C_N, & \text{if } C_N \leq B_{it} \leq B_i^{\star}, \\ C_N + B_{it} - B_i^{\star}, & \text{otherwise,} \end{cases} \tag{1}
$$

where, as elsewhere, i and t identify the household and the time period, C is the non-housing-related consumption, B is the household's available bank balance, C_N is the level of necessary consumption, $B_i^{\star}$ is the household's target bank balance. Figure 2 offers a graphical representation of this consumption function. Two important consequences stem from the adoption of equation 1: the household strives, period by period, to achieve its desired, exogenous target bank balance $B_i^{\star}$ (as in Catapano et al., 2021) by consuming more when it has "excess cash" ($B_{it} - B_i^{\star} > 0$); the household tries to consume the full quantity C_E even when its bank balance is lower than its target cash holdings ($B_{it} - B_i^{\star} < 0$).

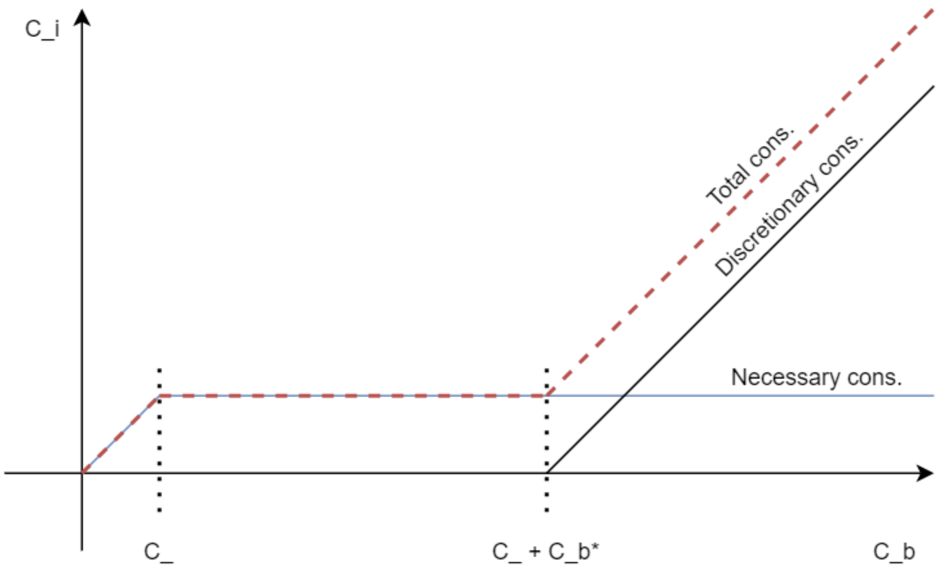

Fig. 2. Household non-housing-related consumption expenditure.

Households demographics

As the model simulates mortgage financing, which typically spans several years, demographic considerations may significantly affect the dynamics of the endogenous variables of interest. As an example, a slowly declining population, over the course of several years, may alter the balance between the demanded and offered housing stocks. Hence, in the model has been included a demographics module that accepts an exogenous expected trajectory for households' birth and death.

Households' indebtedness preferences

Each household, in regards to residential property financing, is endowed with an individual maximum tolerance for indebtedness. In particular, LTV_i and $LSTI_i$ are the household-i mortgage LTV and LSTI individual limits. These limits play an important role in the household's housing-related decisions. Figure 3 offers a high-level depiction of the entire set of decisions and actions involved in a house purchase. In one of the preliminary steps in the process that can lead to a house purchase, the household sets a house-purchase budget P_{it}. This is the maximum cost the household is willing to sustain in order to purchase a residential property. P_{it} is determined by the following expression:

$$P_{it} = Min\{P_{LTV_{it}}, P_{LSTI_{it}}, P_{LTI_{it}}\}, \tag{2a}$$

$$with: \tag{2b}$$

$$P_{LTV_{it}} = B_{it} \cdot \frac{1}{1 - LTV_i}, \tag{2c}$$

$$P_{LSTI_{it}} = LSTI_{it} \cdot \frac{Y_{it}}{f} + B_{it}, \tag{2d}$$

$$P_{LTI_{it}} = Y_{it} \cdot LTI_{it} + B_{it}, \tag{2e}$$

where B_{it} and Y_{it} are the household's cash holdings and income respectively, f is the mortgage repayment factor defined in equation 5d below. Here $P_{LTV_{it}}$, $P_{LSTI_{it}}$ and $P_{LTI_{it}}$ represent the maximum budgets the household is willing to set given its LTV, LSTI, LTI individual limits.

Notice that this is a subjective budgeting decision made by the household. The household must then apply for a mortgage, whose principal may be lower than what is necessary to reach the full P_{it} subjective budget.

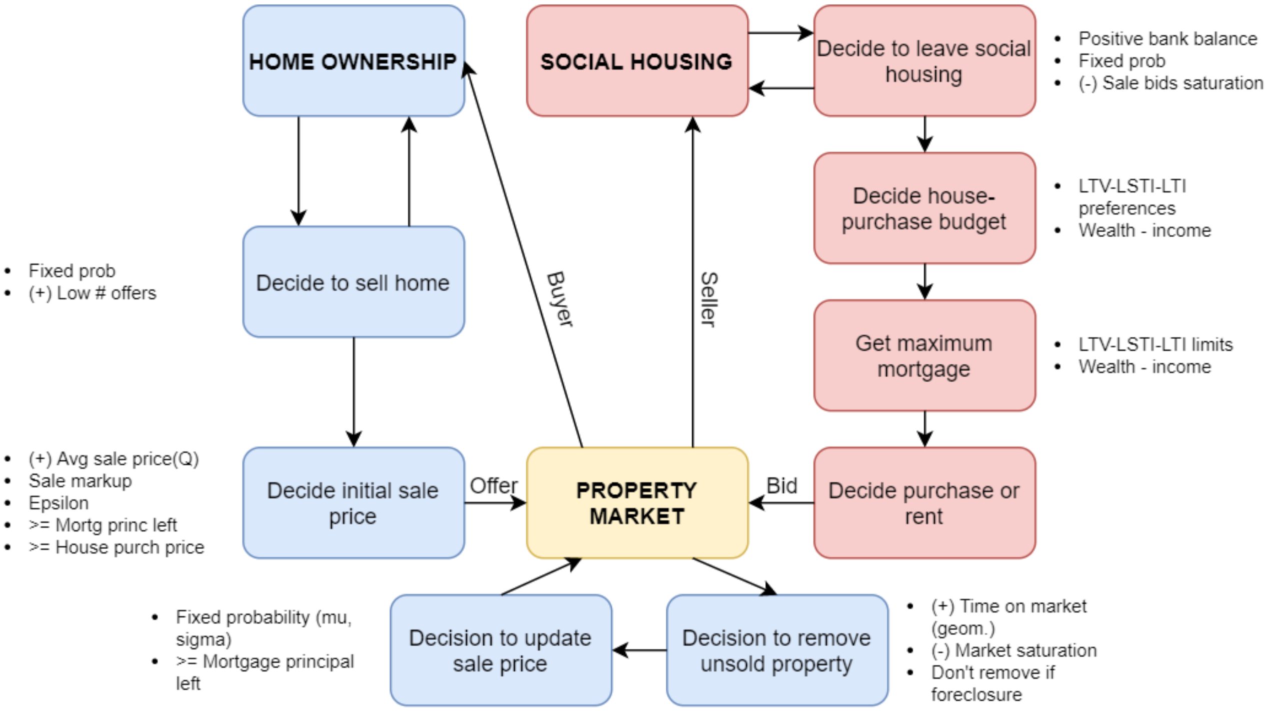

Fig. 3. High-level depiction of the households' housing-related decisions.

Households' target house quality preferences

As mentioned before, each residential property, in the housing stock, has a one-dimensional quality level. In turn, each household i has a house quality preference level q_i. Define $\hat{q}_i$ as the highest quality available on the residential property market with an asking price that is compatible with the household i house purchase budget. If and when household i decides to try and buy a residential property, q_i influences its actions in the following way:

1. If $\hat{q}_i \geq q_i$, the household can apply for a mortgage, and if successful, bids for the residential property. If the bid is successful, the household updates its house quality preference level to $\hat{q}_i$ (hence q_i becomes equal to $\hat{q}_i$).

2. If $\hat{q}_i < q_i$, the household does not apply for a mortgage nor bids for the residential property. In this case, the household may lower its house quality preference by one level with probability p_q (hence q_i may be reduced by one unit with probability p_q).

Sale offers update behavior

As in Catapano et al. 2021, if unmatched with a purchase bid, sale offers stay on the market. Moreover, the seller may probabilistically decide to lower the asking price at each subsequent time-step (which is one month long) if the property is still unsold. With the model presented in this paper, a new update mechanism has been introduced. The perspective seller may decide to remove the offer if:

$$g \leq P(G(p_r) \leq t - t_0^o), \tag{3}$$

where G is a random variable following a geometric distribution with parameter p_r, t_0^o is the time of the initial sale offering, t is the current time period and g is a realization of a random variable uniformly distributed on the unit interval $[0, 1]$. As can be easily seen, the probability to remove the sale offer increases with the amount of time the offer stays unmatched (and the property unsold) on the market.

Mortgage status

The model presented here introduces a mortgage-status classification and behavior. Mortgages may, at any one time, assume one of three states: *performing*; *past-due*; *non-performing*. The status classification is dynamic and complies with the following rules and induces the following behavior:

1. *Performing*: the borrower is paying the mortgage installments regularly and according to the mortgage repayment plan. If the borrower fails to pay an installment, the mortgage is reclassified as *past due*.
2. *Past-due*: each (monthly) installment that is not paid increases the principal due by its principal share. Moreover, the principal outstanding compounds (monthly) at the mortgage interest rate. The monthly installments are recalculated (increased) to reflect the increased principal due. If k mortgage installments are unpaid, the loan is reclassified as *non-performing*. Conversely, if the borrower restarts the monthly payments, the loan gets reclassified as *performing*.

3. *Non-performing*: the borrower is no longer allowed to pay the monthly installments. This status triggers the start of the foreclosure procedure on the mortgage collateral (the real estate property). Once a mortgage is classified as *non-performing*, it cannot subsequently change its status.

Foreclosure treatment

In Catapano et al. 2021, a mortgage default had a very simplified treatment: it was merely a change in the mortgage status. The household would keep paying mortgage installments and receive a cash injection to keep a non-negative cash balance.

The model presented here introduces a more realistic treatment of mortgage default. As seen in section 2.2, a defaulted borrower no longer pays installments and, importantly, a default triggers the start of the foreclosure procedure.

As this procedure starts, the real estate property that guarantees the loan is offered on the market. The defaulted household is never allowed to withdraw the offer (as is normally possible as explained in section 2.2). Once the property has been sold, the proceeds are employed to pay off the mortgage (and the remaining balance, if any, is kept by the household).

Return on lending activity

The model now records all the cash flows (amount and time) related to each mortgage. This allows for the computation of the bank's realized return on mortgages,[5] moreover, this measure can be disaggregated by mortgage status (as illustrated in section 2.2). Currently, the following (very simple) measure has been implemented:

$$R_{mt} = \frac{\sum_{p=t_0}^{t} CF_p}{P}, \tag{4}$$

where R_{mt} is the simple realized return on mortgage m at time t, CF_p is the cash-flow at time p and P is the principal loaned. In the case of an NPL t is lower than the physiologic termination date of the mortgage, which has been agreed-upon at the origination, and R_{mt} is used as a proxy for the NPL recovery rate.

[5] This is a necessary step in order to compute the overall profitability of the lending activity (which, at the moment, have yet to be implemented).

House prices dynamics

Previous iterations of the model presented here (Catapano et al., 2021, Baptista et al., 2016) put some significant constraints on the dynamics of the endogenous housing prices. In particular, the model would, at each time step, determine housing prices as an exponential moving average between endogenous prices and a fixed exogenous housing prices distribution. This restriction has now been removed and prices are fully endogenous.

