

Avanzini, Diego; Martínez, Juan Francisco; Pérez, Víctor

Article

Assessing mortgage default risk in full-recourse economies, with an application to the case of Chile

Latin American Journal of Central Banking (LAJCB)

Provided in Cooperation with:

Center for Latin American Monetary Studies, Mexico City

Suggested Citation: Avanzini, Diego; Martínez, Juan Francisco; Pérez, Víctor (2020) : Assessing mortgage default risk in full-recourse economies, with an application to the case of Chile, Latin American Journal of Central Banking (LAJCB), ISSN 2666-1438, Elsevier, Amsterdam, Vol. 1, Iss. 1/4, pp. 1-18,
<https://doi.org/10.1016/j.latcb.2020.100009>

This Version is available at:

<https://hdl.handle.net/10419/336299>

Standard-Nutzungsbedingungen:

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

Terms of use:

Documents in EconStor may be saved and copied for your personal and scholarly purposes.

You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.

If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.



<https://creativecommons.org/licenses/by-nc-nd/4.0/>

Contents lists available at [ScienceDirect](https://www.sciencedirect.com)

Latin American Journal of Central Banking

journal homepage: www.elsevier.com/locate/latchb

Assessing mortgage default risk in full-recourse economies, with an application to the case of Chile [☆]

Diego Avanzini ^{a,*}, Juan Francisco Martínez ^b, Víctor Pérez ^c^a International Center for Globalization and Development—CIGLOB, Chile^b Central Bank of Chile, Chile^c Provida AFP, Chile

ARTICLE INFO

*JEL classification:*C35
D53
E44
G21*Keywords:*Default
Mortgage loan
Survey data
Full-recourse economy
Rare events
Credit market

ABSTRACT

This paper is aimed at finding individual and systemic determinants of housing default in a full-recourse economy. We propose an empirical strategy that accounts for rare events and choice-based sampling bias and estimates the contribution of idiosyncratic and systemic determinants, as well as their interactions. To support our empirical approach, we adapt and extend a well-known model of mortgage default for nonrecourse economies (Geanakoplos and Zame, 2014), adding a nonpecuniary cost for defaulting to account for possible loss of utility due to the full-recourse framework. This model applies to economies such as Spain, Australia, and Chile, where defaulters can be prosecuted until their debts are completely settled. Under the proposed model, we obtain an analytical expression involving default determinants for micro and macro mortgage loans. As a case study, we estimate this relationship for the Chilean economy using information from the Chilean Survey of Household Finance (EFH). As stated by our micro–macro model, household financial conditions and their interactions with systemic determinants account for an important part of the cross-sectional probability of mortgage default.

1. Introduction

The 2008 financial crisis tested academics and regulators in their ability to anticipate possible sources of instability. Some of the lessons that can be learned from the latest global financial crisis is that policy models and their estimates should take into account factors that might have been overlooked at some point. The recent experience suggests the existence of a mortgage channel that acts as an amplifier of financial instability. This is why, for central banks and policy makers, it is crucial to understand the mechanisms at place and to use richer sources of data to measure them.

[☆] This paper has been prepared for the Central Bank of Chile Workshop on Housing (Santiago, 2014). The current version benefited from discussions at the Superintendence of Banks and Financial Institutions (SBIF, now Financial Market Commission, CMF) Conference on Banking Development, Stability and Sustainability, (Santiago, 2015) and the Irving Fisher Committee Workshop on Combining Micro and Macro Statistical Data for Financial Stability Analysis: Experiences, Opportunities and Challenges (Warsaw, 2015). The views and conclusions presented in this paper are exclusively those of the authors and do not necessarily reflect the position of the Central Bank of Chile or of the board members. We are grateful to Natalia Gallardo for contributing in a preliminary stage of this work. We are indebted to two anonymous referees at the LABJCB and reviewers of earlier versions of this work. All errors are our own.

* Corresponding author.

E-mail address: avanzini@gmail.com (D. Avanzini).<https://doi.org/10.1016/j.latchb.2020.100009>

Received 13 February 2020; Received in revised form 28 July 2020; Accepted 14 September 2020

Available online 24 October 2020

2666-1438/© 2020 The Authors. Published by Elsevier B.V. on behalf of Center for Latin American Monetary Studies. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>)

In this work, we solve the question of finding individual and systemic determinants of housing default in a *full-recourse economy*. In doing so, we contribute to the existing literature in two different ways.¹ On one hand, we improve the approach to analyzing mortgage default determinants empirically, taking into account some particular features of the phenomenon we are studying. On the other hand, we support our presentation with a theoretical model that incorporates micro- and macrofinancial determinants and their interactions for a full-recourse regulatory framework. The theoretical model allows for better understanding of the role determinants play in predicting delinquency and highlighting the distinctive results posed by the full-recourse mortgage regulation. We apply the framework to the Chilean economy as a case study, and test it empirically by using a rich source of microdata coming from the Chilean Survey of Household Finance.²

Recent literature highlights several determinants of mortgage delinquency, especially in the aftermath of the 2008 housing crisis. For example, mortgagors facing negative equity appear more prone to default (e.g. [Geanakoplos and Fostel, 2008](#)). This determinant exacerbates delinquency in nonrecourse economies, as shown in [Foote et al. \(2020\)](#). Furthermore, income distribution ([Kumhof et al., 2015](#); [Adelino et al., 2016](#)), interest rate type ([Campbell and Cocco, 2015](#)), foreclosure regulation ([Chan et al., 2016](#)), expectations ([Brueckner et al., 2016](#)), credit scoring ([Demyanyk et al., 2011](#)), and other household characteristics were included as significant determinants of mortgage default. Moreover, some controversial results related to refinancing versus newly originated mortgages were found, attributing higher delinquency rates to new mortgagors around the 2008 crisis ([Mayer et al., 2009](#)).

Notice that all of these results are framed in *nonrecourse economies*. Nonrecourse credit regulation states that the lender gets the collateral only after the occurrence of a default, and it is not allowed to prosecute other payments or compensations from the debtor. In this way, modelers avoid the imposition of deadweight losses associated to other punishments in cases of default.³

However, when modeling the determinants of mortgage default for economies such as Australia, Chile, and Spain, we need to introduce the case of *full-recourse* regulation. Under this type of regulation, agents can be prosecuted until their debts are completely settled. This implies that the incentives to repay should be enhanced. In a full-recourse framework, the incentive to default due to negative equity is counteracted by the fact that, if the collateral is not sufficient to cover the promises, the creditor has the right to go after the debtor's other assets. There is also a reputational effect given that the prosecuted debtors are listed publicly.

All of these issues motivate us to develop a modeling alternative that adapts the seminal framework of [Geanakoplos and Zame \(2014\)](#)⁴ and extends it to incorporate distinctive features of a full-recourse economy. The theoretical model allows us to improve the identification and estimation of default determinants in the mortgage market under a full-recourse regulatory framework.

Our empirical approach takes advantage of the conclusions coming from this theoretical model and tests the hypothesis, taking into account the particular nature of the phenomenon. First, even though loan delinquency may harm lenders' balance sheets, defaulting a loan is not a usual event. Moreover, this is particularly rare in the case of mortgage loans. Thus, usual estimation strategies based on logistic regression are biased due to finite samples and rare event data. Second, getting suitable data to analyze the problem at hand comes at the cost of oversampling the phenomenon, which introduces a sampling bias that requires proper treatment. We deal with both problems at once by obtaining robust and efficient estimates.

Finally, our results can contribute to support credit policy measures and enhance the analysis and application of mortgage banking stress tests. In particular, we apply this methodology to the Chilean economy, but it may be relevant to other countries, such as those already mentioned.

The rest of the work is structured along the following lines. [Section 2](#) gives context to our contribution, by reviewing different approaches to analyzing mortgage default determinants. [Section 3](#) introduces the theoretical model that supports our empirical approach. [Section 4](#) highlights the role of the determinants as they emerge from the model. In [Section 5](#), we describe the empirical methodology and the dataset we use for the estimations. We present and discuss the results in [Section 6](#). Some final remarks are in [Section 7](#). The Appendix contains derivations and proofs from the model, a supporting glossary, and some data description.

2. Framing our approach to the determinants of mortgage default

The main question of our paper is to find individual and systemic determinants of housing default in a full-recourse economy. Motivated by a stylized general equilibrium model, the main contribution of our work is the empirical evaluation of different hypothesis and the use of a novel dataset that merges information from the Chilean EFH with administrative banking information.

In doing so, we deal, at least, with four features of the problem. First, we need to differentiate nonrecourse from full-recourse regulatory frameworks to identify distinctive features and find a suitable strategy to introduce them in the model. Second, we expect that in a full-recourse economy the determinants of mortgage default may vary relative to the usual findings in the literature, in nature and behavior. Thus, we need to account for these changes in the results. Third, we need to choose the type of data to use in

¹ In recent years, theoretical advances and economic necessity have stimulated the study of the default decision, especially on mortgage loans. Since [Kau et al. \(1994\)](#) and [Capozza et al. \(1997\)](#), theoretical models and empirical testing have been integrated into the search for a better understanding of the phenomenon. Following those efforts, we elaborate on the theoretical modeling of mortgage default and propose an estimation strategy for the resulting model using macro- and microdata.

² From now on, "EFH", for its name in Spanish: "Encuesta Financiera de Hogares". The survey has been conducted by the Central Bank of Chile (BCCh) since 2007.

³ As [Geanakoplos and Zame \(2014\)](#) state, the only seizure of collateral "[...] avoids the moral and ethical issues of imposing penalties in the event of bad luck." However, they recognize that, in practice, the seizure of collateral implies deadweight losses on its own.

⁴ Note that this is a published version of a working paper first issued in 1997.

testing our hypothesis. Finally, based on the answers to all these aspects, we have to find an empirical strategy that ensures robust, efficient estimates.

The first two features are intrinsically related. Determinants of mortgage default are studied extensively for the nonrecourse economy, but the behavior under full-recourse regulation has been less investigated. In particular, incentives to default under both regulatory frameworks differ, affecting the probability of defaulting loans.

It is widely accepted in the current economic literature, that—in aggregate terms—a mortgagor facing a negative equity is prone to default. In this case, when the value of debt is higher than the value of the collateral, there are incentives to decide not to repay because, ideally, it is cheaper to give up the property and to stop repaying. This mechanism is at the heart of various recent crisis-related papers, such as those of Geanakoplos and Foster (2008) and Goodhart et al. (2011).⁵ In particular, Geanakoplos and Zame (2014),⁶ the model that inspires our treatment of the default phenomenon in this work, we detour from the explicit modeling of asymmetric information but allow for an equilibrium with endogenous default. To do this, they base their model—as most of the theoretical literature in this field does—on a *nonrecourse* credit regulation.

Under a full-recourse framework, however, incentives to default are counteracted by the right of the lender to prosecute the debtor until the debt is completely settled. Economic intuition indicates that our model should incorporate a mechanism that further discourages mortgagors from defaulting. This is consistent with the idea that mortgagors do not always default when they face negative equity on their homes, as in Harrison et al. (2004) or Ellul et al. (2010). In fact, Foster and Van Order (1984) and Bhutta et al. (2010) find that many borrowers with negative equity do not default. Conversely, default is often associated with shocks, such as unemployment. In addition, the cost of continuing to repay a mortgage also depends on the agent's idiosyncratic discount factor, and hence on his liquidity position, as Elmer and Seelig (1999), Gerardi et al. (2007), and Bajari et al. (2010) explain.

Our model formulation closely follows part of the Goodhart et al. (2011) work, which is a recent application based on the Geanakoplos and Zame (2014, and the earlier work dated 1997) model. Yet, to modify the mortgage default incentives, we add a nonpecuniary cost that arises as a reputational loss because of the burden of being forced to repay the debt and other possible losses of utility (e.g. being blacklisted from the credit market or being banned from future credit opportunities). Natural references that we consult to address this type of default cost are those of Shubik and Wilson (1977) and Dubey et al. (2005). With Geanakoplos and Zame (2014), these works lie within the general equilibrium literature. Our contribution consists in combining both frameworks to generate a full-recourse economy, such as those of Spain, Australia, and Chile.

Another feature of the full-recourse mortgage contracts is that discouraging defaults imply higher macroeconomic impacts of systemic events. Gete and Zecchetto (2018) show, in a general equilibrium setting, that full-recourse mortgages decrease the liquidity of housing and limit the capacity of the markets to accommodate aggregate shocks. In our work, we incorporate aggregate shocks, such as housing prices drops, which, in the presence of a full-recourse mortgage contract setting, may have a lower impact in the individual default incentives (as we find). However, the drops still play a key general equilibrium factor because they interact with idiosyncratic factors, related to specific income shocks.

Additionally, the literature supports the idea that housing booms and busts are systemic events that trigger defaults in an aggregated manner. In a closely related work, Foote et al. (2020), using a general equilibrium setting and empirical exercises, demonstrate that the distribution of mortgage credit allocation during the boom of 2000s was stable (i.e. housing wealth and debt remained steady during the span). However, they found that housing growth was related to an endogenous relaxation of credit standards. In particular, while the distribution of the housing boom was uniform among agents, mortgage originations increased in low-income households, as did mortgage terminations. This finding allows for understanding of the determinants of defaults during the bust too. In fact, the authors find that the decline in house prices triggered a widespread increase in the default rate across the United States. This gives support to housing prices as systemic determinants of defaults, such as in our work.

The third aspect of the problem relates to the selection of the data type to use in our empirical approach. Deciding on the inclusion of systemic or idiosyncratic information may change the richness of implications derived from our estimations to explain mortgage default behavior.

In this regard, Garriga and Hedlund (2019) discuss the most recent literature on the housing crisis, causes, and consequences and find that, despite the significant degree of heterogeneity of legal and institutional settings, housing cycles share an important set of features among different economies. They suggest that the use of microdata may play a key role in refining current models and explanations of housing crises and, hence, default incentives and cyclical behavior of prices and quantities in this market. Our work gives light to this stream of literature because it concerns the detection of default determinants given a particular feature of mortgage contracts, separating them into systemic and idiosyncratic factors.

To test our framework, we apply it to the Chilean case. The literature modeling default decisions in the Chilean economy is rather brief. One of the most recent investigations is by Alfaro and Gallardo (2012), in which they estimate an empirical characterization of default behavior using the EFH 2007 survey. They find that income and income-related variables are the only significant and robust factors that explain default for both types of debt (consumer and mortgage). Additionally, demographic variables can help to explain further default probabilities.

⁵ Other influential papers that model a collateral financial economy are Kiyotaki and Moore (1997) and Bernanke et al. (1999), but instead of households, these works model firms' dynamics under the presence of a credit market affected by asymmetric information. In their settings, the risk premium depends on the firms' probabilities of default, which in turn relate to the value of net worth.

⁶ Note that this is a published version of a working paper first issued in 1997.

Empirical evidence suggests that there is some rich information hidden away in aggregated (or macro) data. Thus, the use of microdata seems a promising research avenue. That is why, instead of using financial aggregates of credit and macrofinancial conditions to determine default dynamics through time, we follow [Alfaro and Gallardo \(2012\)](#) in the sense that we use microdata coming from the EHF survey. In this work, compared to the latter and beyond contributing with a theoretical modeling framework, we are able to profit from the additional information that the EHF survey has gathered through the years since it was launched in 2007.

Finally, we acknowledge that dealing with loan delinquency imposes additional challenges from an empirical point of view. Most of the literature mentioned above, disregarding if they use microdata, macrodata, or both types of data, rely on logistic regressions to analyze the probability of defaulting loans. However, loan delinquency is a rare event that needs special treatment to avoid logistic regression and finite sample bias. On the other hand, to develop better insights into the phenomenon, we may take advantage of oversampling the defaulted households, but this imposes another source of bias in our estimates. As explained in [Section 5](#), we deal with both problems, adopting an empirical approach taken from the rare event's statistical treatment in medical trials and political conflict.

Our theoretical and empirical approach tries to take into account all of these features. While the theoretical model helps to incorporate the characteristic aspects of the full-recourse economy, highlighting the role of systemic and idiosyncratic determinants, the empirical approach deals with the construction of robust, efficient estimators using microdata and aggregated data on household financial behavior.

3. A theoretical model of the determinants of default

In this section, we introduce and describe a partial equilibrium model that motivates our empirical estimations to provide a general view of the mortgage default mechanism at play. We describe the economy, agents, financial structure, transactions, and its timing.

Our model considers a two-period setup. The beginning ($t = 0$) is deterministic, but the second period ($t = 1$) is stochastic. In the latter, there are s possible states of nature that occur with probability π_s .⁷ To help notation, we also define $S = \{0, s\}$, a tuple that groups both periods, and consider the possible states at the second period.

One representative household composes the economy. There are two goods traded in this economy: a consumption commodity and housing. We also have two types of financial assets: one short-term (intra-period) unsecured loan and one long-term (inter-period) collateralized loan.

The household is endowed with money and a perishable commodity, which it consumes and sells. The endowment is deterministic in the first period, and depends on the realized state of nature in the second period. The agent also consumes housing in both periods that it has to be purchased. There are two differences between commodities and housing. On the one hand, commodities are perishable (they only provide utility in the period they are available), while durable goods (house) purchased at the initial period ($t = 0$) also give utility at the final one ($t = 1$). On the other hand, housing also serves as collateral when contracting a long-term loan.

3.1. Financial intermediation

The financial intermediation in this model is assumed exogenous, and it is treated in a stylized manner. However, it can be thought of as a representative bank (or banking system) that lends short-term to the representative household,⁸ as well as an inter-period collateralized mortgage loan. The latter is only available at $t = 0$. An exogenous amount of liquidity is pumped into the system, and it is reflected in the short- and long-term interest rates (r_s and \bar{r} , respectively).⁹ [Fig. 1](#) depicts the nominal flows of the economy.

3.2. Timing

At the initial period ($t = 0$), short-term liquidity borrowing plus long-term mortgage borrowing from the representative household occur. Provided the financing and transactions in commodity and mortgage markets take place. The representative agent sells part of his endowment of the consumption commodity and uses the revenues to repay the short-term loan obligations. Under the current setup, short-term obligations arise because of the assumption of a cash-in-advance financial economy. The agent also purchases housing, which is financed with a collateralized long-term mortgage loan. Finally, consumption of housing and commodity takes place.

During the second period ($t = 1$), the nature realizes and reveals s , which mainly affects endowments—including monetary—and money supplies, as we observed before. At this period, the intra-period transactions work in a similar manner than at the beginning. However, there are slight, but significant, differences. First, the long-term interest rate is already fixed because the long-term money market does not open at every period. Second, the representative household, conditional on his delivery (or default) decision, settles the mortgage loan. At this period, he uses the short-term money market to repay the long-term loans and finances his housing consumption ([Fig. 2](#)).

⁷ Late, we will specify our state variables as commodity endowments and liquidity conditions (i.e. interest rates and monetary endowments).

⁸ To help the focus of the analysis and without loss of generality, this type of loan is assumed to be default-free.

⁹ It can be thought of as the monetary authority that injects a certain amount of resources in the money market, influencing the short-term rates (e.g. through M_s) and long-term interest rates (e.g. through \bar{M}).

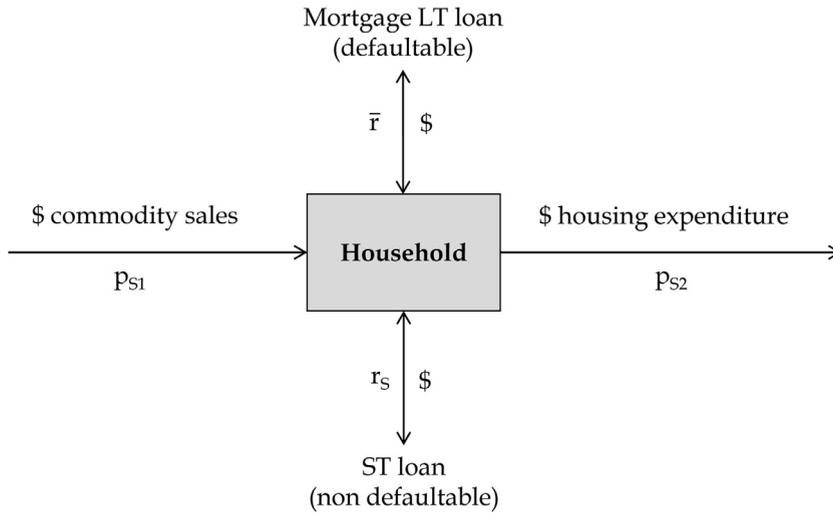


Fig. 1. Nominal flows.

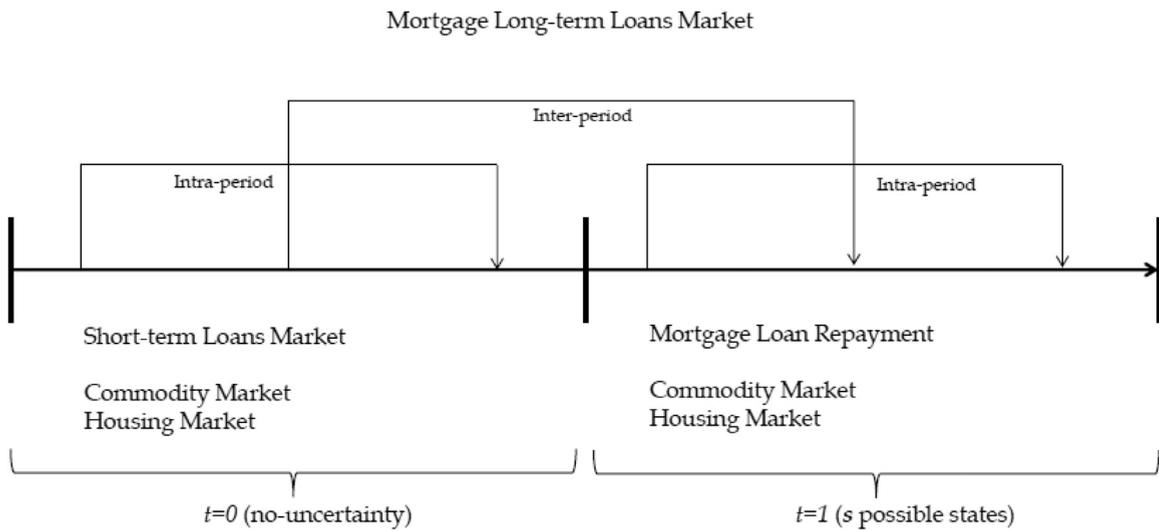


Fig. 2. Timing of markets and transactions.

3.3. Economy and budget set

The economy is composed by a positive endowment of the perishable commodity e_{S1} ; positive monetary endowment m_S ; preferences U ; financial assets consisting of long- and short-term loans at rates \bar{r} and r_S , respectively. We assume that, in this economy, preferences are monotonic and utility is quasi-concave.

Given a set of securities (i.e. short- and long-term loans) Λ ; commodity price p_{S1} ; housing price p_{S2} ; rate of return of the short- and long-term credit market r_S and \bar{r} , respectively; the mortgagor with commodity endowment e_{S1} makes consumption plans, credit demands, sales of commodity, and deliveries against promises.¹⁰ Following Geanakoplos and Zame (2014), in the case of mortgages, optimal deliveries will always be the minimum of promises (i.e. credit demand) and the value of the collateral. Thus, we define the budget set for the representative household as $B(p_1, p_2, r_S, \bar{r}, e_{S1}, \Lambda)$ to be the set of plans $(\mu, \bar{\mu}, q_{S1}, b_{S2})$, where μ stands for the short term borrowing, $\bar{\mu}$ is the mortgage borrowing, q_{S1} represents the commodity sales, and b_{S2} stands for housing expenditure.