2.3 Experimental setting simplifications

As the aim of this paper is to present the new model and carry out some initial experiments to test and study its behavior, hence the following simplified setting has been chosen:

1. Flat demographics: the population size stays on average constant throughout the simulation.
2. Flat income dynamics: as explained above, the model can accept any exogenous income data $\varUpsilon$. For the initial set of experiments carried out here, the cross-sectional distribution of household income remains constant ($\varUpsilon_t = \varUpsilon_{\neq t}$).
3. No target house quality shifts: the probability to reduce the desired residential property quality level p_q (defined in section 2.2) has been set to zero. Effectively eliminating the possibility to lower this level even if such a property is unavailable for a long time at market conditions.

3 Experimental configuration

This section details the setting used to perform the policy experiments described in this article. In particular, the first subsection describes how some important variables[6] are interconnected (simultaneously determined) and why it is important to acknowledge that. The second one delineates how the household synthetic population, used in the experiments, is generated. Finally, the last subsection presents the actual sequence of experiments that have been performed.

[6] Some of which are endogenous as explained below.

3.1 Connected variables

Table 1 describes and classifies some of the most important variables in the model. These variables refer to a specific mortgage, indexed by the subscript k.

Table 1. Classification of some important variables in the model. *Partially exogenous* variables are endogenously determined as a function of exogenous data and other endogenous variables.

Symbol	Description	Type
LTV_k	Mortgage loan to value	Partially exogenous
$LSTI_k$	Mortgage loan service to income	Partially exogenous
P_k	Mortgage principal	Endogenous
V_k	House value	Endogenous
f	Fraction of L_k to be repaid monthly	Exogenous
Y_k	Borrower's income	Exogenous
D_k	House downpayment	Endogenous
r	Mortgage interest rate	Exogenous
L	Mortgage duration in years	Exogenous

The variables in table 1 are simultaneously determined, as illustrated by the following set of equations (used in the model):

$$LTV_k = \frac{P_k}{V_k}, \tag{5a}$$

$$LSTI_k = \frac{f \cdot P_k}{Y_k}, \tag{5b}$$

$$P_k = V_k - C_k, \tag{5c}$$

$$f = \frac{r}{1-(1+r)^{-L}}. \tag{5d}$$

It is straightforward to realize that these equations impose a set of restrictions on the values that those variables can assume simultaneously.[7] The model can be calibrated either with empirical micro-data or with synthetic data (that match available empirical moments). While this study uses the latter method, the following reasons illustrate how the system of equations 5 impacts both calibration approaches:

[7] The system of equations 5 has 9 unknowns. Once the value of 5 variables is supplied, the value of the remaining 4 unknowns is determined by solving the system of equations.

1. **Use of empirical (micro-)data**: empirical micro-data regarding these variables may come from a variety of data sources. It is important that the data is internally consistent to satisfy the system of equations 5. Indeed, if the model is calibrated using internally inconsistent data, its endogenous variables (refer to table 1) will not match their empirical counterparts.
2. **Generating synthetic data**: if the model is run, as in the present work, using synthetic data[8] it is necessary to only select a subset of the variables in table 1 and let the system 5 determine the value of the remaining ones.

3.2 Synthetic populations

To calibrate the parameters of the household population[9] either empirical or synthetic data can be used. In the former case the empirical micro-data can be directly used to calibrate the model's household population. In the latter case instead, a synthetic households population is generated, possibly using the available evidence[10] on the empirical population of interest. It is important to highlight that the model does not impose any restriction on the approach to used to generate this input data.

For the experiments presented here, the household population has been synthetically generated. The particular procedure used to generate the synthetic data operates as follows:

1. Set the desired levels for r and L. These values are constant across time and households.
2. Draw two samples from two independent Beta distributions suitably parametrized with their mean and standard deviations. Join the two samples via a Gaussian copula function, with the desired correlation, to obtain a joint distribution. These observations are used for the joint $(LTV_i, LSTI_i)$ distribution.
3. Draw a sample from a uniform distribution with the desired parameters. This data is used for the cross-section of house values V_i.
4. Given the data generated at the previous steps, obtain Y_i and D_i by solving the system of equations 5. The result of this process is graphically represented in figure 4.

[8] Having certain desirable statistical properties of empirical data.

[9] Mainly the individual values for the following parameters: labor income, financial income, target and initial cash balance, subjective maximum LTV and LSTI.

[10] For example moments of some of the variables of interest.

5. The vector $(Y_i, D_i, LTV_i, LSTI_i)$ is used to initialize the following parameters of household i: labor income, cash balance, subjective maximum LTV, subjective maximum LSTI.

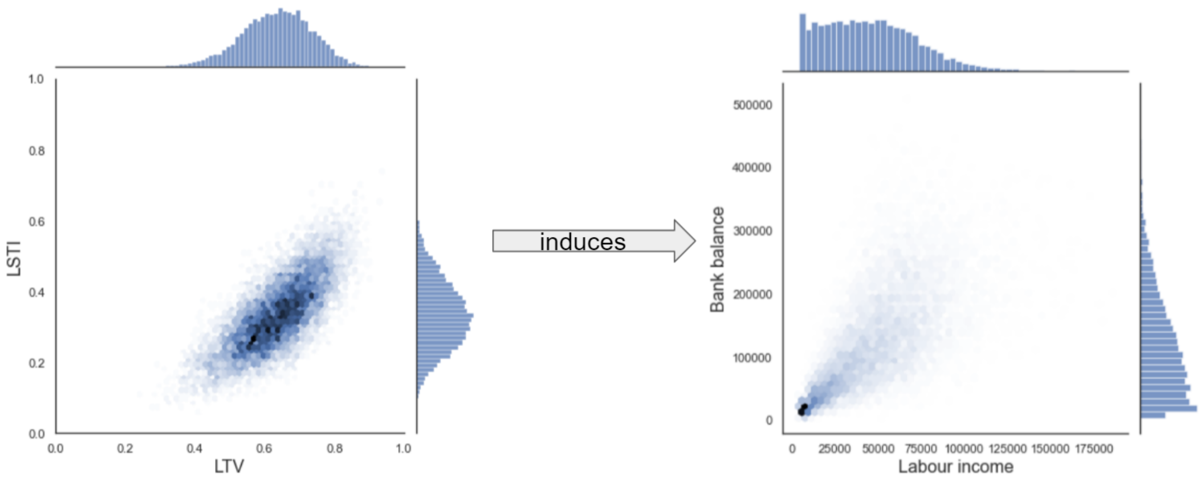

Fig. 4. The synthetic joint distribution $(LTV_i, LSTI_i)$ induces a realization of the joint distribution of the cash balance and labor income once the other constants and the house-value distribution are fixed.

3.3 Validation

The main objective of the present work has been to implement the new features of the model, carry out preliminary testing and perform a set of experiments. Hence, less emphasis has been placed on precise calibration (with the objective of achieving a very good match with empirical data). Nonetheless, for all the experiments, the baseline scenario is roughly calibrated to the Italian economy, as to avoid an unrealistic setting. Table 2 offers a comparison of the central moments of some endogenous variables and their empirical counterparts. As can be clearly seen, the discrepancies are very small.[11]

[11] A perfect calibration was not the objective of the present work. Potentially, the model can be calibrated even more precisely, eliminating any discrepancy.

Table 2. Comparison of empirical and simulated means. The empirical data refers to a 13-year time-series average of data referring to the Italian economy.

Variable	Moment	Simulated	Empirical
New defaults rate[1]	Mean	0.0030	0.0033
LTV	Mean	0.60	0.62
LSTI	Mean	0.30	0.32
Transaction rate[2]	Mean	0.003	0.003
Interest rate	Mean	0.050	0.047

[1]Monthly rate.

[2]Monthly percentage of transacted residential properties.

Finally, in the baseline scenario, both endogenous and exogenous variables are stationary.[12]

3.4 Monte Carlo analysis

Each individual experiment is performed 200 times[13] using a sequence of different random seeds.[14] Different experiments are performed using the same sequence of different random seeds. This allows removing the effects of the sampling variability across experiments. The results are presented as the Monte Carlo ensemble average of each experiment.

4 Policy experiments

This section presents and describes the three sets of policy experiments performed. It is articulated in four parts. The first describes the outcome variables considered in this study and the other three describe in detail each experimental setting and its results.

While all the experiments study the effects of the introduction of an LTV cap on newly issued mortgages, each set studies the impact of a different parameter of the model. In particular, the first set (set "1") is concerned with the mean of the household indebtedness tolerance. The second set (set "2") focuses on the cross-sectional dispersion

[12] Notably labor incomes, cash holdings, and idiosyncratic indebtedness tolerances oscillate around their means without a trend.

[13] This quantity strikes a balance between the computational cost (which increases with the number of repetitions) of the simulations and the variability in the Monte Carlo average trajectories (which decreases with the number of repetitions) of the endogenous variables.

[14] Thus allowing to gauge the impact of the sampling variability on the simulation outcome.

of the household indebtedness tolerance. Finally, the third set (set "3") analyses the impact of timing and phasing-in of the introduction of the LTV caps. Table 3 offers a high-level description of the characteristics of the experiments. Notice that experiment sets "2" and "3" entail scenarios characterized by growing indebtedness tolerance, in contrast with the first set of experiments.[15] Each experiment set is presented in finer detail in the next sections. Finally, table 4 presents the parameters that are kept constant across all policy experiments.

Table 3. High-level description of the three sets of experiments performed. In bold are the parameters that are varied and the object of study.

Parameter	Experiment set "1"	Experiment set "2"	Experiment set "3"
$(LTV_i, LSTI_i)^1$ mean	0.60	**(0.60, 0.70, 0.80)**	**(0.60, 0.70, 0.80)**
$(LTV_i, LSTI_i)^1$ std. dev.	**(0.10, 0.15, 0.20)**	0.15	0.15
$(LTV_i, LSTI_i)^1$ growth	NO	YES	YES
LTV cap level	**(0.9, 0.8, 0.7, 0.6, 0.5)**	**(0.9, 0.8, 0.7, 0.6)**	0.70
LTV cap *phase-in* steps	NO	NO	**(1, 3, 6)**[2]

[1]The households' distribution of indebtedness tolerance.

[2]A proactive introduction with 6 steps is also tested.

Table 4. Moments of non-household variables. Moments described as "Constant" refer to a variable that has zero cross-sectional variability.

Variable	Moment	Value
r	Constant	0.05
L	Constant	25
V_k	Mean	325,000
V_k	Std.dev.	170,000
Y_i	Median	43,000
C_i	Median	111,000

[15] The specific scenario will be described in more detail in the relevant section. In the model, the growing indebtedness tolerance induces increasing house prices, indebtedness, and default rates.

4.1 Outcome variables

The following endogenous variables will be considered in the analysis:

1. **Average sale price**: the market price for residential properties is computed as the simple average of the average transaction price for each house-quality level.
2. **Average months on the market**: the number of months a residential property stays on the market before it is sold. It is computed as the simple average of the average time on the market across all house-quality levels.
3. **Number of sales**: the total number of transactions concluded in the residential property market (summing across all quality levels).
4. **Percentage of new mortgages defaults**: The monthly incidence of new mortgage defaults. It is computed as the ratio of the number of newly defaulted mortgages over the total number of active mortgages.
5. **LTV on new mortgages**: the monthly simple average of the LTV ratios on newly issued mortgages.
6. **LSTI on new mortgages**: the monthly simple average of the LSTI ratios on newly issued mortgages.
7. **Percentage of NPL stock**: the share of the active mortgages that are *non-performing* as defined in section 2.2.
8. **Average NPL recovery rate**: this variable tracks the recovery rate (as defined in the section 2.2) of newly terminated, non-performing mortgages.
9. **Average foreclosure duration**: this variable represents the time it took for newly terminated, defaulted mortgages, to complete the foreclosure procedure (including selling the residential property and using the proceeds to pay off the loan). It is computed as the simple average across loans.

4.2 Indebtedness tolerance heterogeneity

Experimental setting

The first set of experiments studies the effects of the introduction of a range of progressively stricter LTV caps[16] on three different households populations (labelled "A1", "B1", "C1" respectively). These populations differ only by their spread (standard deviation) in the households' subjective LTV and LSTI limits. The objective is to analyze the

[16] From 90% to 50% as explained below.

interaction between the spread of household indebtedness tolerance and the level of the LTV cap being introduced. Table 5 offers a synthetic description of the characteristics of these populations.

Table 5. Characteristics of the synthetic household populations in experiment set "1". In bold are highlighted the moments that change across the populations.

Variable	Moment	Population "A1"	Population "B1"	Population "C1"
LTV_i	Mean	0.60	0.60	0.60
LTV_i	Std.dev.	**0.10**	**0.15**	**0.20**
$LSTI_i$	Mean	0.30	0.30	0.30
$LSTI_i$	Std.dev.	**0.10**	**0.11**	**0.12**
$(LTV_i, LSTI_i)$	Correlation	0.75	0.75	0.75
$(LTV_i, LSTI_i)$	Growth rate	0.00	0.00	0.00

LTV_i and $LSTI_i$ standard deviations scale differently across populations, as can be seen from table 5. This is intentionally done in order to keep the central moment of the Y_i and C_i distributions unchanged.[17]

Table 6 catalogues and labels the experiments of this section. Figure 5 plots the joint $(LTV_i, LSTI_i)$ distributions for the three populations.

Table 6. List of the experiments performed and their labeling convention. As an example, an 80% LTV cap on population "B" is labelled "B.90".

LTV cap	Population "A1"	Population "B1"	Population "C1"
90%	A1.90	B1.90	C1.90
80%	A1.80	B1.80	C1.80
70%	A1.70	B1.70	C1.70
60%	A1.60	B1.60	C1.60
50%	A1.50	B1.50	C1.50

[17] They are computed solving the system of equations 5 and the expected value of Y_i is a function of the ratio of two random variables.

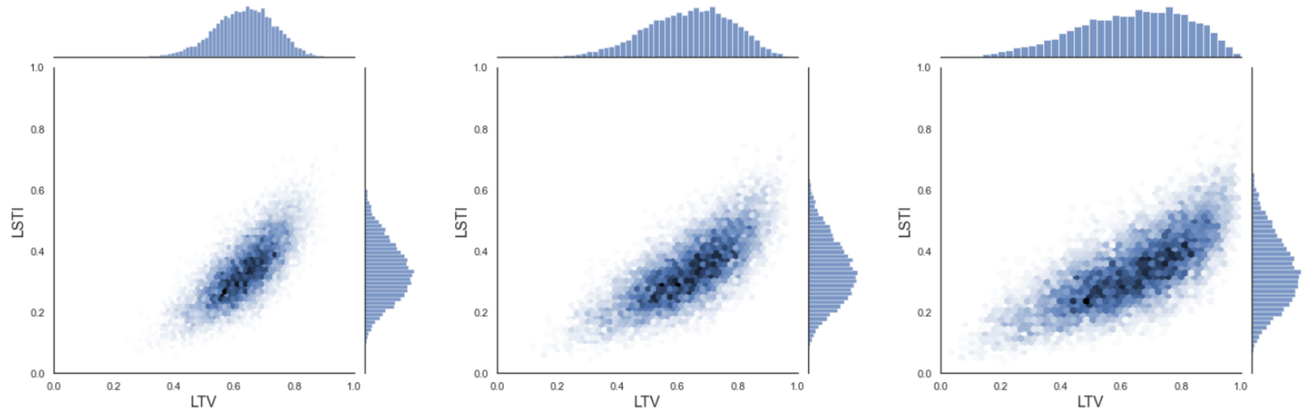

Fig. 5. From left to right are depicted the synthetic joint distributions $(LTV_i, LSTI_i)$ for population "A1", "B1", "C1", respectively. The mean (and correlation of marginals) of the joint distribution is the same across populations.

Results

This section starts with an evaluation of the effects of the introduction of the 70% LTV cap (experiments "A1.70", "B1.70", "C1.70"), it continues with the analysis of the stricter 50% LTV cap (experiments "A1.50", "B1.50", "C1.50") and concludes with a general assessment of the entire set of experiments (listed in table 6).

The first set of experiments under study refers to the introduction of a 70% LTV cap on newly issued mortgages (experiments "A1.70", "B1.70" and "C1.70" in table 6). Figure 6 presents graphically the time-series dynamics. Tables 7, 8 and 9 quantify the effects at one, five, and ten years post-policy intervention, respectively. The following are the main observations:

1. **Household indebtedness**: LTV and LSTI on new mortgages drop immediately (as expected) after the introduction of the policy and stay constant afterward.
2. **Credit risk**: in the short term (table 7) the policy has no significant effect. Over the medium-term (tables 8 and 9) there is a statistically significant (but with a low economic magnitude) reduction in the NPL stock. This dynamic is accompanied by an increase in the NPL realized return.
3. **Housing markets**: irrespective of the time horizon, housing markets, in terms of prices, the volume transacted, and residential properties liquidity, are largely unaffected by the introduction of the LTV cap.

Hence, according to the model, and given the current calibration, the introduction of the 70% LTV cap seems to only have a mild economic impact.

The second set of experiments refers to the introduction of a much stricter 50% LTV cap, on newly issued mortgages (experiments "A1.50", "B1.50" and "C1.50" of table 6). The results of these experiments are presented in figure 7 and tables 10, 11 and 12. As for the previous set of experiments, the following are the more important observations:

1. **Household indebtedness**: in line with the results from the introduction of the 70% LTV cap, LTV and LSTI on new mortgages drop immediately and stay constant afterward. With the 50% cap, the reduction is sharper and it is followed, over time, by a mild recovery.

2. **Credit risk**: the short-term effects are not significant (table 10). At the 10-year horizon (table 12) the return on terminated NPLs increases (with a variation that is economically significant) and the NPL stock decreases. It is interesting to note that at the 5-year horizon (table 12 and figure 7) there is a statistically significant, yet transitory, increase in the NPL stock with population "A1" (experiment "A1.50").

3. **Housing markets**: in the short term (1-year post-intervention, table 10) the housing markets are not significantly affected by the introduction of the macroprudential policy. Over longer time horizons (5 and 10 years post-intervention, tables 11 and 12) there is a statistically significant reduction in house prices, a reduction in the number of transactions, and an increase in the average time required to sell a residential property. It is interesting to observe that these effects are more pronounced for the populations with a comparatively lower LTV_i standard deviation (population "A1" and "B1").

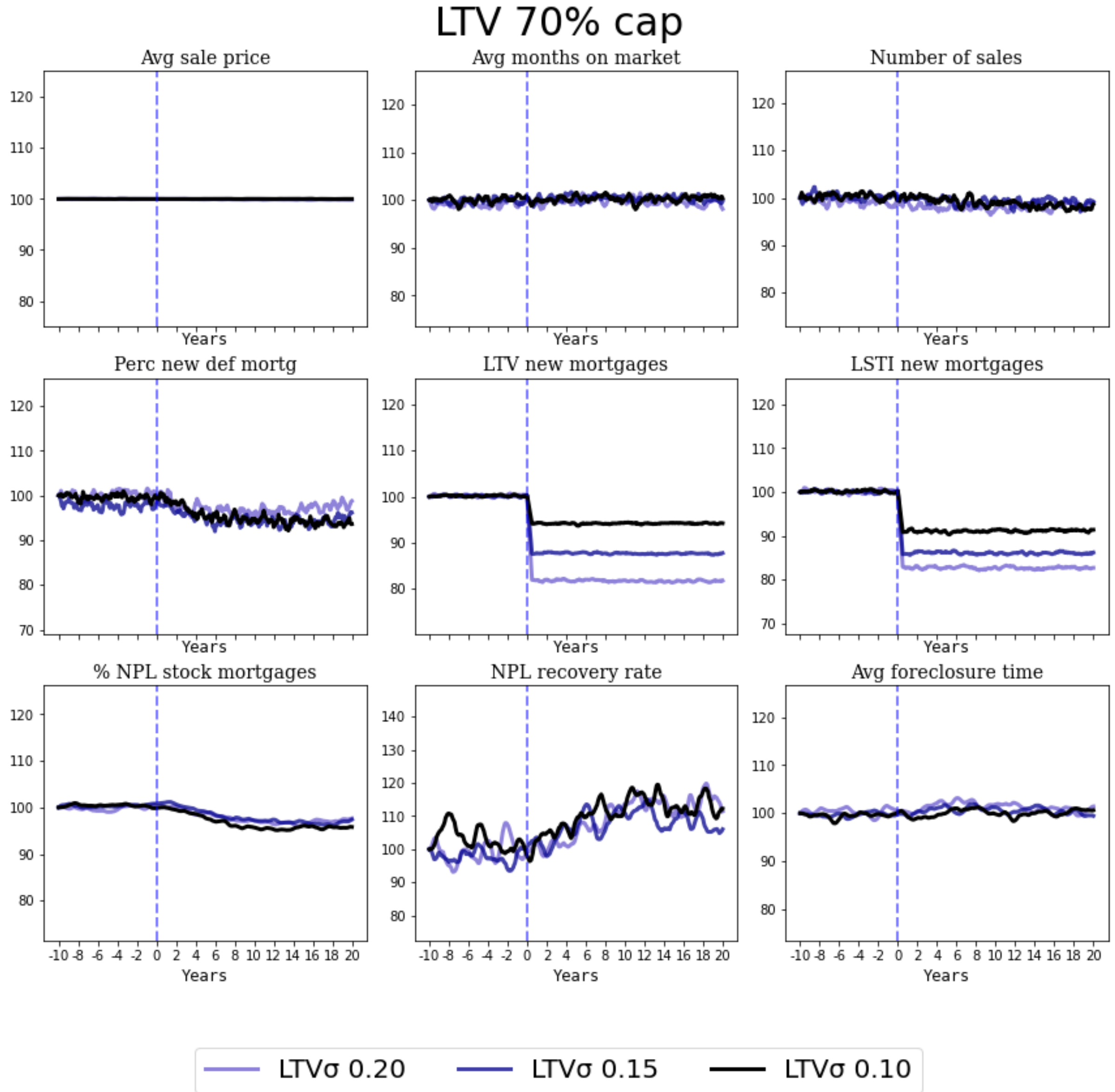

Fig. 6. Endogenous dynamics for experiments "A1.70", "B1.70", "C1.70". The plots show a total of 60 simulated years, the first 30 correspond to a baseline dynamic without policy intervention. The policy shock is introduced at year 30. The variables are indexed with value equal to 100 at time $t = 0$. Each plot depicts the average trajectory across the simulations in the Monte Carlo ensemble.

Experiment	A1.70 (LTVσ 0.10)	B1.70 (LTVσ 0.15)	C1.70 (LTVσ 0.20)
Years post intervention	1	1	1
Avg sale price	-0.00%	-0.04%	0.00%
Avg months on market	-0.82%	0.01%	0.44%
Number of sales	-0.46%	-1.71%	-0.38%
Perc new def mortg	0.23%	-1.09%	-1.32%
LTV new mortgages	-5.90%**	-12.50%**	-18.47%**
LSTI new mortgages	-9.08%*	-14.33%**	-17.45%**
NPL stock mortgages	-0.20%	-0.02%	-0.69%
Avg return NPL	-3.56%	7.19%	1.86%
Avg foreclosure duration	0.19%	-0.05%	-0.07%

Table 7. Percentage variation between the average baseline and post-policy intervention values. "*", "**", "***" represent the statistical significance at the 0.05, 0.01 and 0.001 level, respectively.

Experiment	A1.70 (LTVσ 0.10)	B1.70 (LTVσ 0.15)	C1.70 (LTVσ 0.20)
Years post intervention	5	5	5
Avg sale price	0.01%	-0.05%	-0.02%
Avg months on market	-0.14%	-0.13%	2.04%
Number of sales	-0.96%	-2.84%	-1.00%
Perc new def mortg	-4.15%	-5.13%	-5.20%
LTV new mortgages	-6.05%**	-12.29%**	-18.45%***
LSTI new mortgages	-9.17%**	-13.81%**	-17.53%**
NPL stock mortgages	-2.96%*	-2.31%*	-2.40%*
Avg return NPL	6.20%	16.24%*	8.36%
Avg foreclosure duration	1.30%	0.83%	2.10%

Table 8. Percentage variation between the average baseline and post-policy intervention values. "*", "**", "***" represent the statistical significance at the 0.05, 0.01 and 0.001 level, respectively.