We have that, at the initial date ($t = 0$), the agent is subject to three budget constraints. First, the short-term loans must not exceed the revenues from commodity sales. Second, the housing expenditure must be lower than or equal to its long- and short-term credits

¹⁰ Our notation for prices, quantities, and monetary expenditures contains a subindex with two components. The first one is the period (or state at $t = 1$), and the second term indicates the type of good: 1 for commodities and 2 for housing.

and monetary endowments. Finally, the third constraint considers an element of mortgage credit regulation. There is a fixed portion of collateral (i.e. ϕ) required for a mortgage loan.¹¹

Formally, we have that, at $t = 0$

$$\begin{aligned} \mu_0 &\leq p_{01}q_{01} \\ b_{02} &\leq \frac{\mu_0}{1+r_0} + \frac{\bar{\mu}}{1+\bar{r}} + m_0 \\ \frac{\bar{\mu}}{1+\bar{r}} &\leq \phi b_{02} \end{aligned}$$

Conversely, at the final date ($t = 1$), the agent is subject to two budget constraints. The first constraint reflects the fact that the short-term loans must not exceed the revenues from commodity sales. The second budget constraint depends on the state of nature that is realized. Thus, under a good state of nature (i.e. $s \in S_G$, where no default is exerted), the constraint states that the repayment of the mortgage loans plus the household's new housing consumption (i.e. a type of housing top-up) must not exceed the agent's short-term borrowing and monetary endowment. Under a bad state of nature (i.e. $s \in S_B$, there is default), the constraint accounts for the fact that there is no mortgage repayment.

Formally, at $t = 1$, the constraints are

$$\begin{aligned} \mu_s &\leq p_{s1}q_{s1} \\ b_{s2} + \bar{\mu} &\leq \frac{\mu_s}{1+r_s} + m_s \quad \forall s \in S_G \\ b_{s2} &\leq \frac{\mu_s}{1+r_s} + m_s \quad \forall s \in S_B \end{aligned}$$

3.4. Preferences

At the beginning of the time ($t = 0$), the representative household maximizes its expected utility, subject to the budget constraints previously described. In our case, the agent's utility has the particularity that default incentives are mitigated by seizing the collateral of the mortgagor.¹² However, to adapt the problem to a *full-recourse* economy, we also introduce a nonpecuniary default penalty proportional to the defaulted amount, similar to Shubik and Wilson (1977) and Dubey et al. (2005). Thus, subject to their budget set, the agent solves the following program:

$$\begin{aligned} \max_{\mu_s, \bar{\mu}, b_{s2}, q_{s1}} \quad & U = u(e_{01} - q_{01}) + u\left(\frac{b_{02}}{p_{02}}\right) + \sum_{s \in S} \pi_s \{u(e_{s1} - q_{s1})\} + \\ & + \sum_{s \in S_G} \pi_s \left\{u\left(\frac{b_{02}}{p_{02}} + \frac{b_{s2}}{p_{s2}}\right)\right\} + \sum_{s \in S_B} \pi_s \left\{u\left(\frac{b_{s2}}{p_{s2}}\right)\right\} - 0 \end{aligned}$$

That is, the agent optimizes their utility function by solving his plan for short- and long-term borrowing, housing expenditure (in monetary terms), and commodity sales (quantity) subject to his budget constraints. At the first period ($t = 0$), the agent obtains utility from consuming the commodity that remains from their sales and the housing units that they purchase. At the final period ($t = 1$), the representative household faces the two possible sets of states of nature: good and bad. If a good state is realized, there is no default. Thus, the agent enjoys their housing consumption from the initial date plus the additional housing they buy in the final period. Conversely, if the household faces a bad state of nature, they (optimally) default.¹³ In such cases, the (non-modeled) banking sector seizes the collateral, so that the agent cannot benefit from consuming the initial period housing. Thus, the agent is subject to a default penalty (linearly) proportional to the defaulted amount. Note that in this model, the agent is not expelled from the market. The agent is still allowed to obtain short-term credit.¹⁴

3.5. Equilibrium

This section provides a brief note on equilibrium. From the problem formulation, we have that this economy is composed only by the representative household. Here, we assume that he behaves in a competitive manner and takes prices as given.

The competitive collateral equilibrium (CCE) in this economy consists of a set of commodity prices (p_{s1}), security prices (interest rates r_s, \bar{r}), and consumption plans $(\mu, \bar{\mu}, q_{s1}, b_{s2})$, such that the short-term commodity market clears, the durable housing market clears, the security markets clear, the plans are budget feasible, and consumers optimize.

There are important particularities to be highlighted in this type of economy. On the one hand in this partial equilibrium model, we abstract from a housing pricing amplification mechanism first described by Fisher (1933) and, more recently, by Goodhart et al. (2011). In these works, if a bad state is attained and there is mortgage default, the representative household will have to give-up the collateral, and the housing goes back to the market. In such a situation, the housing market clearing condition incorporates that there is a decrease in prices that further increase default incentives, given that the collateral loses value and the debt face value remains. This spiral-type mechanism is called debt-deflation.

¹¹ Without loss of generality, we assume that this constraint is always binding in equilibrium.

¹² We interpret this as an exogenous commercial banking sector that is compensated by receiving the collateral. In turn, it sells it back into the market to cash-in.

¹³ As we previously mentioned, the optimal delivery is the minimum between the current value of collateral and the promises (i.e. $\min\{\bar{\mu}, (b_{02}p_{s2}/p_{02})\}$). We assume that default penalty works as a scalar and does not affect optimal delivery, but it does influence the default decision.

¹⁴ The agent program's first order conditions appear in the Appendix.

Another issue to be considered concerns rational expectations. In this work, we also abstract from explicitly modeling the financial (banking) sector. Thus, we do not need to consider the rational expectations of the lending activity. Nevertheless, in cases where the banking sector appears (e.g. Goodhart et al., 2011), and to incorporate the default possibility under rational expectations, the effective return on the mortgage will be the ratio between (i) the minimum between the collateral value at $t = 1$ and the mortgage promise $\bar{\mu}$; and (ii) the initial mortgage extension (credit supply). That is, a bank should rationally anticipate the optimal household delivery and account for this into the risk premium.

Theorem 1. *Existence: Assuming rational expectations, a well-behaved (e.g. normally distributed) state probability space, monotonic preferences, quasi-concave utility (quasi-concavity is assumed to be maintained in the presence of linear penalties), and convex budget sets and provided that all the markets clear, this economy admits a competitive equilibrium.¹⁵*

Proof. It appears in Geanakoplos and Zame (2014).

4. Determinants of mortgage default

Proposition 2 Existence of full-recourse determinants of mortgage default: *From the household optimization problem solution, and assuming without loss of generality that there are only two possible states of nature (the good G, where there is full delivery, and the bad B, where there is default) we can obtain an equation that represents the mortgage default determinants. Furthermore, the default depends on idiosyncratic and systemic factors, as well as their interactions. The explicit equation is given by*

$$1 - \frac{b_{02} p_{B2}}{\bar{\mu} p_{02}} = \omega_0 + \omega_1 \bar{\mu} u' \left(\frac{b_{02}}{p_{02}} \right) + \omega_2 \bar{\mu} u' \left(\frac{b_{02}}{p_{02}} + \frac{b_{G2}}{p_{G2}} \right) + \omega_3 \bar{\mu} u' (e_{01} - q_{01}) \tag{1}$$

where

$$\begin{aligned} \omega_0 &= 1 - \frac{\lambda^\alpha \pi_B p_{B2}}{p_{02}(1+\bar{r})^\phi} \\ \omega_1 &= - \frac{1}{p_{02} \lambda \pi_B (1+\bar{r})^\phi} \\ \omega_2 &= \frac{\pi_G (\phi p_{02} (1+\bar{r}) - p_{G2})}{p_{G2} p_{02} \lambda \pi_B (1+\bar{r})^\phi} \\ \omega_3 &= - \frac{(1+r_0)(1-\phi)}{p_{01} \lambda \pi_B (1+\bar{r})^\phi} \end{aligned}$$

Proof. See the Appendix.

Notice that the left-hand side of Eq. (1) corresponds to the expected default frequency on the mortgage loans (i.e. the complement of the expected repayment). The right-hand side is composed by systemic and idiosyncratic factors and their interactions. All of them constitute the determinants of mortgage default.

Remark 3. Systemic factors: Notice that ω_0 , the first term at the RHS of Eq. (1), accounts for the banking regulation and financing standards faced by the household. This is a systemic factor that affects households independently from their idiosyncrasies (i.e. it is exogenous to them). By inspecting the expression in (1), it can be observed that the default frequency decreases with (i) a higher default penalty, (ii) a lower LTV (ϕ), (iii) a higher interest rate, and (iv) a decrease in housing prices. Our interpretation is consistent with Jaffee and Stiglitz (1990), who stated that the higher the screening, the lower the default incentives. On the other hand, tighter regulation provides lower incentives to default, as in OECD (2011). Additionally, the terms ω_1, ω_2 , and ω_3 depend only on exogenous variables or parameters. Thus, they also work as exogenous systemic factors that interact with an agent's idiosyncrasies.

Remark 4. Systemic and idiosyncratic interaction – housing and mortgage demand in the first period: The second term at the RHS of Eq. (1) shows a systemic factor interacting with credit demand and the marginal utility of housing at $t = 0$. Given that ω_1 is always negative, we interpret that the higher the marginal utility of housing consumption and mortgage demand, the lower the incentives to default will be. Alternatively, given we assume that preferences are quasi-concave, the higher the preference for housing consumption, the higher the expected mortgage default will be.

Remark 5. Systemic and idiosyncratic interaction – housing and mortgage demand in the second period: The third term at the RHS of Eq. (1) also contains the systemic factor interacting with the marginal utility, but in this case, it is in the good state at $t = 1$. The systemic factor ω_2 , in this case, has an ambiguous sign. If prices are in a growing phase¹⁶ (i.e. $p_{02} < p_{G2}$) and credit supply standards are sufficiently relaxed (i.e. $\phi(1+\bar{r}) > 1$), then the dynamics of mortgage default and housing demand work in the same direction as in the second term of (1).¹⁷ To summarize, under the specified conditions, higher mortgage or housing demand is associated with greater expected defaults.

Remark 6. Systemic and idiosyncratic interaction - income: The fourth term at the RHS of Eq. (1) works in a similar fashion with regard to the systemic component. There is a negative relationship between tighter (short-term) credit standards and higher mortgage default probabilities. The effect is proportional to the ratio between current housing and commodity prices.¹⁸ This result is conditioned on the marginal

¹⁵ Our assumption here is that the inclusion of default penalties to the model does not introduce a severe non-convexity to the problem and equilibrium properties are preserved.

¹⁶ This ensures that the good state is attained.

¹⁷ This is straightforward if we notice that $\omega_2 = \omega_1 p_{G2} \pi_G$.

¹⁸ This is easy to see if we notice that $\omega_3 = \omega_1 (p_{02}/p_{01})(1+r_0)(1+\phi)$. Descriptions of the variables collected by the survey as well as basic statistical descriptions of the main measures and indicators are available at the survey webpage: <https://www.efhweb.cl/enand> <https://www.efhweb.cl/EN/EFH/EncuestasAnteriores>.

utility of consumption. Assuming risk aversion (e.g. logarithmic utilities), we have that, for a given mortgage credit standard and price ratio, the higher the commodity endowment, the lower the mortgage default frequency will be. In this case, we interpret endowments as the availability of resources. Thus, it expresses the importance of housing income in this context. Our conjecture is that the combination of systemic credit standards and household income (or a related variable) is key to determining mortgage default frequency.

From the findings provided by our theoretical model, we conjecture that mortgage default determinants are associated with credit costs and/or regulation standards and their interaction with idiosyncratic factors such as the demand for housing and income. At this point, it is important to notice the interaction we found. This will be key in our empirical specification, which is based on our theoretical model results.