Experiment	A1.70 (LTVσ 0.10)	B1.70 (LTVσ 0.15)	C1.70 (LTVσ 0.20)
Years post intervention	10	10	10
Avg sale price	0.01%	-0.10%*	-0.03%
Avg months on market	-0.51%	0.05%	1.22%
Number of sales	-1.43%	-2.39%	-1.36%
Perc new def mortg	-4.02%	-5.11%	-5.08%
LTV new mortgages	-5.81%**	-12.51%**	-18.72%***
LSTI new mortgages	-8.68%**	-14.16%**	-17.45%**
NPL stock mortgages	-4.76%**	-3.88%**	-3.98%**
Avg return NPL	12.81%*	14.95%*	15.90%*
Avg foreclosure duration	0.29%	0.76%	1.42%

Table 9. Percentage variation between the average baseline and post-policy intervention values. "*", "**", "***" represent the statistical significance at the 0.05, 0.01 and 0.001 level, respectively.

Experiment	A1.50 (LTVσ 0.10)	B1.50 (LTVσ 0.15)	C1.50 (LTVσ 0.20)
Years post intervention	1	1	1
Avg sale price	-0.11%	-0.02%	0.01%
Avg months on market	0.79%	0.20%	0.70%
Number of sales	-4.64%	-2.90%	-3.56%
Perc new def mortg	-2.35%	-1.50%	-1.74%
LTV new mortgages	-27.35%***	-33.35%***	-39.15%**
LSTI new mortgages	-35.48%**	-32.60%**	-32.36%**
NPL stock mortgages	0.29%	0.75%	1.16%
Avg return NPL	6.83%	1.81%	7.72%
Avg foreclosure duration	-0.14%	0.27%	-0.00%

Table 10. Percentage variation between the average baseline and post-policy intervention values. "*", "**", "***" represent the statistical significance at the 0.05, 0.01 and 0.001 level, respectively.

Experiment	A1.50 (LTVσ 0.10)	B1.50 (LTVσ 0.15)	C1.50 (LTVσ 0.20)
Years post intervention	5	5	5
Avg sale price	-4.40%***	-0.43%**	-0.15%*
Avg months on market	11.55%*	3.19%	2.13%
Number of sales	-21.16%**	-7.35%	-5.72%*
Perc new def mortg	-16.91%*	-12.21%*	-10.32%
LTV new mortgages	-25.43%***	-32.54%***	-38.65%***
LSTI new mortgages	-34.31%***	-31.86%***	-31.91%***
NPL stock mortgages	3.69%**	-6.91%***	-3.97%**
Avg return NPL	23.42%**	21.38%*	24.00%*
Avg foreclosure duration	14.15%***	5.84%**	3.57%*

Table 11. Percentage variation between the average baseline and post-policy intervention values. "*", "**", "***" represent the statistical significance at the 0.05, 0.01 and 0.001 level, respectively.

Experiment	A1.50 (LTVσ 0.10)	B1.50 (LTVσ 0.15)	C1.50 (LTVσ 0.20)
Years post intervention	10	10	10
Avg sale price	-8.79%***	-3.09%***	-0.84%***
Avg months on market	17.05%**	6.61%	3.38%
Number of sales	-14.27%**	-11.62%*	-7.45%*
Perc new def mortg	-20.33%**	-13.55%*	-10.11%
LTV new mortgages	-25.61%***	-31.11%***	-37.96%***
LSTI new mortgages	-35.32%***	-31.57%***	-31.48%***
NPL stock mortgages	-0.57%	-3.73%**	-4.09%**
Avg return NPL	39.64%**	37.62%**	40.46%**
Avg foreclosure duration	26.10%***	9.66%**	4.79%**

Table 12. Percentage variation between the average baseline and post-policy intervention values. "*", "**", "***" represent the statistical significance at the 0.05, 0.01 and 0.001 level, respectively.

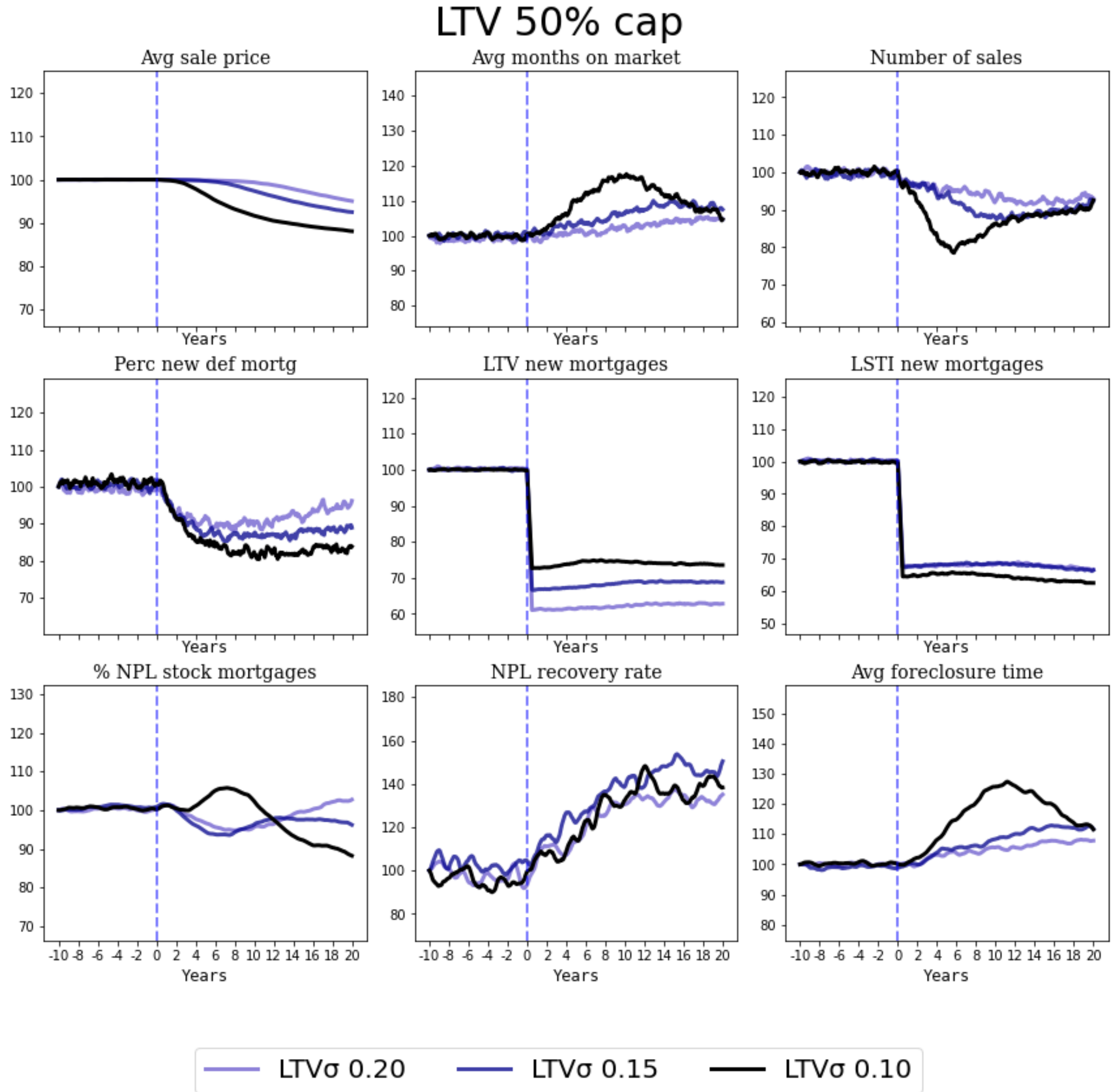

Fig. 7. Endogenous dynamics for experiments "A1.50", "B1.50", "C1.50". The plots show a total of 60 simulated years, the first 30 correspond to a baseline dynamic without policy intervention. The policy shock is introduced at year 30. The variables are indexed with value equal to 100 at time $t = 0$. Each plot depicts the average trajectory across the simulations in the Monte Carlo ensemble.

Figure 8 presents the effects, on selected variables, of the entire set of experiments. The main observed patterns, which grow stronger as the LTV cap gets stricter, are the following: the bank credit is reduced while the return on mortgages increases (due to the lower riskiness); the households become less indebted while fewer of them can afford to buy a residential property; house prices tend to fall and the time required to sell a property tends to increase (although these latter effects are mild in most experiments). In the context of these general patterns, it is interesting to highlight the role played by the different dispersion in risk tolerance, $\sigma(LTV_i)$, of the three populations (whose characteristics are reported in table 5). In particular:

1. **Household indebtedness and house affordability**: household indebtedness and house affordability appear to be highly correlated in the medium term (5 to 10 years post-policy intervention). There is an economically significant non-linear interaction between how strict the LTV cap is and the $\sigma(LTV_i)$ level: with the less strict LTV caps (90% to 70%), the higher the $\sigma(LTV_i)$ is, the stronger is the reduction in indebtedness and house affordability; with stricter LTV caps (60% and 50%) these differences tend to vanish.
2. **Credit risk**: for all but the strictest of the LTV caps tested (90% to 60%), $\sigma(LTV_i)$ has a significant impact on the size of the reduction in credit supply (which is due to the specular increase in the share of constrained households). At the 50% LTV cap level, there is a significant difference in the results among different populations: the introduction of the policy, with population "A" (experiment "A.50"), induces, in the medium term, an increase in the NPL stock. This is due to a marked increase in the time required to sell a property (and hence complete the sale of a foreclosed property) which prevails on the simultaneous reduction of mortgage defaults (and hence a reduced flow of new NPLs); for populations "B" and "C" (those with the higher $\sigma(LTV_i)$) these effects are not significant (the reduction in mortgage defaults prevails on the longer time required to complete a foreclosure).
3. **Housing market**: housing markets, in terms of prices, the volume transacted and the liquidity of the residential properties, are largely unaffected by the introduction of all but the strictest LTV cap (50%). The $\sigma(LTV_i)$ level (and hence the different synthetic populations) has a significant impact on the effects of the introduction of the 50% LTV cap: lowering it increases exponentially the impact on the housing market variables (prices, volumes and liquidity).

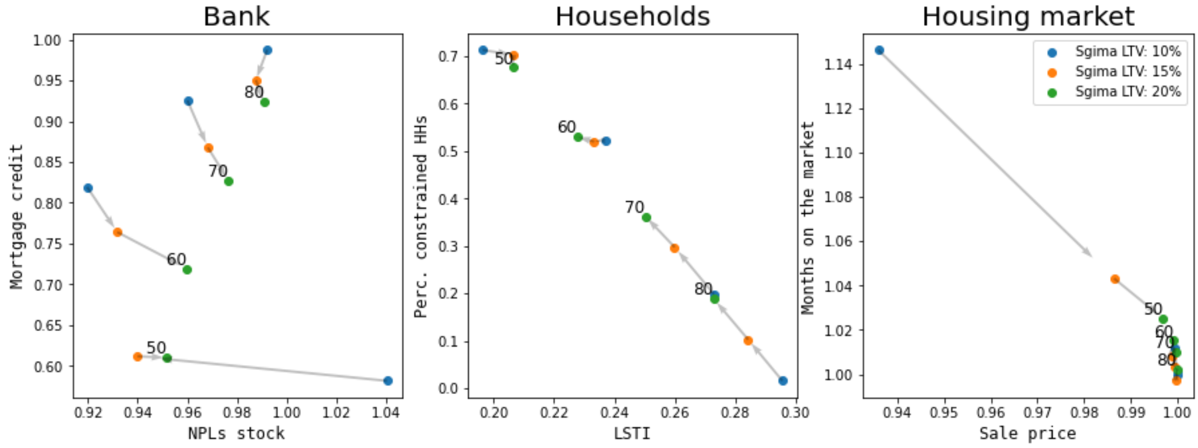

Fig. 8. For each variable, the plots compare their baseline (with no macroprudential policy) average level against their post-policy-intervention average level. The post-policy intervention levels are calculated as an average over the +5 and +10 years window. For the "Bank" and for the "Housing market" panels the values are indexed, with 1.0 being the baseline value. The "Households" panel, instead, depicts the actual values. The number on the green dots (corresponding to population "C") indicates the level of the LTV cap (the 90% cap is not shown as it does not induce significant effects). The experiments performed with the same LTV cap are linked by a grey arrow. For example, for the"Bank" panel, the green dot marked with the number "60" along with the other two dots linked with it by the two gray arrows, indicate the experiments that study the introduction of a 60% LTV cap on the three populations characterized by a different dispersion of the prevailing LTV (10%, 15%, and 20%).