5. Estimation methodology and data

In this section, we briefly describe the problems that we face in obtaining unbiased and efficient estimators, and the characteristics of the data used in the estimations.

5.1. Estimation methodology

In this work, we explain households' decision to default on their mortgage loans based on idiosyncratic and systemic variables. To do so, we use logistic regressions to estimate the behavior of a discrete variable representing the fact that some households in our sample have defaulted on their mortgages.

Our data on mortgage delinquency present two important features that we must account for in the estimation. First, defaulting on a loan (especially mortgages) is not a usual event. Furthermore, it can be considered as a rare event when compared with the occurrence of the contrary. Thus, if we take into account the whole population of outstanding mortgage loans in an economy, delinquency is highly underrepresented in any sample. However, our sample captures an important mass of delinquent to better appreciate its behavior. This means that the sample is intentionally biased to account for the phenomenon. This is known in econometrics as *choice-based* or *endogenous stratified* sampling. This sampling method is often supplemented with known or estimated prior knowledge on the population fractions of the rare event (as in our case).

Second, popular statistical procedures, including logistic regression, can sharply underestimate the probability of rare events. As King and Zeng (2002) point out, the literature documents well that logit coefficients are biased in small samples, but the fact that the biases in probabilities can be substantively meaningful in rare-event data is less known and understood. In particular, finite-sample, rare-event data have at least three features we should account for:

- i increasing the sample size does not alleviate the bias because the rare events do not increase their share of the sample more quickly than the growth rate of the sample;
- ii the bias of the coefficients estimated using logistic regression when rare events are present is known to cause underestimation of the rare event's probability; and
- iii the computation of probabilities of events in logit analysis is suboptimal in finite samples of rare-event data, leading to errors in the same direction as the biases in the coefficients.

To deal with these features together, we follow the developments of King et al. (2000) and King and Zeng (2001, 2002). Assume that we have a dataset of $i = 1, \dots, n$ observations for which we have gathered information on the variable Y_i as well as a set of $k - 1$ variables recorded in \mathbf{x}_i . The variable Y_i is a dichotomous variable that represents an underlying continuous variable Y_i^* following $Y_i = 1$ if $Y_i^* > 0$ and $Y_i = 0$ if $Y_i^* \leq 0$. Y_i^* follows a Bernoulli distribution, while Y_i^* follows a logistic distribution. The behavior of Y_i^* can be adequately inferred from the maximum likelihood estimation of the behavior of Y_i .

We assume that the ones ($Y_i = 1$) are the rare outcome, representing households that hold a delinquent mortgage loan. The *prior population information* refers to the fraction of ones in the population, τ , while the *observed fraction of ones in the sample* refers to the sampling probability, \bar{y} .

We use a weighting procedure to compensate for differences in the sample (\bar{y}) and population (τ) fractions of ones induced by choice-based sampling. This procedure maximizes the weighted log-likelihood:

$$\begin{aligned} \ln L_w(\beta|\mathbf{y}) &= w_1 \sum_{\{Y_i=1\}} \ln(\pi_i) + w_0 \sum_{\{Y_i=0\}} \ln(1 - \pi_i) \\ &= - \sum_{i=1}^n w_i \ln(1 + \exp[(1 - 2Y_i)\mathbf{x}_i\beta]), \end{aligned} \tag{2}$$

where the weights are $w_1 = \tau/\bar{y}$ and $w_0 = (1 - \tau)/(1 - \bar{y})$, and where

$$w_i = w_1 Y_i + w_0 (1 - Y_i).$$

The resulting $\hat{\beta}$ is the *weighted exogenous sampling maximum-likelihood estimator* (Manski and Lerman, 1977). One of the advantages of this method is that weighting can outperform other approaches (e.g. prior correction) when both a large sample is available and the functional form is misspecified (see Xie and Manski, 1989). However, weighting is asymptotically less efficient in small samples (see Scott and Wild, 1986; Amemiya and Vuong, 1987).

When information about τ is available, we can remedy these problems using an analytical approximation to the bias based on McCullagh and Nelder (1989). The bias in $\hat{\beta}$ can be estimated with the following weighted least-squares expression:

$$bias(\hat{\beta}) = (\mathbf{X}'\mathbf{W}\mathbf{X})^{-1} \mathbf{X}'\mathbf{W}\xi,$$

Table 1
Distribution of households by income group (%).

Strata	2007	2008	2009	2010	2011	Total
Stratum 1	26.38	31.28	25.88	29.46	30.45	28.65
Stratum 2	24.97	29.03	31.09	29.7	29.1	28.1
Stratum 3	48.64	39.69	43.03	40.84	40.45	43.25

Table 2
Mortgage loans and delinquency (%).

	2007	2008	2009	2010	2011	Total
Mortgage holders	16.77	13.17	13.70	18.85	15.00	15.90
Defaulted mortgages	8.26	13.82	9.2	8.07	8.87	8.92
Delinquent mortgages (SBIF)	0.97	1.29	1.95	2.01	1.70	1.58

where $\xi_i = 0.5Q_{ii}[(1 + w_1)\hat{\pi}_i - w_1]$, Q_{ii} are the diagonal elements of $\mathbf{Q} = \mathbf{X}(\mathbf{X}'\mathbf{W}\mathbf{X})^{-1}\mathbf{X}'$, and $\mathbf{W} = \text{diag}\{\hat{\pi}_i(1 - \hat{\pi}_i)w_i\}$. The bias-corrected estimate is then

$$\tilde{\beta} = \hat{\beta} - \text{bias}(\hat{\beta}).$$

Notice that this correction affects both the constant term directly and also the other coefficients, primarily as a consequence (King and Zeng, 2001).

The variance of the approximately unbiased estimate of β , $\tilde{\beta}$, is approximated by a multiple of the usual variance matrix,

$$V(\tilde{\beta}) = \left(\frac{n}{n+k}\right)^2 V(\hat{\beta}).$$

A key point is that since $(n/(n+k))^2 < 1$, $V(\tilde{\beta}) < V(\hat{\beta})$. Thus, reducing the bias also reduces the variance.

5.2. Data description

The primary information source for our estimations is the Chilean Survey of Household Finance (EFH). The EFH is an initiative of the Central Bank of Chile to collect information about the households' finances, including socioeconomic characteristics, information about asset holdings, and detailed information on the debts of each household member. We used the first five waves of the EFH:

- The first wave (2007) collected information from 3828 urban households at the national level.
- The second (2008), third (2009), and fourth (2010) waves accounted for 1154, 1190, and 2037 urban households in the Santiago Metropolitan Region of Chile, respectively.
- Finally, the fifth wave (2011–12) collected information from 4059 urban households at the national level.¹⁹

For each wave, higher income households were oversampled to obtain better insight into their indebtedness pattern. In Table 1, we show the percentage of households per income stratum.²⁰

Table 2 shows information from the EFH about mortgage holdings and delinquency. However, to correct the bias induced by rare events, we also incorporate some prior information from the delinquencies reported monthly by the banking system to the Superintendence of Banks and Financial Institutions. Ideally, we would use the number of delinquent loans versus the total number of outstanding loans. However, that information is not available. Instead, we used the amounts of loans. Thus, the prior information was given by the average ratio of the amount of nonperforming mortgage loans to the total amount of outstanding mortgage loans in the Chilean financial system, during the months when each wave of the EFH was collected. Although imperfect, this measure is a good approximation, given the almost even distribution of the amount of loans in delinquency in each wave of the EFH (see the Appendix for charts showing the distribution for each year, particularly Figs. 3–7). Notice that while the oversampling of defaulted loans is similar in the EFH, the delinquency rate (as reported by the SBIF/CMF) changed over time following the impacts of the global crisis in Chile.

The EFH collects information on various aspects of the credit, but specific variables must be constructed for our estimations. For each mortgage loan, we calculate the loan-to-value ratio (LTV) for both the initial loan amount and current outstanding debt. While most of existing analyses use the initial LTV (e.g. Kau et al., 1994; Harrison et al., 2004; Bajari et al., 2010, 2012; Bhutta et al., 2010; Campbell and Cocco, 2015; Elul et al., 2010; Paniza Bontas, 2010; Hatchondo et al., 2012), we used the current LTV (as in Capozza et al., 1997, 1998; Ambrose and Capone, 1998; Wong et al., 2004). Our perspective is that the current LTV better reflects the financial burden faced by households and is the appropriate measure for households to include in their optimization problem for evaluating the default decision. The initial LTV is useful when the loan is in its first stages of payment or when we want to evaluate

¹⁹ Stratum 1: 1st-50th percentile; Stratum 2: 51st-80th percentile; Stratum 3: 81st-100th percentile.

²⁰ The distinction of motivations is based on a specific question for mortgagors that have renegotiated their loans conditions, as collected by the EFH.

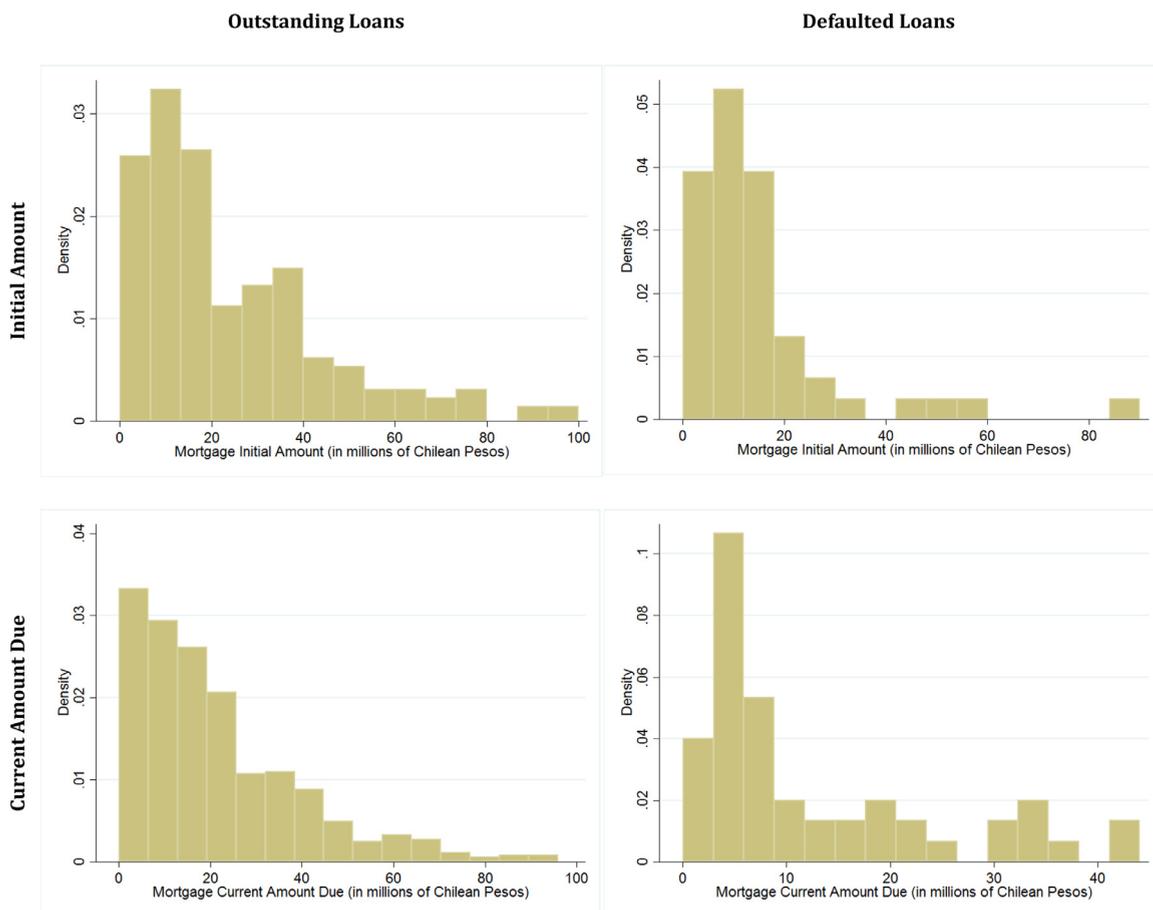


Fig. 3. Distribution of the volume of mortgage loans, 2007.