4.3 Indebtedness tolerance level

Experimental setting

As for the first set of experiments, also the second one studies the effects of the introduction of a range of progressively stricter LTV caps[18] on three different households populations (labeled "A2", "B2", "C2" respectively). This time, the population discriminating feature is their mean value for the subjective LTV and LSTI subjective limits. The second set of experiments aims at analyzing the interaction between the mean level of household indebtedness tolerance and the level of the LTV cap introduced. Table 13 offers a synthetic description of the characteristics of these populations.

Differently from the experiment set "1" of the previous section, the $(LTV_i, LSTI_i)$ joint distribution is not stationary. This set of experiments simulates a 2% yearly increase in households' subjective LTV and LSTI indebtedness limits (see table 13). As will be

[18] From 90% to 60% as explained below.

Variable	Moment	Population "A1"	Population "B1"	Population "C1"
LTV_i	Mean	**0.60**	**0.70**	**0.80**
LTV_i	Std.dev.	0.15	0.15	0.15
$LSTI_i$	Mean	**0.30**	**0.35**	**0.40**
$LSTI_i$	Std.dev.	0.11	0.11	0.11
$(LTV_i, LSTI_i)$	Correlation	0.75	0.75	0.75
$(LTV_i, LSTI_i)$	Growth rate	0.02	0.02	0.02

Table 13. Characteristics of the synthetic household populations in experiment set "2". In bold are highlighted the moments that change across the populations.

shown in the results, this induces an upward trend in house prices, mortgage credit, and defaults.

Table 14 catalogues and labels the experiments of this section. Figure 9 plots the joint $(LTV_i, LSTI_i)$ distributions for the three populations.

LTV cap	Population "A2"	Population "B2"	Population "C2"
90%	A2.90	B2.90	C2.90
80%	A2.80	B2.80	C2.80
70%	A2.70	B2.70	C2.70
60%	A2.60	B2.60	C2.60

Table 14. List of the experiments performed and their labeling convention. As an example, an 80% LTV cap on population "B2" is labelled "B2.90".

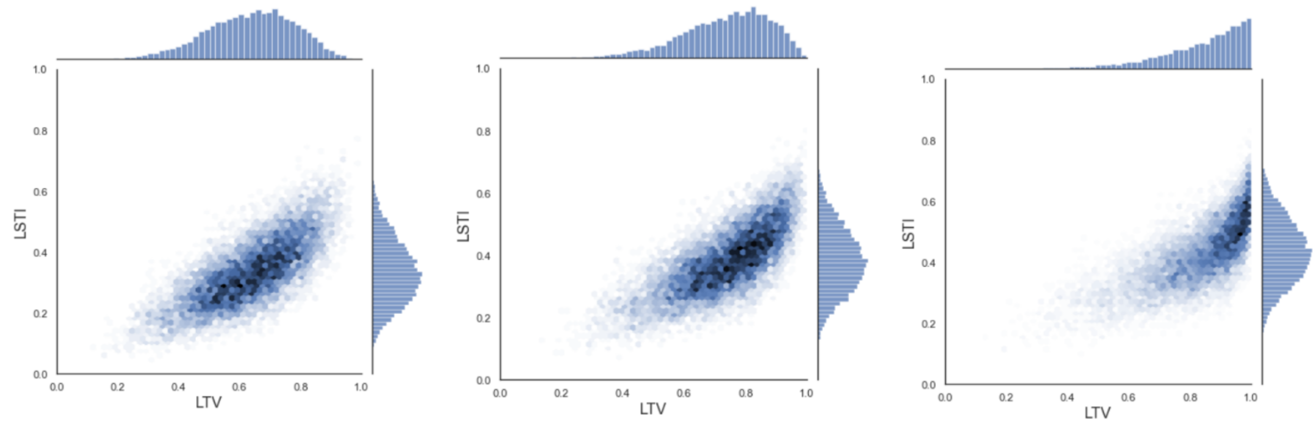

Fig. 9. From left to right are depicted the synthetic joint distributions $(LTV_i, LSTI_i)$ for population "A2", "B2", "C2", respectively. The mean (and correlation of marginals) of the joint distribution is the same across populations.

Results

This section starts with an evaluation of the effects of the introduction of the 80% LTV cap (experiments "A2.80", "B2.80", "C2.80"), it continues with the analysis of the stricter 70% LTV cap (experiments "A2.70", "B2.70", "C2.70") and concludes with a general assessment of the entire set of experiments (listed in table 14). The experiments analyzed in this section consider a scenario with growing household indebtedness.

Since this set of experiments is carried out in an environment of growing household indebtedness (due to increasing debt tolerance), the baseline scenario is characterized by increasing LTV-LSTI on new mortgages, default rates, and house prices (see figures 10 and 11).

The first set of experiments under study refers to the introduction of an 80% LTV cap on newly issued mortgages (experiments "A2.80", "B2.80", "C2.80" in table 14). Figure 10 presents graphically the time-series dynamics. Tables 15, 16 and 17 quantify the effects at one, five, and ten years post-policy intervention, respectively. The following are the main observations:

1. **Household indebtedness**: LTV and LSTI on new mortgages drop immediately (as expected) after the introduction of the policy. Afterward, notwithstanding the

increasing household indebtedness tolerance,[19] their upward trajectory slopes down significantly or flattens out altogether.

2. **Credit risk**: in the short to medium term (tables 15 and 16) the policy induces a significant increase in the NPL stock while over the longer-term (table 17) it falls below the baseline trend. Also, compared to the baseline trend, the policy stops the reduction in the realized return of terminated NPL.
3. **Housing markets**: in the short term, the policy induces a transitory but significant reduction in the number of transactions in the housing market (table 15). Compared to their baseline trend, house prices experience a modest decline in the short term;[20] afterward, they resume their upward trend at a slower pace.

The second set of experiments refers to the introduction of a stricter 70% LTV cap, on newly issued mortgages (experiments "A2.70", "B2.70" and "C2.70" of table 14). The results of these experiments are presented in figure 11 and tables 18, 19 and 20. As for the previous set of experiments, the following are the more important observations:

1. **Household indebtedness**: in line with the results from the introduction of the 80% LTV cap, LTV and LSTI on new mortgages drop immediately after the introduction of the policy. Afterward, their slope flattens or turns negative (in the baseline scenario they were trending upwards). These effects are more pronounced than with the 80% LTV cap.
2. **Credit risk**: the effects on credit risk are essentially similar to those induced by the introduction of the 70% cap. A notable difference with the previous set of experiments is represented by the initial drop in the return of terminated NPLs for population "B2".[21]
3. **Housing markets**: in the short term, the policy induces a transitory but significant reduction in the number of transactions in the housing market (table 18). Compared to their baseline trend, house prices experience a modest decline in the short term,[22] afterward for population "A.2", they resume their upward trend at a slower pace, for the others, they follow a down-sloping trajectory.

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[19] As described in the experimental setting for these experiments.

[20] 1-year post-policy intervention.

[21] This is due to the fact that this particular scenario entails an initial mean LTV of 70% with an upward trend. At the time the policy is instated the average LTV on new mortgages is well over 80% hence the macroprudential measure induces a very significant drop in demand for housing thus reducing the realized return of terminated NPLs.

[22] 1-year post-policy intervention.

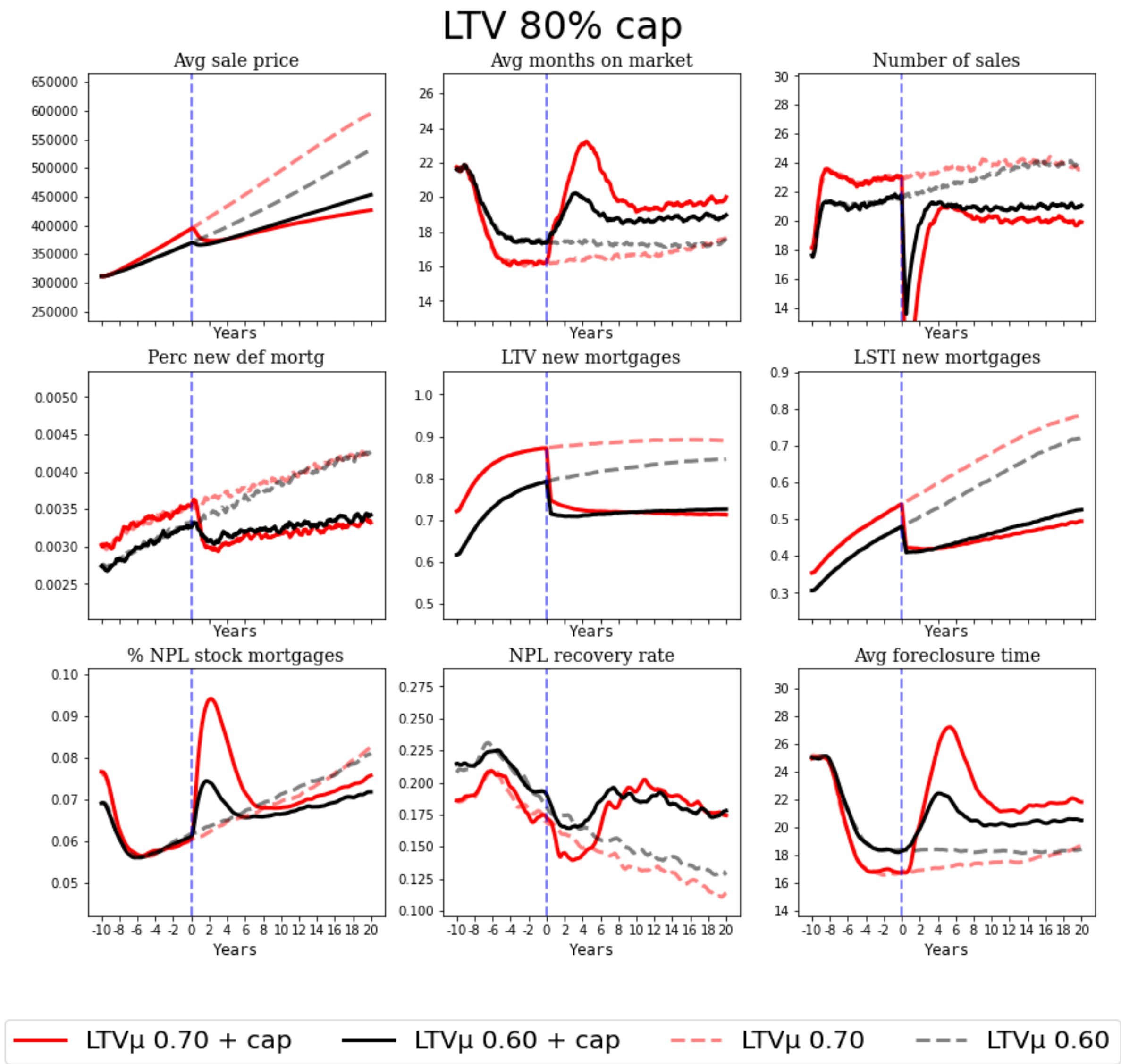

Fig. 10. Endogenous dynamics for experiments "A2.80", "B2.80", "C2.80". The plots show a total of 30 simulated years, the first 10 correspond to a baseline dynamic without policy intervention. The policy shock is introduced at year 0 (marked by the dashed blue vertical line). The shaded trajectories depict the dynamics without policy intervention. Each plot depicts the average trajectory across the simulations in the Monte Carlo ensemble.