Table 3
Distribution of mortgage characteristics.

	p25	p50	p75
Current loan to value	24.6%	45.1%	67.9%
Initial loan to value	63.6%	85.0%	100.0%
Monthly installment	\$95,000	\$185,000	\$320,000
Term of credit (in years)	19	20	20
Age of debt (in years)	3	6	11

the risk involved at the time when the loan is granted. However, for long-term forms of credit such as mortgages, the changing natures of the economic context and the household financial balance sheet hinder the usefulness of the initial LTV. Nevertheless, in our analysis, we tested the role of both measures, as shown in the next section.

In Table 3, we present information on the quartiles of the current and initial LTV and on the monthly installments. The median mortgage loan in our sample was granted to cover 85% of the home value, and the current due amount represents 45% of the current home value. The median monthly installment is about \$185,000 (around US\$350). Also, notice that the median term of the credit was 20 years, while the median age of the credit (the time elapsed from the granting of the mortgage) was 6 years. As can be seen, most of the credit was granted for a term of around 20 years, while in more advanced economies, the usual term is around 30 years.

We make a final note on the situation of renegotiated mortgages to gain some insight on the behavior of mortgagors who might be observed as defaulting but have renegotiated their loans to avoid default. In our complete sample (12,268 households), 15.9% of households have an outstanding mortgage loan. Of them, 19.5% have renegotiated the conditions of their loans at some point. Table 4 shows the default situation of mortgagors who have renegotiated their loans. Notice the distinct reasons for households to renegotiate the loan, depending on whether they are defaulting or repaying their debts after refinancing: the main motivation for defaulters to renegotiate was “to decrease the mortgage payment by increasing the term”; for those who kept paying their loan after renegotiation,

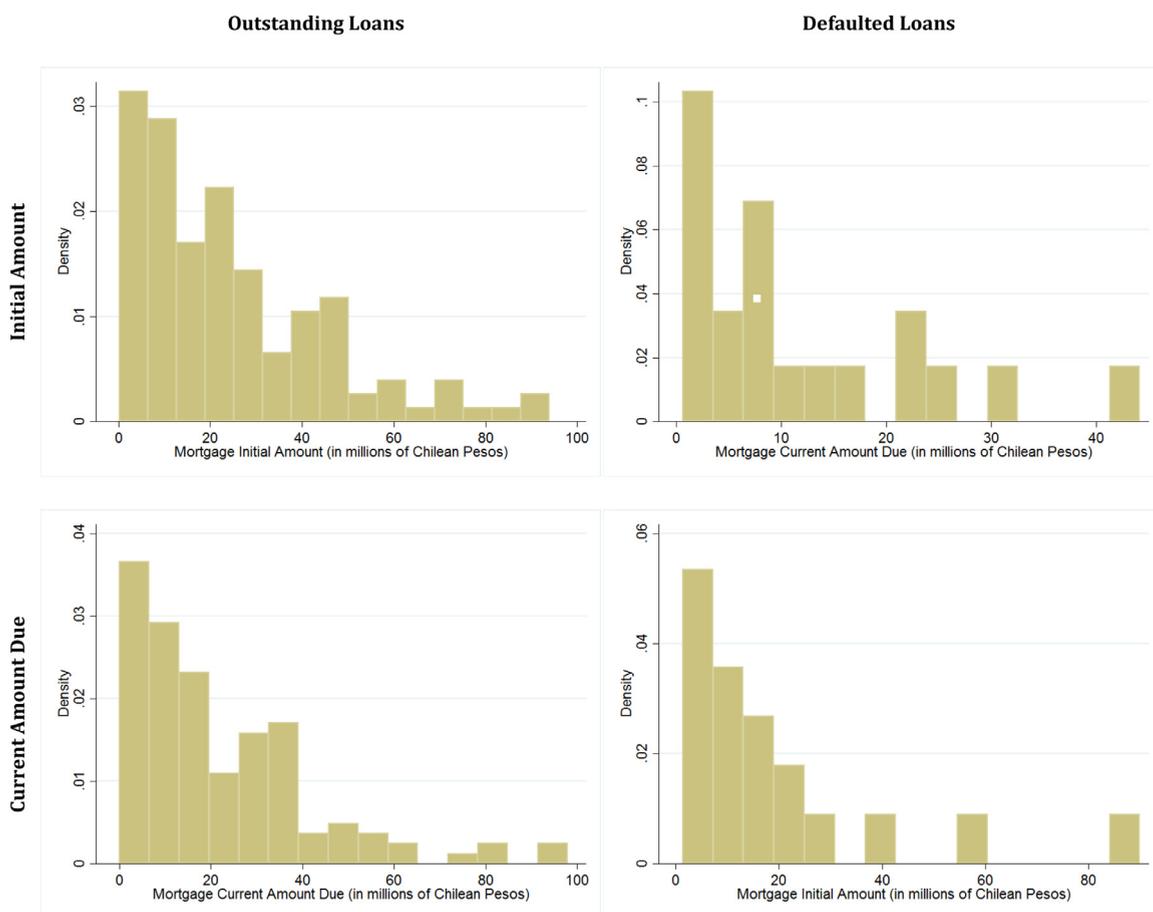


Fig. 4. Distribution of the amounts of mortgage loans, 2008.

Table 4
Default and renegotiation in the sample.

	Did not renegotiate	Renegotiated	Total
Paying	74.5%	16.6%	91.1%
DEFAULTED	6.0%	2.9%	8.9%
Total	80.5%	19.5%	100%

the main motivation was “a decrease in the interest rate.”²¹ The difference in motivations between both type of mortgagors allow us to break the pooling equilibrium that arises in the analysis of Mayer et al. (2009), where refinancing appears as a single characteristic giving rise to speculative conclusions about the reasons for the particular behavior among this group of debtors.

6. Results

In this section, we present estimation results using the method described in the previous section.²² There are two sets of estimations in the following tables. In Table 5, each idiosyncratic and systemic variable is entered directly into the regressions to explain the decision to default. Table 6 shows the interactions between these variables included as regressors in the estimation, as suggested by our theoretical model.

²¹ We performed a complete set of estimations including a wide range of variables that were included in previous empirical analyses of mortgage default. We also tried single-step and two-step estimations to correct for possible endogeneity in the decision to get a loan and then defaulting, as in Alfaro and Gallardo (2012). We did not find any technical or empirical reason to keep track of the two-step estimation procedure. However, all of the additional results are available from the authors upon request.

²² Our general equilibrium framework incorporates these two levels of analysis together with the partial equilibrium we are presenting in this paper.

Table 5
Estimation results 1: no interactions.

Dep. Var.: Mortgage default dummy	Model 1	Model 2	Model 3	Model 4
Idiosyncratic – Demographic variables				
Number of persons in house	0.211*** (0.0715)	0.235*** (0.0826)	0.214** (0.0844)	0.213** (0.0856)
Income (in logs)	-0.827*** (0.133)	-0.563*** (0.153)	-0.734*** (0.155)	-0.524*** (0.162)
Primary education	0.348 (0.333)	0.0446 (0.424)	0.215 (0.440)	0.109 (0.466)
Tertiary education	-0.633*** (0.241)	-0.417 (0.291)	-0.554* (0.308)	-0.397 (0.309)
Gender	-0.285 (0.199)	-0.214 (0.229)	-0.285 (0.244)	-0.301 (0.242)
Age 18–35 years	-0.0218 (0.260)	-0.155 (0.295)	0.0266 (0.306)	0.105 (0.308)
Age 55–99 years	-0.699 (0.603)	-0.0802 (0.675)	-0.0578 (0.696)	-0.0759 (0.683)
Idiosyncratic – Finance variables				
Negative shock	1.745*** (0.207)	1.715*** (0.245)	1.668*** (0.255)	1.683*** (0.256)
Credit applications rejected	0.276 (0.398)			
Renegotiation	1.352*** (0.244)	1.352*** (0.274)	1.398*** (0.293)	1.386*** (0.287)
Systemic variables				
Current loan to value		0.253** (0.117)	0.199 (0.129)	
Initial house price (in logs)		-0.416*** (0.113)		-0.450*** (0.152)
Initial loan to value			0.0407 (0.0249)	-0.0835 (0.0794)
Constant	6.125*** (1.761)	9.095*** (2.302)	4.663** (2.074)	9.413*** (2.631)
Observations	1894	1446	1301	1337

Note: Robust standard errors in parentheses. Significance: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 6
Estimation results 2: including interactions.

Dep. Var.: Mortgage default dummy	Model 1	Model 2
Idiosyncratic – Demographic variables		
Number of persons in house	0.237*** (0.0820)	0.231*** (0.0819)
Income (in logs)	-0.578*** (0.150)	-0.582*** (0.149)
Primary education	0.0564 (0.421)	0.0804 (0.414)
Tertiary education	-0.423 (0.290)	-0.425 (0.290)
Gender	-0.260 (0.228)	-0.247 (0.227)
Age 18–35	-0.189 (0.298)	-0.195 (0.298)
Age 55–99	-0.0714 (0.675)	-0.0950 (0.675)
Idiosyncratic – Finance variables		
Negative shock	1.678*** (0.245)	
Credit applications rejected	0.687 (0.437)	0.677 (0.439)
Renegotiation	1.319*** (0.277)	1.325*** (0.276)
Systemic variables		
Initial house price (in logs)	-0.417*** (0.112)	-0.443*** (0.111)
Interaction variables		
Income and current loan to value	0.0199** (0.00810)	0.0195** (0.00814)
Initial house price and negative shock		0.102*** (0.0147)
Constant	9.326*** (2.265)	9.817*** (2.243)
Observations	1446	1446

Note: Robust standard errors in parentheses. Significance: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

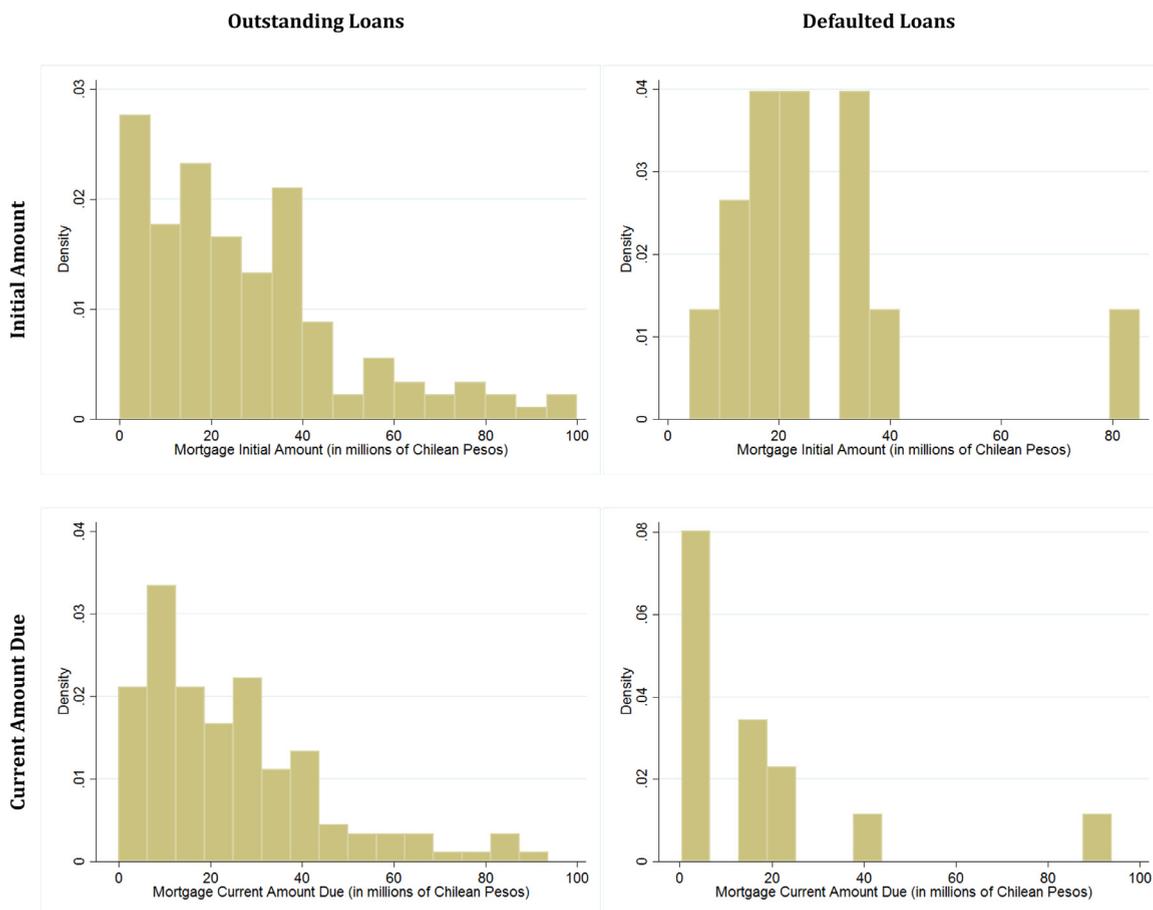


Fig. 5. Distribution of the amounts of mortgage loans, 2009.

In Table 5, we show four models that differ in their inclusion of idiosyncratic financial variables and systemic variables. In the final regression specifications shown in the table, we include 10 idiosyncratic variables, with three of them representing household financial characteristics. We also include three systemic variables to characterize the default behavior. We find *five main results*, which contribute to our discussion on mortgage default determinants under a full-recourse regulatory framework.

First, *income* is an important idiosyncratic determinant of the probability of default, and it enters the regressions with the expected negative sign. In this case, income refers to monthly income flows, mostly coming from labor sources, including the income of all household members. Higher income favors mortgage repayment, as shown by the relevant literature.

Second, we find that *suffering a negative shock* in the recent past significantly increases the probability of defaulting on a mortgage loan. The EFH collects information from a specific question that inquires about the occurrence of an event that significantly lowered the household’s income or increased expenditures and was not planned. Thus, our negative shock is directly related to a household balance sheet worsening, and it has the expected sign.

Third, households that renegotiated the conditions of their loans also are more likely to default on them. This result goes in line with the supplementary information explained above: renegotiation mainly is aimed at reducing a household’s monthly financial burden, which turns out to be an important indicator of household financial stress.

In summary, the idiosyncratic determinants tell us that the household balance sheet is key to understanding the decision to default on a mortgage. The decision takes into account the income flow as a baseline but is subject to economic shocks that worsen the balance sheet. The first attempt to overcome those problems is to renegotiate the mortgage in order to reduce the financial burden.

On the systemic side of the determinants, the current loan-to-value (CLTV) coefficient implies that a bigger CLTV increases the probability of default, all other things equal. Our results indicate that a higher amount due (higher long-term financial burden) may positively affect the decision to default (as in Elul et al., 2010). Thus, less mature loans are more prone to default.

On the other hand, higher house prices (usually associated with higher loan amounts) lessen the probability of default. This result may be explained in several ways: it could be the result of a higher expected loss if a household defaults (corresponding to the already paid installments or the potential gains from reselling the real estate) or of a higher dead loss (corresponding to the down payment). It may also follow a greater cost of default resulting from complete debt settlement, as allowed in a full-recourse framework, which may imply losing other assets. We can also argue that a costlier reputational effect may prevent defaulting on loans.

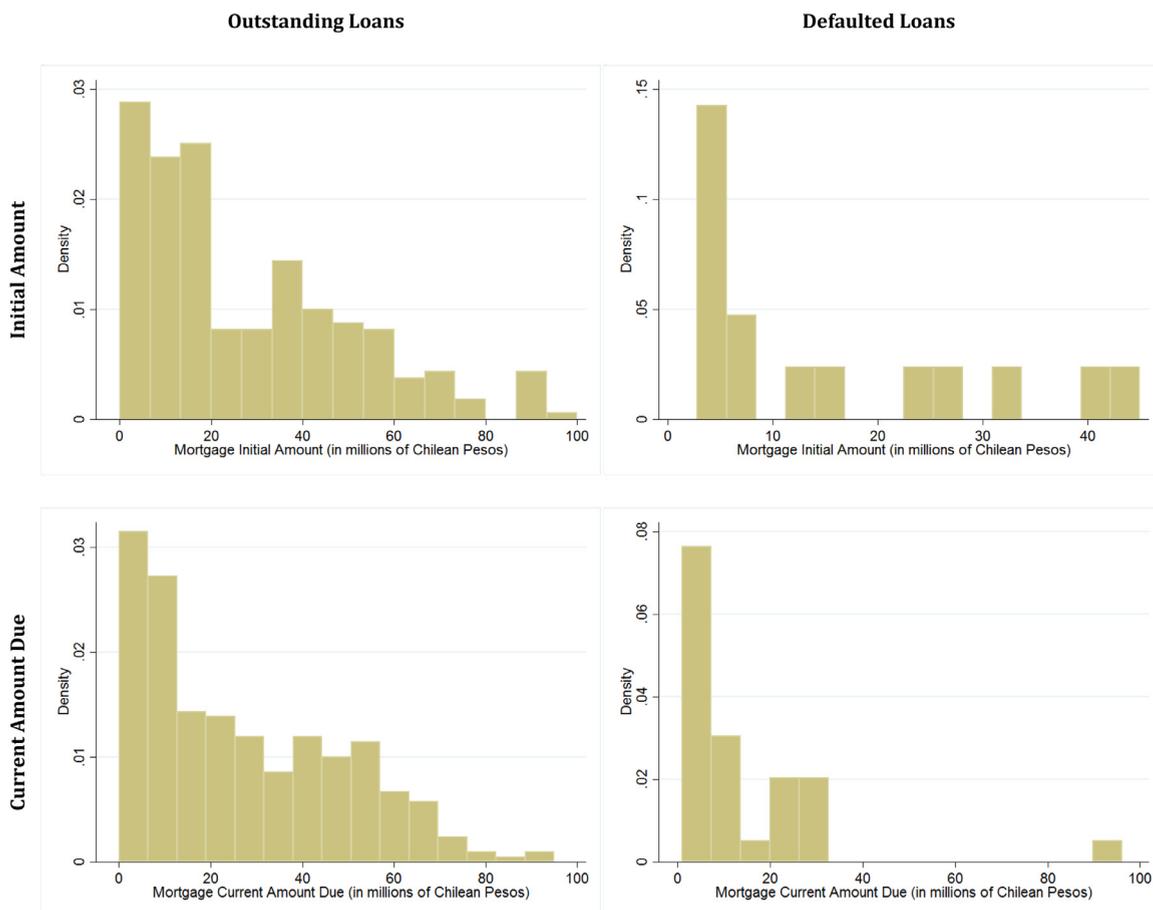


Fig. 6. Distribution of the amounts of mortgage loans, 2010.

In the overall model (see Model 2), the systemic variables tell us that larger mortgage loans are less likely to default. This form of credit predominantly has been granted since 2005, accompanying important aggregate phenomena within the Chilean economy: a sustained high-growth period (even during the global crisis) and a real estate price boom. These two aspects require more detailed analysis, in terms of the risk-taking decisions of the financial system and the aggregate push-pull effect of commodity prices and other macro determinants, all of which are far beyond the scope of this paper.²³

A supplementary set of results appears in the regressions representing the relevance of other determinants that typically were included in the surveyed literature. For example, the set of demographic variables remained the same for all estimated models. Notice that the sign, magnitude, and significance of the coefficients accompanying the latter set of variables are stable throughout the model specifications.

Perhaps a counterintuitive result is that the number of persons in the household positively affects the probability of default. This outcome may be associated with the fact that, in most cases at hand, a more densely populated household is not directly associated with higher household total income (for example, because the increased number of household members is due to the presence of children or the elderly).

The LTV of origination does not have major impact on the decision to default. This result supports our argument that CLTV is the relevant information for the household, especially if older loans have relatively more defaults. In addition, having rejected credit applications does not appear to be significant for explaining default behavior.

The second set of results appears in Table 6. Idiosyncratic demographic and financial variables, as well as systemic variables, play similar roles to those of the results in Table 5. The *novel results* come from the interaction between systemic and idiosyncratic variables, as our theoretical model suggested.

We find that the interaction between income and current loan-to-value positively affected the chances of default as well as the interaction between the home's price at the origination moment and the household suffering an unexpected negative shock. In the

²³ Although the financial stability reports were developed and published first in the mid-2000s, their importance increased after the 2008 global financial crisis. Various central banks have developed their own periodic reports, such as the UK, the US, Spain, Australia, and Chile.

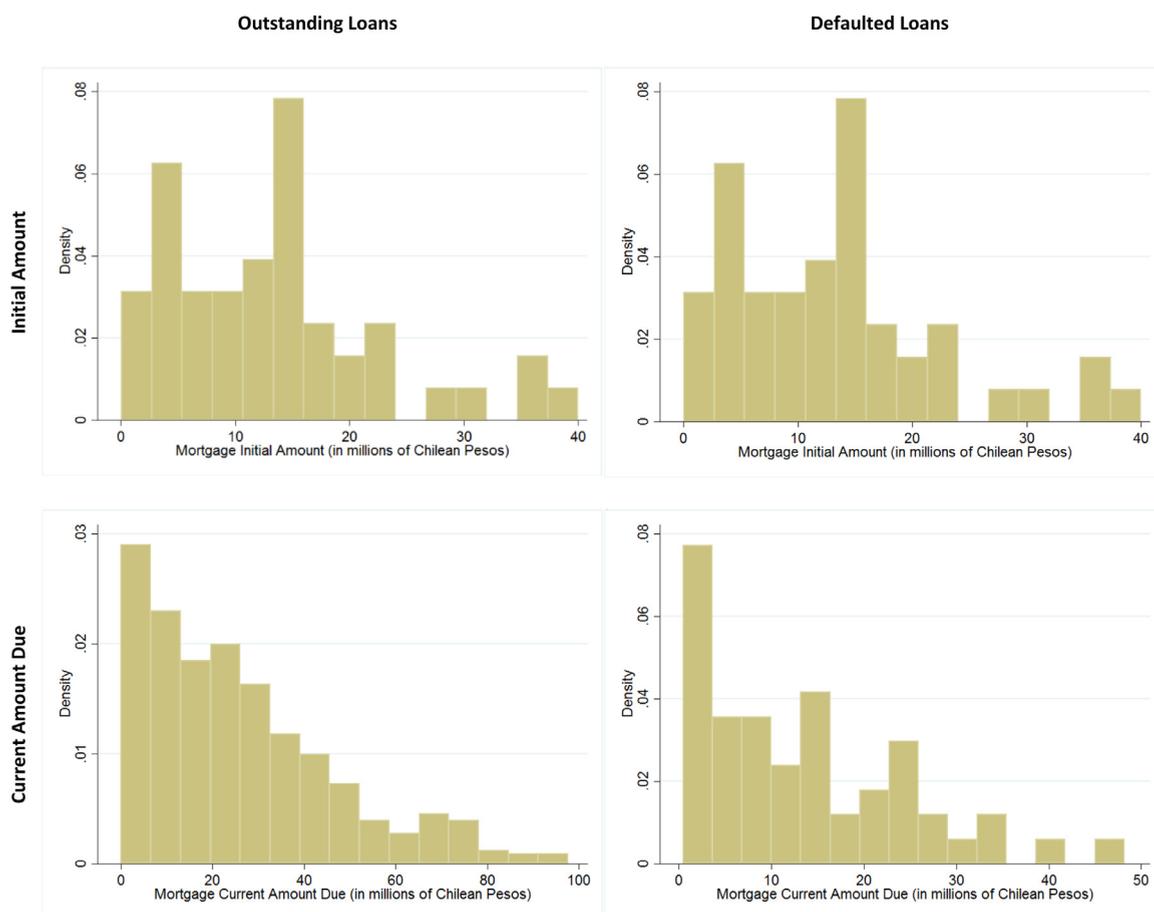


Fig. 7. Distribution of the amounts of mortgage loans, 2011–12.

first case, even though income has a negative effect on the default probability, the CLTV dominates overall. In the second case, the effect of the negative shock dominates the scene. These results emphasize that shocks affecting the household balance sheet (income or expenditure) or the remaining (long-term) financial burden are key aspects when analyzing default probabilities. For example, sustained high unemployment rates may influence income levels by simultaneously configuring an unexpected shock that aggravates the financial burden.