Experiment	A2.80 (LTVμ 0.60)	B2.80 (LTVμ 0.70)	C2.80 (LTVμ 0.80)
Years post intervention	1	1	1
Avg sale price	-3.71%*	-9.12%**	-13.04%**
Avg months on market	8.53%*	19.76%**	32.17%**
Number of sales	-12.45%**	-36.80%***	-64.57%***
Perc new def mortg	-9.15%*	-17.35%*	-20.12%**
LTV new mortgages	-11.31%***	-16.27%***	-19.65%***
LSTI new mortgages	-18.08%**	-25.82%***	-26.62%***
NPL stock mortgages	17.09%***	49.57%***	73.95%***
Avg return NPL	-4.62%**	-10.65%*	-18.88%**
Avg foreclosure duration	6.94%***	16.72%***	30.20%***

Table 15. Percentage variation between the average baseline and post-policy intervention values. "*", "**", "***" represent the statistical significance at the 0.05, 0.01 and 0.001 level, respectively.

Experiment	A2.80 (LTVμ 0.60)	B2.80 (LTVμ 0.70)	C2.80 (LTVμ 0.80)
Years post intervention	5	5	5
Avg sale price	-6.34%**	-15.33%**	-24.65%***
Avg months on market	10.13%**	33.44%***	71.30%***
Number of sales	-7.15%**	-11.56%*	-25.30%**
Perc new def mortg	-12.26%*	-16.85%*	-25.31%**
LTV new mortgages	-12.49%***	-18.47%***	-24.07%***
LSTI new mortgages	-21.85%**	-31.49%***	-36.42%***
NPL stock mortgages	-1.56%	10.64%***	55.43%***
Avg return NPL	17.33%**	8.72%**	-10.50%*
Avg foreclosure duration	17.97%***	56.46%***	98.20%***

Table 16. Percentage variation between the average baseline and post-policy intervention values. "*", "**", "***" represent the statistical significance at the 0.05, 0.01 and 0.001 level, respectively.

Experiment	A2.80 (LTVμ 0.60)	B2.80 (LTVμ 0.70)	C2.80 (LTVμ 0.80)
Years post intervention	10	10	10
Avg sale price	-9.26%**	-20.48%***	-33.88%***
Avg months on market	7.97%**	15.76%**	45.80%***
Number of sales	-10.38%**	-16.42%**	-28.71%***
Perc new def mortg	-15.00%**	-19.12%**	-25.81%**
LTV new mortgages	-13.18%***	-19.34%***	-26.26%***
LSTI new mortgages	-24.73%***	-34.76%***	-43.72%***
NPL stock mortgages	-7.03%**	-2.50%**	17.49%**
Avg return NPL	26.41%**	51.93%***	43.89%**
Avg foreclosure duration	10.59%***	21.51%***	75.60%***

Table 17. Percentage variation between the average baseline and post-policy intervention values. "*", "**", "***" represent the statistical significance at the 0.05, 0.01 and 0.001 level, respectively.

Experiment	A2.70 (LTVμ 0.60)	B2.70 (LTVμ 0.70)	C2.70 (LTVμ 0.80)
Years post intervention	1	1	1
Avg sale price	-7.15%**	-12.61%**	-13.09%**
Avg months on market	14.45%**	30.54%***	58.96%***
Number of sales	-27.20%**	-61.21%***	-85.38%***
Perc new def mortg	-15.04%**	-23.23%**	-20.97%**
LTV new mortgages	-23.97%***	-28.59%***	-32.62%***
LSTI new mortgages	-33.09%***	-38.29%***	-39.54%***
NPL stock mortgages	36.67%***	71.26%***	90.60%***
Avg return NPL	-5.96%**	-29.48%**	-54.77%***
Avg foreclosure duration	13.06%***	29.67%***	46.01%***

Table 18. Percentage variation between the average baseline and post-policy intervention values. "*", "**", "***" represent the statistical significance at the 0.05, 0.01 and 0.001 level, respectively.

Experiment	A2.70 (LTVμ 0.60)	B2.70 (LTVμ 0.70)	C2.70 (LTVμ 0.80)
Years post intervention	5	5	5
Avg sale price	-11.69%**	-22.76%***	-32.43%***
Avg months on market	23.64%**	64.42%***	103.34%***
Number of sales	-12.24%**	-22.46%**	-48.85%***
Perc new def mortg	-21.41%**	-26.77%**	-31.87%**
LTV new mortgages	-26.13%***	-32.36%***	-37.63%***
LSTI new mortgages	-38.10%***	-46.28%***	-50.80%***
NPL stock mortgages	0.56%	39.36%***	130.09%***
Avg return NPL	19.48%**	-7.93%**	-12.28%*
Avg foreclosure duration	42.61%***	92.70%***	120.76%***

Table 19. Percentage variation between the average baseline and post-policy intervention values. "*", "**", "***" represent the statistical significance at the 0.05, 0.01 and 0.001 level, respectively.

Experiment	A2.70 (LTVμ 0.60)	B2.70 (LTVμ 0.70)	C2.70 (LTVμ 0.80)
Years post intervention	10	10	10
Avg sale price	-16.34%***	-31.20%***	-46.62%***
Avg months on market	15.21%**	37.07%***	132.46%***
Number of sales	-17.92%**	-27.45%**	-47.06%***
Perc new def mortg	-26.37%**	-27.48%**	-36.91%**
LTV new mortgages	-27.30%***	-33.80%***	-37.06%***
LSTI new mortgages	-41.79%***	-51.77%***	-59.69%***
NPL stock mortgages	-10.99%***	7.80%***	85.25%***
Avg return NPL	52.18%***	55.39%***	3.26%
Avg foreclosure duration	20.77%***	61.10%***	185.47%***

Table 20. Percentage variation between the average baseline and post-policy intervention values. "*", "**", "***" represent the statistical significance at the 0.05, 0.01 and 0.001 level, respectively.

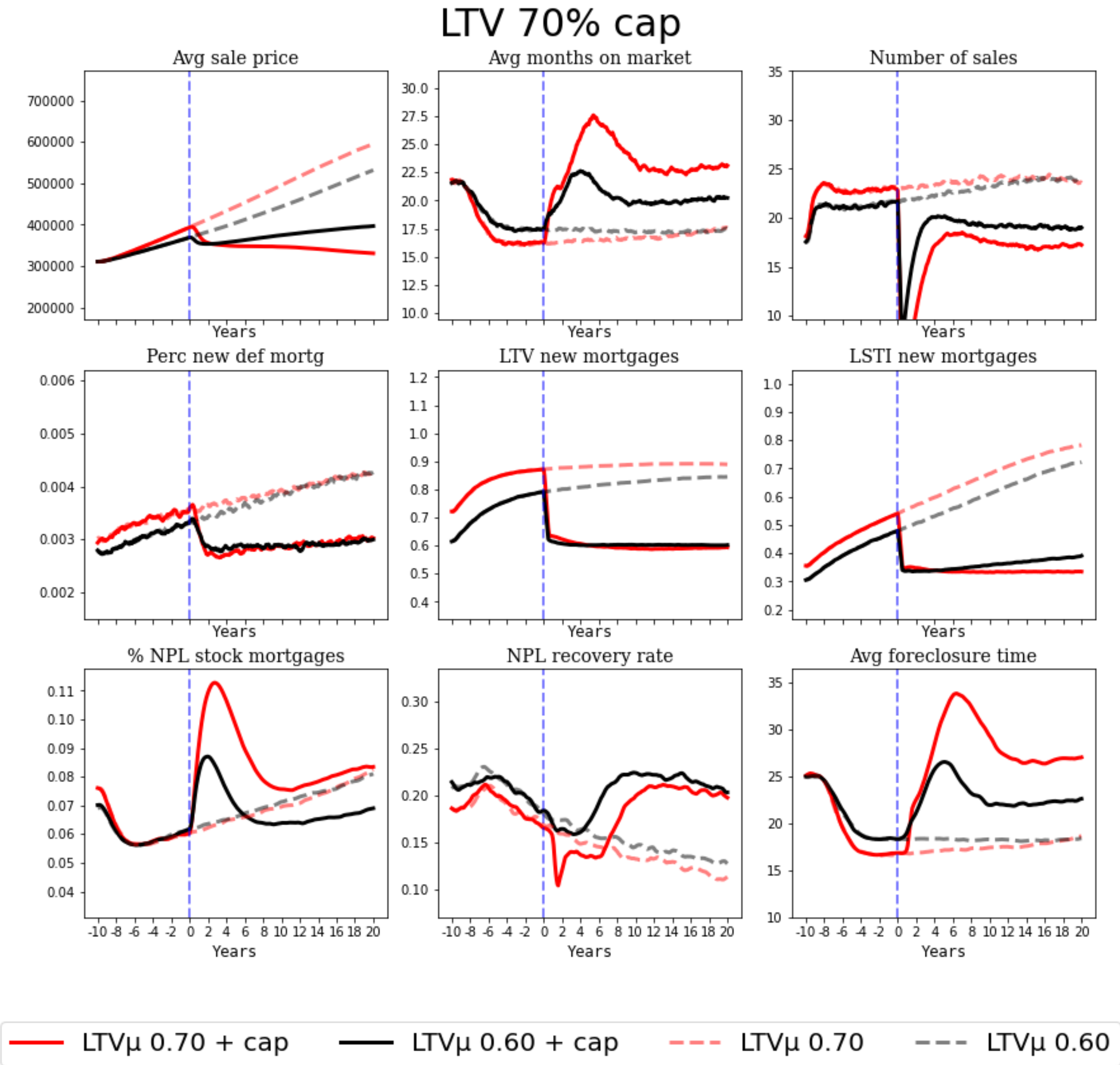

Fig. 11. Endogenous dynamics for experiments “A2.80”, “B2.80”, “C2.80”. The plots show a total of 30 simulated years, the first 10 correspond to a baseline dynamic without policy intervention. The policy shock is introduced at year 0 (marked by the dashed blue vertical line). The shaded trajectories depict the dynamics without policy intervention. Each plot depicts the average trajectory across the simulations in the Monte Carlo ensemble.

Figure 12 presents the effects, on selected variables, of the entire set of experiments presented in this section (experiment set “1”). The main patterns resulting from the introduction of an LTV cap are similar to those observed for experiment set “1” (presented in section 4.2). As described before (section 4.3), the major difference in this set of experiments (experiment set "2") is represented by the upward trend in households' subjective indebtedness tolerance (and the resulting trends in house prices, default rates, and indebtedness). The results show that the LTV caps successfully curb these trends and that their effectiveness depends both how strict the cap introduced is and on how high the average LTV is at the time of the introduction of the policy.[23]

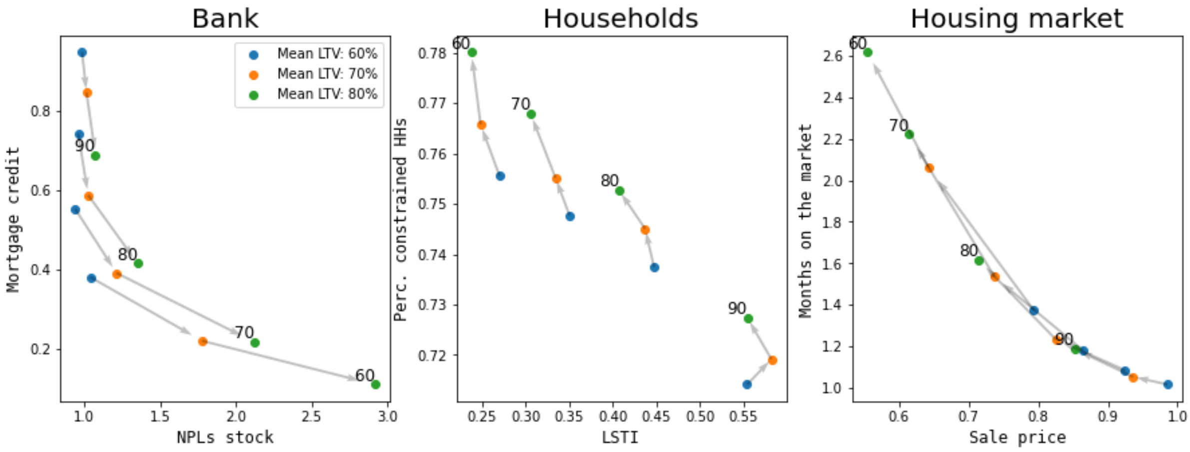

Fig. 12. For each variable, the plots compare their baseline (with no macroprudential policy) average level against their post-policy-intervention average level. The post-policy intervention levels are calculated as an average over the +5 and +10 years window. For the "Bank" and for the "Housing market" panels the values are indexed, with 1.0 being the baseline value. The "Households" panel, instead, depicts the actual values. The number on the green dots (corresponding to population "C") indicates the level of the LTV cap. The experiments performed with the same LTV cap are linked by a grey arrow. For example, for the"Bank" panel, the green dot marked with the number "60" along with the other two dots linked with it by the two gray arrows, indicate the experiments that study the introduction of a 60% LTV cap on the three populations characterized by a different mean of the prevailing LTV (60%, 70%, and 80%).

4.4 Phasing-in and timing

Experimental setting

The third, and last, set of experiments focuses on the impact that timing and a gradual adoption (*phase-in*) have on the effects of the introduction of an LTV cap. The experiments are performed on the same three populations used for the second set of exercises (labelled "A2", "B2", "C2" respectively). These household populations only differ by

[23] Generally the higher the initial mean LTV is, the stronger the effects are for the same cap level.

their mean household indebtedness tolerance level (table 13 describes their characteristics, figure 9 plots their joint $(LTV_i, LSTI_i)$). As for the experiment set "2" of the previous section, the $(LTV_i, LSTI_i)$ joint distribution is not stationary and the experiments simulate a 2% yearly increase in households' subjective LTV and LSTI indebtedness limits (see table 13).

Table 21 catalogues and labels the experiments of this section. All the experiments test the adoption of an eventual 70% LTV cap that is introduced in four hypothetical ways:

1. **"1 step"**: the full 70% LTV cap is introduced 10 years past the onset of the increasing trend in household indebtedness tolerance. Experiments: "A2.70", "B2.70", "C2.70".
2. **"3 steps"**: the 70% LTV cap is introduced gradually in three yearly steps (90%, 80%, 70%). The first policy intervention is carried out 10 years past the onset of the increasing trend in household indebtedness tolerance; Experiments: "A2.70.T1", "B2.70.T1", "C2.70.T1".
3. **"6 steps"**: the 70% LTV cap is introduced gradually in six yearly steps (95%, 90%, 85%, 80%, 75%, 70%). The first policy intervention is carried out 10 years past the onset of the increasing trend in household indebtedness tolerance; Experiments: "A2.70.T2", "B2.70.T2", "C2.70.T2".
4. **"6 steps - proactive"**: the 70% LTV cap is introduced gradually in six yearly steps (95%, 90%, 85%, 80%, 75%, 70%). The first policy intervention is carried out at the onset of the increasing trend in household indebtedness tolerance; Experiments: "A2.70.T3", "B2.70.T3", "C2.70.T3".

LTV cap introduction	Population "A2"	Population "B2"	Population "C2"
1 step	A2.70	B2.70	C2.70
3 steps	A2.70.T1	B2.70.T1	C2.70.T1
6 steps	A2.70.T2	B2.70.T2	C2.70.T2
6 steps - proactive	A2.70.T3	B2.70.T3	C2.70.T2

Table 21. List of the experiments performed and their labeling convention. As an example, a 70% LTV cap on population "B2" is labelled "B2.70".

Results

The third set of experiments aims to shed light on the impact that the gradualness and timing have on the introduction of an LTV cap. The results are presented in figures 13 and 14 and in tables 22, 23, 24 for population "A2" and in tables 25, 26, 27 for population "B2". As for the previous experiment set (experiment set "2"), the baseline scenario is characterized by growing household indebtedness tolerance. The difference from the previous experiments is the timing and how gradual is the introduction of the macroprudential measure. The following are the main observations:

1. **Household indebtedness**: as before (experiment sets "1" and "2"), LTV and LSTI on new mortgages drop. The length of the phase-in determines how quick and sharp is such reduction. Once the phase-in period is concluded, LTV and LSTI on new mortgages follow the same trajectory, irrespective of the initial phase-in length. With the proactive introduction of the LTV limit, the drop in these variables is less steep as it is introduced earlier in the upward trend in indebtedness.

2. **Credit risk**: as before (in the experiment set "2"), in the short to medium term (tables 22, 23, 25 and 26) the policy induces a significant increase in the NPL stock while over the longer-term (tables 24 and 27) its trajectory falls below the baseline trend. Also, compared to the baseline trend, the policy stops the reduction in the realized return of terminated NPL. These experiments (experiment set "3") show that the longer the phase-in the more spread-out the surge in the NPL stock becomes. Finally, a proactive introduction of the 70% LTV cap prevents a significant increase in the NPLs stock and the decrease in their realized returns.

3. **Housing markets**: the length of the phase-in period determines the severity of the impact of the borrower-based measure on the real estate market: the longer it is the less severe its impact (on both house prices and on the number of transactions). Over the medium term, once the introduction of the policy is concluded, there is no significant difference between the length of the phase-in period.

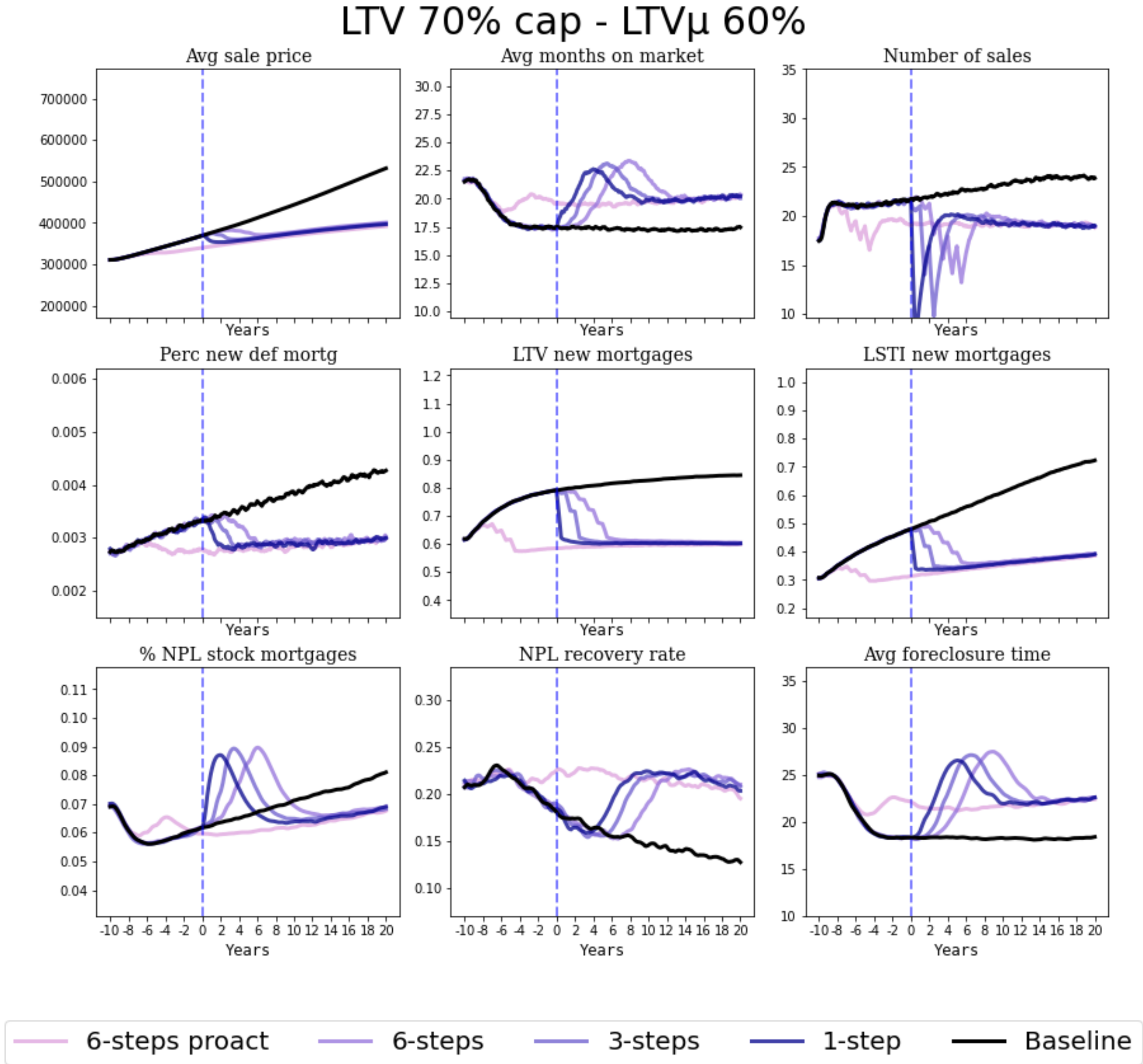

Fig. 13. Endogenous dynamics for experiments “A2.70”, “A2.70.T1”, “A2.70.T2”, “A2.70.T3”. The plots show a total of 30 simulated years, the first 10 correspond to a baseline dynamic without policy intervention. The policy shock is introduced either at year 0 (marked by the dashed blue vertical line), “1-step”, “3-steps”, “6-steps”, or at year −10 (at the onset of the positive trend in indebtedness), “6-step proact”. Each plot depicts the average trajectory across the simulations in the Monte Carlo ensemble.

Experiment	A2.70	A2.70.T1	A2.70.T2	A2.70.T3
Years post intervention	1	1	1	1
Avg sale price	-7.15%**	-2.39%*	-0.38%	0.02%
Avg months on market	14.45%**	4.54%*	0.49%	-0.22%
Number of sales	-27.20%**	-29.42%***	-4.06%*	0.80%
Perc new def mortg	-15.04%*	-3.63%	-1.35%	1.43%
LTV new mortgages	-23.97%***	-10.36%***	-1.79%*	-0.02%
LSTI new mortgages	-33.09%***	-16.77%**	-2.98%	-0.11%
NPL stock mortgages	36.67%***	13.11%**	2.13%*	0.60%*
Avg return NPL	-5.96%**	-3.48%*	-0.89%	-1.88%
Avg foreclosure duration	13.06%***	1.90%**	0.62%	0.40%

Table 22. Percentage variation between the average baseline and post-policy intervention values. "*", "**", "***" represent the statistical significance at the 0.05, 0.01 and 0.001 level, respectively.

Experiment	A2.70	A2.70.T1	A2.70.T2	A2.70.T3
Years post intervention	5	5	5	5
Avg sale price	-11.69%**	-11.31%**	-9.24%**	0.01%
Avg months on market	23.64%**	32.94%***	25.52%***	-1.07%
Number of sales	-12.24%**	-11.63%**	-35.05%***	0.30%
Perc new def mortg	-21.41%*	-21.96%**	-19.40%*	-0.34%
LTV new mortgages	-26.13%***	-25.61%***	-23.70%***	-0.07%
LSTI new mortgages	-38.10%***	-37.65%***	-34.95%***	-0.45%
NPL stock mortgages	0.56%	14.17%**	32.52%***	0.23%
Avg return NPL	19.48%**	2.26%	-0.35%	2.16%
Avg foreclosure duration	42.61%***	45.41%***	24.83%***	-0.19%

Table 23. Percentage variation between the average baseline and post-policy intervention values. "*", "**", "***" represent the statistical significance at the 0.05, 0.01 and 0.001 level, respectively.