As we have analyzed above—and in contrast to [Alfaro Gallardo \(2012\)](#), which also analyzed the Chilean mortgage market—the current LTV (CLTV), as a systemic factor, is statistically and economically significant, as is the house price at origination. This suggests that both idiosyncratic and systemic factors (and their interactions) simultaneously determine mortgage defaults.

7. Final remarks

In this paper, we answer the question of finding individual and systemic determinants of housing default in a *full-recourse economy*. In doing so, we propose and develop a theoretical framework with which to model mortgage default in full-recourse economies. With such a framework, it is possible to derive an analytical expression of a household's default decision that involves idiosyncratic and systemic factors and their combinations.

To test this framework empirically, we took into account two important issues of the type of phenomenon we studied: first, its occurrence is rare; and second, the sampling framework favors the collection of data on default cases but contributes to worsening the estimators' statistical properties. Overall, traditional logistic regression provides biased and inefficient estimators. We overcame these problems by adopting appropriate adjustments suggested by the literature.

Following our theoretical description of default and the empirical strategy, we estimated the determinants of default decision for the representative Chilean household, using information from the EFH survey.

Based on our theoretical model, we empirically found that systemic and idiosyncratic factors are statistically important in determining the default decision. Moreover, the interactions between systemic and idiosyncratic factors play a key role in determining default probability.

Our results suggest that aggregated macrofinancial variables—such as prices and loan-to-value ratios—and their interactions with microeconomic information can contribute to explain an important portion of mortgage risks. In turn, this implies that when assessing the quality of a mortgage or any other credit portfolio, the use of microeconomic or demographic information is not enough. Accordingly, financial regulators and supervisors should invest into developing aggregated measures that can act as early warning indicators as well as incorporate market trend information into risk analyses. Furthermore, this constitutes another rationale reinforcing the idea that monetary and banking authorities should inform the market about this type of financial development in a consistent and integrated report that uses macro- and microfinancial information. Financial stability reports appear to be natural channels through which to issue this information.²⁴

Appendix

Glossary

Nonperforming Loans: A loan is nonperforming when interest and/or principal payments are past due by 90 days or more; if interest payments for 90 days or more have been capitalized, refinanced, or delayed by agreement; or if payments are less than 90 days overdue but there are other good reasons (such as a debtor filing for bankruptcy) to doubt that payments will be made in full. After a loan is classified as nonperforming, it (and possibly replacement loans) should remain classified as such until written off or until interest and/or principal payments are received (IMF, 2005).

Default: Default essentially means that a debtor has not paid a debt that he or she is required to have paid. Debt-service default occurs when the borrower has not made a scheduled interest or principal payment.

Reputational Effects of Default: A loan becomes *delinquent* the first day after the borrower misses a payment. The *delinquency* will continue until all payments are made to *bring the loan current*. Loan servicers report all delinquencies of at least 90 days to the SBIF and other credit bureaus (e.g. SINACOFI and DICOM). The financial market agents use this information to evaluate risk and grant credit. In particular, being listed in DICOM implies that the debtor also may have trouble getting a job, signing up for utilities, leasing, getting homeowner’s insurance, getting a cellphone plan, or getting approval to rent an apartment (credit checks usually are required for renters).

First-Order Conditions for the Household Problem

$$\frac{\partial L^\alpha}{\partial q_{01}^\alpha} : -U^{\alpha'}(e_{01}^\alpha - q_{01}^\alpha) - \eta_{01}^\alpha p_{01} = 0 \tag{3}$$

$$\frac{\partial L^\alpha}{\partial q_{11}^\alpha} : -\pi_G U^{\alpha'}(e_{11}^\alpha - q_{11}^\alpha) - \eta_{11}^\alpha p_{11} = 0 \tag{4}$$

$$\frac{\partial L^\alpha}{\partial q_{21}^\alpha} : -\pi_B U^{\alpha'}(e_{21}^\alpha - q_{21}^\alpha) - \eta_{21}^\alpha p_{21} = 0 \tag{5}$$

$$U^{\alpha'} \left(\frac{b_{02}^\alpha}{p_{02}} \right) \frac{1}{p_{02}} + \pi_G U^{\alpha'} \left(\frac{b_{02}^\alpha}{p_{02}} + \frac{b_{G2}^\alpha}{p_{G2}} \right) \frac{1}{p_{02}} + \eta_{02}^\alpha - \phi \eta_\phi^\alpha + \frac{\lambda^\alpha \pi_B p_{B2} b_{02}^\alpha}{\bar{\mu} p_{02}} = 0 \tag{6}$$

$$\frac{\partial L^\alpha}{\partial b_{G2}^\alpha} : \pi_G U^{\alpha'} \left(\frac{b_{02}^\alpha}{p_{02}} + \frac{b_{G2}^\alpha}{p_{G2}} \right) \frac{1}{p_{G2}} + \eta_{G2}^\alpha = 0 \tag{7}$$

$$\frac{\partial L^\alpha}{\partial b_{B2}^\alpha} : \pi_B U^{\alpha'} \left(\frac{b_{B2}^\alpha}{p_{B2}} \right) \frac{1}{p_{B2}} + \eta_{B2}^\alpha = 0 \tag{8}$$

$$\frac{\partial L^\alpha}{\partial \mu_0^\alpha} : \eta_{01}^\alpha - \frac{\eta_{02}^\alpha}{1 + r_0} = 0. \tag{9}$$

$$\frac{\partial L^\alpha}{\partial \mu_1^\alpha} : \eta_{11}^\alpha - \frac{\eta_{G2}^\alpha}{1 + r_1} = 0 \tag{10}$$

$$\frac{\partial L^\alpha}{\partial \mu_2^\alpha} : \eta_{21}^\alpha - \frac{\eta_{B2}^\alpha}{1 + r_2} = 0 \tag{11}$$

$$\frac{\partial L^\alpha}{\partial \bar{\mu}^\alpha} : -\frac{\eta_{02}^\alpha}{1 + \bar{r}} + \eta_{G2}^\alpha + \frac{\eta_\phi^\alpha}{1 + \bar{r}} - \frac{\lambda^\alpha \pi_B p_{B2} b_{02}^\alpha}{\bar{\mu}^2 p_{02}} = 0 \tag{12}$$

$$\frac{\partial L^\alpha}{\partial \eta_{01}^\alpha} : \mu_0^\alpha - p_{01} q_{01}^\alpha = 0 \tag{13}$$

$$\frac{\partial L^\alpha}{\partial \eta_{02}^\alpha} : b_{02}^\alpha - \frac{\mu_0^\alpha}{1 + r_0} - \frac{\bar{\mu}^\alpha}{1 + \bar{r}} - m_0^\alpha = 0 \tag{14}$$

²⁴ Although the financial stability reports were developed and published first in the mid-2000s, their importance increased after the 2008 global financial crisis. Various central banks have developed their own periodic reports, such as the UK, the US, Spain, Australia, and Chile.

$$\frac{\partial L^\alpha}{\partial \eta_\phi^\alpha} : \frac{\bar{\mu}^\alpha}{1 + \bar{r}} - \phi b_{02}^\alpha = 0 \tag{15}$$

$$\frac{\partial L^\alpha}{\partial \eta_{11}^\alpha} : \mu_1^\alpha - p_{11} q_{11}^\alpha = 0 \tag{16}$$

$$\frac{\partial L^\alpha}{\partial \eta_{21}^\alpha} : \mu_2^\alpha - p_{21} q_{21}^\alpha = 0 \tag{17}$$

$$\frac{\partial L^\alpha}{\partial \eta_{G2}^\alpha} : b_{G2}^\alpha + \bar{\mu}^\alpha - \frac{\mu_1^\alpha}{1 + r_1} - m_1^\alpha = 0 \tag{18}$$

$$\frac{\partial L^\alpha}{\partial \eta_{B2}^\alpha} : b_{B2}^\alpha - \frac{\mu_2^\alpha}{1 + r_2} - m_2^\alpha = 0 \tag{19}$$

Proof of Proposition 1

From (5),

$$U^{\alpha'} \left(\frac{b_{02}^\alpha}{p_{02}} \right) \frac{1}{p_{02}} + \pi_1 U^{\alpha'} \left(\frac{b_{02}^\alpha}{p_{02}} + \frac{b_{G2}^\alpha}{p_{G2}} \right) \frac{1}{p_{02}} - \phi \eta_\phi^\alpha + \frac{\lambda^\alpha \pi_2 p_{B2}}{\bar{\mu} p_{02}} = -\eta_{02}^\alpha$$

From (3), we have $\frac{-U^{\alpha'}(e_{01}^\alpha - q_{01}^\alpha)}{p_{01}} = \eta_{01}^\alpha$, and from (9), $\eta_{01}^\alpha (1 + r_0) = \eta_{02}^\alpha$. Combining these results,

$$\begin{aligned} \frac{U^{\alpha'}(e_{01}^\alpha - q_{01}^\alpha)}{p_{01}} (1 + r_0) &= U^{\alpha'} \left(\frac{b_{02}^\alpha}{p_{02}} \right) \frac{1}{p_{02}} + \pi_1 U^{\alpha'} \left(\frac{b_{02}^\alpha}{p_{02}} + \frac{b_{G2}^\alpha}{p_{G2}} \right) \frac{1}{p_{02}} - \phi \eta_\phi^\alpha \\ \frac{-U^{\alpha'}(e_{01}^\alpha - q_{01}^\alpha)}{p_{01} \phi} (1 + r_0) + \frac{1}{p_{02} \phi} \left[U^{\alpha'} \left(\frac{b_{02}^\alpha}{p_{02}} \right) + \pi_1 U^{\alpha'} \left(\frac{b_{02}^\alpha}{p_{02}} + \frac{b_{G2}^\alpha}{p_{G2}} \right) + \frac{\lambda^\alpha \pi_2 p_{B2}}{\bar{\mu}} \right] &= \eta_\phi^\alpha \end{aligned}$$

On the other hand, using (7), $-\pi_G U^{\alpha'} \left(\frac{b_{02}^\alpha}{p_{02}} + \frac{b_{G2}^\alpha}{p_{G2}} \right) \frac{1}{p_{G2}} = \eta_{G2}^\alpha$, we can replace this expression with (6) in (12), which yields,

$$\begin{aligned} \frac{-1}{p_{02}(1-\phi)} \left[U^{\alpha'} \left(\frac{b_{02}^\alpha}{p_{02}} \right) + \pi_1 U^{\alpha'} \left(\frac{b_{02}^\alpha}{p_{02}} + \frac{b_{G2}^\alpha}{p_{G2}} \right) + \frac{\lambda^\alpha \pi_2 p_{B2}}{\bar{\mu}} \right] + \frac{\lambda^\alpha \pi_2 p_{B2} b_{02}^\alpha (1+\bar{r})}{\bar{\mu}^2 p_{02} (1-\phi)} + \\ + \pi_1 (1 + \bar{r}) U^{\alpha'} \left(\frac{b_{02}^\alpha}{p_{02}} + \frac{b_{G2}^\alpha}{p_{G2}} \right) \frac{1}{p_{G2}(1-\phi)} = \eta_\phi^\alpha \end{aligned}$$