Experiment Years post intervention	A2.70 10	A2.70.T1 10	A2.70.T2 10	A2.70.T3 10
Avg sale price	-16.34%**	-15.98%**	-15.44%**	-3.96%*
Avg months on market	15.21%**	15.82%**	22.17%**	10.49%*
Number of sales	-17.92%**	-16.92%**	-15.96%**	-18.00%**
Perc new def mortg	-26.37%**	-24.94%**	-24.58%**	-9.32%*
LTV new mortgages	-27.30%***	-26.91%***	-26.39%***	-23.97%***
LSTI new mortgages	-41.79%***	-41.64%***	-40.87%***	-29.51%***
NPL stock mortgages	-10.99%***	-10.09%***	-5.54%**	13.54%**
Avg return NPL	52.18%***	50.78%***	39.42%**	1.23%
Avg foreclosure duration	20.77%***	23.71%***	39.61%***	9.77%*

Table 24. Percentage variation between the average baseline and post-policy intervention values. "*", "**", "***" represent the statistical significance at the 0.05, 0.01 and 0.001 level, respectively.

Experiment Years post intervention	B2.70 1	B2.70.T1 1	B2.70.T2 1	B2.70.T3 1
Avg sale price	-12.61%**	-6.29%*	-1.86%	0.02%
Avg months on market	30.54%***	16.55%**	3.98%*	-0.41%
Number of sales	-61.21%***	-59.67%***	-19.79%**	-0.74%
Perc new def mortg	-23.23%**	-9.14%*	-3.61%	1.47%
LTV new mortgages	-28.59%***	-15.21%***	-4.42%***	0.07%
LSTI new mortgages	-38.29%***	-24.30%**	-7.74%*	0.12%
NPL stock mortgages	71.26%***	35.23%***	10.86%**	0.04%
Avg return NPL	-29.48%**	-8.76%*	-2.58%	-0.11%
Avg foreclosure duration	29.67%***	7.21%**	1.62%*	0.46%

Table 25. Percentage variation between the average baseline and post-policy intervention values. "*", "**", "***" represent the statistical significance at the 0.05, 0.01 and 0.001 level, respectively.

Experiment	B2.70	B2.70.T1	B2.70.T2	B2.70.T3
Years post intervention	5	5	5	5
Avg sale price	-22.76%***	-21.63%***	-17.96%**	-0.04%
Avg months on market	64.42%***	63.72%***	47.82%***	0.11%
Number of sales	-22.46%**	-24.37%**	-51.28%***	-1.21%
Perc new def mortg	-26.77%**	-27.64%**	-25.41%**	-0.51%
LTV new mortgages	-32.36%***	-31.46%***	-28.99%***	-0.86%
LSTI new mortgages	-46.28%***	-44.80%***	-41.08%***	-1.33%
NPL stock mortgages	39.36%***	55.55%***	70.04%***	0.08%
Avg return NPL	-7.93%**	-9.17%**	-9.99%**	0.83%
Avg foreclosure duration	92.70%***	82.14%***	53.24%***	-0.09%

Table 26. Percentage variation between the average baseline and post-policy intervention values. "*", "**", "***" represent the statistical significance at the 0.05, 0.01 and 0.001 level, respectively.

Experiment	B2.70	B2.70.T1	B2.70.T2	B2.70.T3
Years post intervention	10	10	10	10
Avg sale price	-31.20%***	-30.37%***	-28.84%***	-9.18%**
Avg months on market	37.07%***	41.65%***	58.24%***	26.35%**
Number of sales	-27.45%**	-27.44%**	-25.26%**	-30.83%**
Perc new def mortg	-27.48%**	-26.51%**	-27.51%**	-16.65%*
LTV new mortgages	-33.80%***	-33.34%***	-32.82%***	-31.40%***
LSTI new mortgages	-51.77%***	-50.98%***	-49.73%***	-37.79%***
NPL stock mortgages	7.80%***	9.49%***	21.02%***	30.12%***
Avg return NPL	55.39%***	48.48%***	23.54%***	3.88%
Avg foreclosure duration	61.10%***	71.97%***	94.48%***	28.83%***

Table 27. Percentage variation between the average baseline and post-policy intervention values. "*", "**", "***" represent the statistical significance at the 0.05, 0.01 and 0.001 level, respectively.

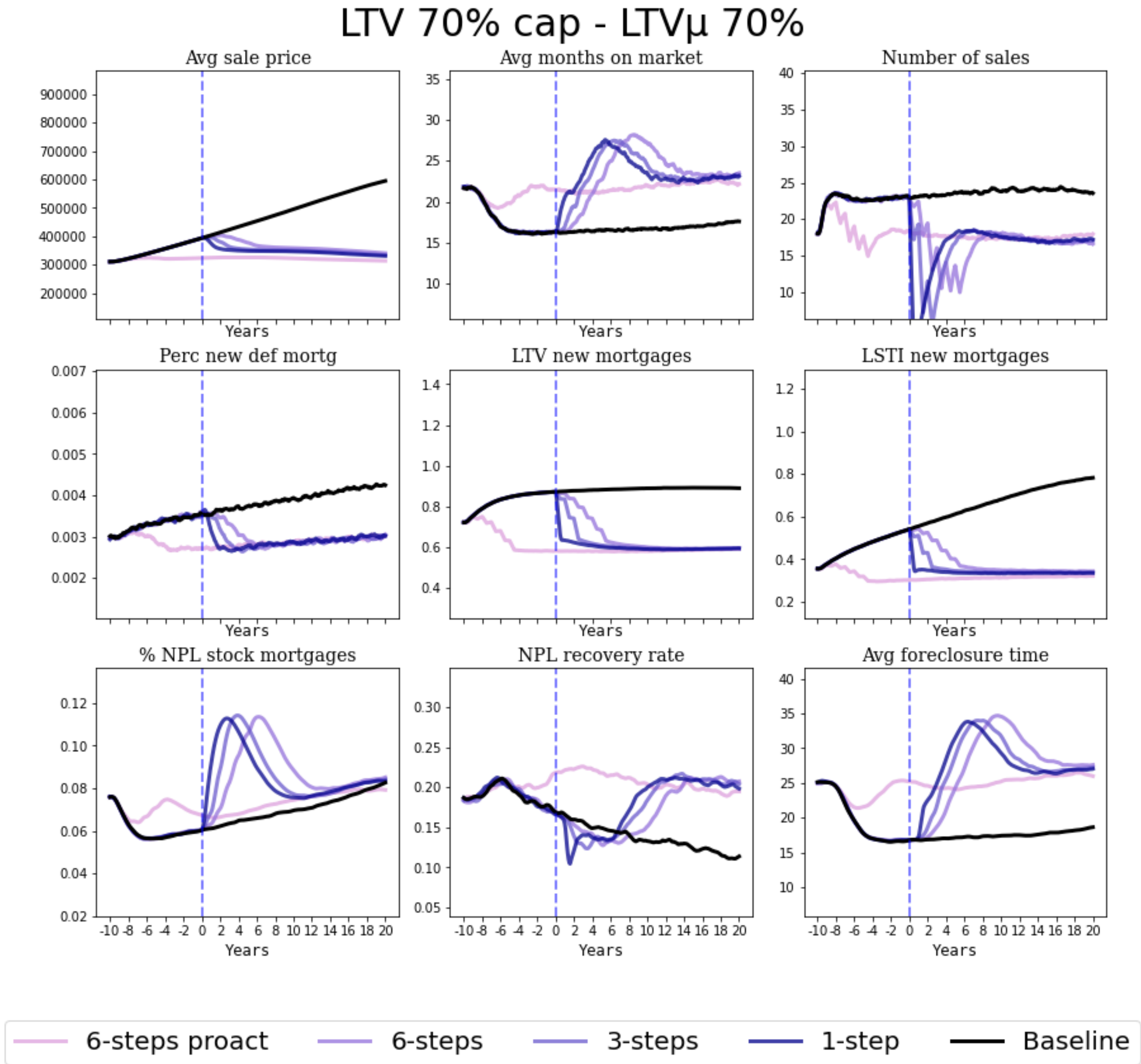

Fig. 14. Endogenous dynamics for experiments "B2.70", "B2.70.T1", "B2.70.T2", "B2.70.T3". The plots show a total of 30 simulated years, the first 10 correspond to a baseline dynamic without policy intervention. The policy shock is introduced either at year 0 (marked by the dashed blue vertical line), "1-step", "3-steps", "6-steps", or at year −10 (at the onset of the positive trend in indebtedness), "6-step proact". Each plot depicts the average trajectory across the simulations in the Monte Carlo ensemble.

5 Results

5.1 Comments on the results

From a qualitative standpoint, these results are in line with economic intuition. In general, the introduction of the LTV caps on newly issued mortgages tends to reduce the loan riskiness (favoring a reduction in the NPL stock and an increase in their realized return potentially causing an increase in the bank profitability)[24] and household indebtedness. It also tends to reduce the price and, temporarily, the liquidity of residential properties while making it harder for some households to afford a house via mortgage financing.

From a quantitative standpoint, the numerous experiments described in this paper suggest that the magnitude and duration of each of the effects (both on banks and households) and the possible presence of transient dynamics (for example on housing liquidity) is context-depended. In particular, the experiments highlighted the main factors driving the results: the severity of the cap in relation to the prevailing mean LTV and LSTI (section 4.3); the dispersion in households' subjective indebtedness tolerance (section 4.2); the presence of an upward trend in household indebtedness (sections 4.3 and 4.4); the length of the phase-in period and timing of introduction (section 4.4).

The results show that particularly favorable consequences materialize when a relatively moderate LTV cap (from 90 to 70%) is introduced gradually (in the experiments using a 6-year phase-in period) in a scenario characterized by relatively high and growing household indebtedness (from a mean LTV of 70%). In this context, the macroprudential policy intervention effectively curbs the accumulation of risks (reducing the flow of new defaults) and the rise in house prices while minimizing the negative and transient effects on real estate liquidity and the NPL stock. Moreover, the experiments indicate that the best approach could be the preemptive introduction of a moderate LTV cap at the onset of an upward trend in prevailing LTV and LSTI (section 4.4). In this latter case, the policy intervention would prevent the build-up of risks and excessive indebtedness while having little or no impact on the real estate market in terms of liquidity or prices.

The experiments illustrated in this paper have focused on the analysis of a particular form of household heterogeneity: the households' individual indebtedness preferences (LTV_i and $LSTI_i$). In particular, the experiments used three synthetic populations characterized by an increasing level of dispersion in the cross-sectional distribution of the

[24] Bank profitability may initially drop as a result of the reduced flow of credit.

maximum indebtedness tolerated ($\sigma(LTV_i)$ and $\sigma(LSTI_i)$). The results highlighted the fact that this type of heterogeneity does impact the dynamics induced by the introduction of the macroprudential policies studied in this paper. In particular, its impact ranges from the economically significant and widespread across different experimental settings to the more severe outcomes of some specific scenarios. The milder and more general of these effects concerns the differential impact on house affordability and on the supply of credit. The more severe, and specific to particular settings, concerns a medium-term (5 to 10 years post-intervention) increase in the NPL stock and a considerable negative impact on the real estate markets.

6 Conclusions and future work

The model presented in this paper is a direct evolution of the one described in Catapano et al., 2021, which in turn, is a descendent of the model studied in Baptista et al., 2016. It introduces several extensions and improvements like a more refined idiosyncratic income process for households, and a more realistic treatment of the mortgage status and of defaults and foreclosures. Furthermore, it reduces some of the costs associated with the use of a large-scale ABM as it is easier to calibrate and has a drastically lower computational cost.

While the model exhibits several enhancements in comparison to its direct predecessor, there could still be scope for further improvements. As an example, further research might focus on a more complete assessment of the banking-system profitability (which is now indirectly evaluated). Moreover, as the main objective of the present work has been to implement and describe the extensions to the original model, the calibration used for the experiment is only loosely based on empirical Italian data.

Besides presenting the new model, this paper describes three sets of experiments concerning the introduction of various LTV caps in a plethora of different scenarios (section 5.1). The results indicate that the borrower-based measure is generally effective in reducing or preventing the excessive accumulation of risks or rising house prices. The macroprudential measure may also have unintended side effects (for example a transitory reduction in liquidity in the housing markets). The experiments performed in this article shed light on some of the main drivers behind the prevalence, intensity, and type of these effects and thus indicate the scenarios in which an LTV cap might have the most favorable outcome profile. Thus, the arguments proposed and the model presented in this article might contribute to the policy debate concerning the calibration of and the potential advantages afforded by the use of borrower-based macroprudential measures.

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