Equating for η_ϕ^α , we have,

$$\begin{aligned} \frac{-U^{\alpha'}(e_{01}^\alpha - q_{01}^\alpha)}{p_{01} \phi} (1 + r_0) &= \frac{-1}{p_{02}(1-\phi)\phi} \left[U^{\alpha'} \left(\frac{b_{02}^\alpha}{p_{02}} \right) + \pi_1 U^{\alpha'} \left(\frac{b_{02}^\alpha}{p_{02}} + \frac{b_{G2}^\alpha}{p_{G2}} \right) + \frac{\lambda^\alpha \pi_2 p_{B2}}{\bar{\mu}} \right] + \\ + \frac{\lambda^\alpha \pi_2 p_{B2} b_{02}^\alpha (1+\bar{r})}{\bar{\mu}^2 p_{02} (1-\phi)} + \pi_1 (1 + \bar{r}) U^{\alpha'} \left(\frac{b_{02}^\alpha}{p_{02}} + \frac{b_{G2}^\alpha}{p_{G2}} \right) \frac{1}{p_{G2}(1-\phi)} \\ \frac{-U^{\alpha'}(e_{01}^\alpha - q_{01}^\alpha)}{p_{01}} (1 + r_0) &= \\ = \frac{1}{p_{02}(1-\phi)} \left[-U^{\alpha'} \left(\frac{b_{02}^\alpha}{p_{02}} \right) + \frac{\pi_1 (\phi p_{02} (1+\bar{\mu}) - p_{G2})}{p_{G2}} U^{\alpha'} \left(\frac{b_{02}^\alpha}{p_{02}} + \frac{b_{G2}^\alpha}{p_{G2}} \right) - \frac{\lambda^\alpha \pi_2 p_{B2}}{\bar{\mu}} \right] + \\ + \frac{\lambda^\alpha \pi_2 p_{B2} b_{02}^\alpha (1+\bar{r}) \phi}{\bar{\mu}^2 p_{02} (1-\phi)} \\ \frac{-b_{02}^\alpha p_{B2}}{\bar{\mu} p_{02}} &= \\ = \frac{\bar{\mu}}{p_{02} \lambda^\alpha \pi_2 (1+\bar{r}) \phi} \left[-U^{\alpha'} \left(\frac{b_{02}^\alpha}{p_{02}} \right) + \frac{\pi_1 (\phi p_{02} (1+\bar{\mu}) - p_{G2})}{p_{G2}} U^{\alpha'} \left(\frac{b_{02}^\alpha}{p_{02}} + \frac{b_{G2}^\alpha}{p_{G2}} \right) - \frac{\lambda^\alpha \pi_2 p_{B2}}{\bar{\mu}} \right] + \\ + \frac{-U^{\alpha'}(e_{01}^\alpha - q_{01}^\alpha) (1+r_0) (1-\phi) \bar{\mu}}{p_{01} \lambda^\alpha \pi_2 (1+\bar{r}) \phi} \end{aligned}$$

Adding 1 and regrouping, we have:

$$1 - \frac{b_{02}^\alpha p_{B2}}{\bar{\mu}^\alpha p_{02}} = \omega_0 + \omega_1 \bar{\mu}^\alpha U^{\alpha'} \left(\frac{b_{02}^\alpha}{p_{02}} \right) + \omega_2 \bar{\mu}^\alpha U^{\alpha'} \left(\frac{b_{02}^\alpha}{p_{02}} + \frac{b_{G2}^\alpha}{p_{G2}} \right) + \omega_3 \bar{\mu}^\alpha U^{\alpha'} (e_{01}^\alpha - q_{01}^\alpha), \tag{20}$$

where $\omega_0 = 1 - \frac{\lambda^\alpha \pi_B p_{B2}}{p_{02} (1+\bar{r}) \phi}$, $\omega_1 = \frac{-1}{p_{02} \lambda^\alpha \pi_B (1+\bar{r}) \phi}$, $\omega_2 = \frac{\pi_G (\phi p_{02} (1+\bar{\mu}) - p_{G2})}{p_{G2} p_{02} \lambda^\alpha \pi_B (1+\bar{r}) \phi}$, $\omega_3 = \frac{-(1+r_0)(1-\phi)}{p_{01} \lambda^\alpha \pi_B (1+\bar{r}) \phi}$.

Q.E.D.

References

- Adelino, M., Schoar, A., Severino, F., 2016. Loan originations and defaults in the mortgage crisis: the role of the middle class. *Rev. Financ. Stud.* 29 (7), 1635–1670.
- Alfaro, R., Gallardo, N., 2012. The determinants of household debt default. *Econ. Anal. Rev.* 27 (1), 55–70.
- Ambrose, B.W., Capone, C.A., 1998. Modeling the conditional probability of foreclosure in the context of single-family mortgage default resolutions. *Real Estate Econ.* 26 (3), 391–429.
- Amemiya, T., Vuong, Q.H., 1987. A comparison of two consistent estimators in the choice-based sampling qualitative response model. *Econometrica* 55 (3), 699–702.
- Bajari, P., Chu, S., Park, M., 2010. An Empirical Model of Subprime Mortgage Default From 2000 to 2007. Mimeo.
- Bajari, P., Chu, S., Nekipelov, D., Park, M., 2012. A Dynamic Model of Subprime Mortgage Default: Estimation and Policy Implications. Mimeo.
- Bernanke, B.S., Gertler, M., Gilchrist, S., 1999. The financial accelerator in a quantitative business cycle framework. In: *Handbook of Macroeconomics*, 1. Elsevier, pp. 1341–1393 Chapter 21.
- Bhutta, N., Dokko, J., Shan, H., 2010. The Depth of Negative Equity and Mortgage Default Decisions. Divisions of Research & Statistics and Monetary Affairs, Federal Reserve Board (USA) Finance and Economics Discussion Series (FEDS) 2010-35.
- Brueckner, J.K., Calem, P.S., Nakamura, L.I., 2016. House-price expectations, alternative mortgage products, and default. *J. Money Credit Bank.* 48 (1), 81–112.
- Campbell, J.Y., Cocco, J.F., 2015. A model of mortgage default. *J. Financ.* 70 (4), 1495–1554.
- Capozza, D.R., Kazarian, D., Thomson, T.A., 1997. Mortgage default in local markets. *Real Estate Econ.* 25 (4), 631–655.
- Capozza, D.R., Kazarian, D., Thomson, T.A., 1998. The conditional probability of mortgage default. *Real Estate Econ.* 26 (3), 359–389.
- Chan, S., Haughwout, A., Hayashi, A., Van Der Klaauw, W., 2016. Determinants of mortgage default and consumer credit use: the effects of foreclosure laws and foreclosure delays. *J. Money Credit Bank.* 48 (2–3), 393–413.
- Demyanyk, Y., Kojien, R.S.J., Van Hemert, O., 2011. Determinants and consequences of mortgage default. *SSRN Electron. J.* doi:10.2139/ssrn.1706844.
- Dubey, P., Geanakoplos, J., Shubik, M., 2005. Default and punishment in general equilibrium. *Econometrica* 73 (1), 1–37.
- Elmer, P.J., Seelig, S.A., 1999. Insolvency, trigger events, and consumer risk posture in the theory of single-family mortgage default. *J. Hous. Res.* 10, 1–25.
- Elul, R., Souleles, N.S., Chomsisengphet, S., Glennon, D., Hunt, R., 2010. What 'triggers' mortgage default? *Am. Econ. Rev. Pap. Proc.* 100 (2010), 490–494.
- Fisher, I., 1933. The debt-deflation theory of great Depressions. *Econometrica* 1 (4), 337–357.
- Foote, C.L., Loewenstein, L., Willen, P.S., 2020. Expectations and the housing boom and bust. An open economy view. *J. Hous. Econ.* 49, 101690. doi:10.1016/j.jhe.2020.101690.
- Foster, C., Van Order, R., 1984. An option-based model of mortgage default. *Hous. Financ. Rev.* 3 (4), 351–372.
- Garriga, C., Hedlund, A., 2019. Crises in the Housing Market: Causes, Consequences, and Policy Lessons. Federal Reserve Bank of St. Louis Research Working Paper Series, Working Paper 2019-033A.
- Geanakoplos, J., Fostel, A., 2008. Leverage cycles and the anxious economy. *Am. Econ. Rev.* 98 (4), 1211–1244.
- Geanakoplos, J., Zame, W., 2014. Collateral equilibrium: a basic framework. *Econ. Theory* 56 (3), 443–492.
- Gerardi, K., Shapiro, A.H., Willen, P.S., 2007. Subprime Outcomes: Risky Mortgages, Homeownership Experiences, and Foreclosures. Federal Reserve Bank of Boston Working Papers 07-15.
- Gete, P., Zecchetto, F., (2018). Franco, mortgage design and slow recoveries: the role of recourse and default. Available at SSRN: <https://ssrn.com/abstract=3082409> or <http://dx.doi.org/10.2139/ssrn.3082409>.
- Goodhart, C.A.E., Tsomocos, D.P., Vardoulakis, A.P., 2011. Modeling a housing and mortgage crisis. In: Alfaro, R. (Ed.). In: *Financial Stability, Monetary Policy, and Central Banking*, 15. Central Bank of Chile, pp. 215–253 Chapter 8 Central Banking, Analysis, and Economic Policies Book Series.
- Harrison, D.M., Noordewier, T.G., Yavas, A., 2004. Do riskier borrowers borrow more? *Real Estate Econ.* 32 (2), 385–411.
- Hatchondo, J.C., Martinez, L., Sanchez, J.M., 2012. Mortgage Defaults. IMF Working Paper WP/12/26.
- IMF, 2005. The treatment of nonperforming loans. In: *Proceedings of the Eighteenth Meeting of the IMF Committee on Balance of Payments Statistics BOPCOM-05/29*.
- Jaffee, D., Stiglitz, J., 1990. Credit rationing. In: *Handbook of Monetary Economics*, 2. Elsevier, pp. 837–888.
- Kau, J.B., Keenan, D.C., Kim, T., 1994. Default probabilities for mortgages. *J. Urban Econ.* 35, 278–296.
- King, G., Zeng, L., 2001. Logistic regression in rare events data. *Polit. Anal. Semin.* 9 (2), 137–163.
- King, G., Zeng, L., 2002. Estimating risk and rate levels, ratios and differences in case-control studies. *Stat. Med.* 21, 1409–1427.
- King, G., Tomz, M., Wittenberg, J., 2000. Making the most of statistical analyses: improving interpretation and presentation. *Am. J. Pol. Sci.* 44 (2), 341–355.
- Kumhof, M., Rancière, R., Winant, P., 2015. Inequality, leverage, and crises. *Am. Econ. Rev.* 105 (3), 1217–1245.
- Manski, C.F., Lerman, S.R., 1977. The estimation of choice probabilities from choice based samples. *Econometrica* 45 (8), 1977–1988.
- Mayer, C., Pence, K.M., Sherlund, S.M., 2009. The rise in mortgage defaults. *J. Econ. Perspect.* 23 (1), 27–50.
- McCullagh, P., Nelder, J.A., 1989. *Generalized Linear Models*, 2nd ed. Chapman and Hall, New York.
- OECD, 2011. Housing and the economy: policies for renovation. In: *Proceedings of the Economic Policy Reforms: Going for Growth Chapter 4*.
- Paniza Bontas, J., 2010. Combined LTV at Origination and Household Default Probability. University of Chicago Mimeo.
- Scott, A.J., Wild, C.J., 1986. Fitting logistic models under case-control or choice based sampling. *J. R. Stat. Soc. B* 48 (2), 170–182.
- Shubik, M., Wilson, C., 1977. The optimal bankruptcy rule in a trading economy using fiat money. *Z. Natl.* 37 (3–4), 337–354.
- Wong, J., Fung, L., Fong, T., Sze, A., 2004. Residential mortgage default risk and the loan-to-value ratio. *Hong Kong Monet. Auth. Q. Bull.* 35–45.
- Xie, Y., Manski, C.F., 1989. The logit model and response-based samples. *Sociol. Methods Res.* 17 (3), 283–302.