4 ANNEXES

* Les opinions et résultats décrits dans les études présentées dans cette partie sont ceux des auteurs. Ils ne doivent pas être considérés comme étant ceux de la BCL ou de l'Eurosystème.

1. EXPOSITION DU SECTEUR FINANCIER LUXEMBOURGEOIS AU RISQUE CLIMATIQUE

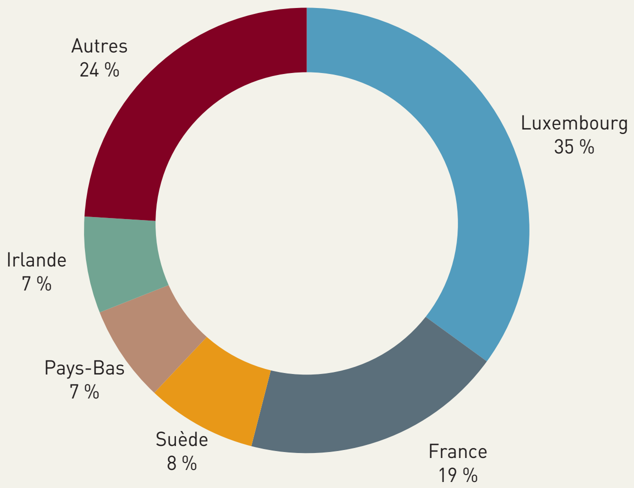
Daniel Morell[99]

RÉSUMÉ

L'impact des activités économiques sur le climat s'est accentué au fil du temps, provoquant alors une situation d´urgence face à l'amplification du risque climatique et ses diverses répercussions, tant sur les enjeux de développement des sociétés au niveau global que sur la stabilité des systèmes financiers mondiaux. Cette situation a contribué à la réorientation des flux financiers vers des activités durables et à la mise en place par la Commission européenne d'un « plan d'action pour la finance durable[100] ». Dans ce contexte, les autorités publiques et financières nationales doivent évaluer l'importance de l'impact potentiel du risque climatique sur la stabilité financière. Compte tenu du poids de la place financière luxembourgeoise au niveau international et de son rôle moteur pour la croissance économique au niveau national, il est important que le système financier luxembourgeois et ses différentes composantes demeurent résilients face aux risques induits par la transition écologique et par la décarbonation de leur portefeuille d'actifs.

Les conséquences globales des chocs climatiques peuvent entraîner des dépréciations rapides et brutales des actifs détenus par le secteur financier, affectant ainsi la stabilité du système financier dans son ensemble. Il est donc primordial que les différents acteurs de la place financière intègrent le risque climatique et les enjeux de développement durable dans leurs activités. Ainsi, un suivi régulier des expositions des acteurs financiers aux secteurs dont l'empreinte carbone est élevée permettrait de prévenir l'accumulation de risques systémiques et, par là même, d'inciter les acteurs de la place à développer leurs propres indicateurs pour quantifier le risque climatique et son impact sur leur portefeuille d'actifs.

Graphique 1
Répartition géographique des fonds d'investissement durable en Europe, en % de l'actif total



Sources : KPMG, FundFile

INTRODUCTION

La place financière luxembourgeoise est l'un des promoteurs de la finance durable qui a réussi à mobiliser des capitaux internationaux pour des projets d'investissements durables, lui permettant

99 Département Stabilité Financière et Surveillance Macroprudentielle, Banque centrale du Luxembourg.
100 Voir un descriptif du plan sur le site de la Commission européenne : https://ec.europa.eu/luxembourg/news/finance-durable-plan-daction-de-la-commission-pour-une- %C3 %A9conomie-plus-verte-et-plus-propre_fr

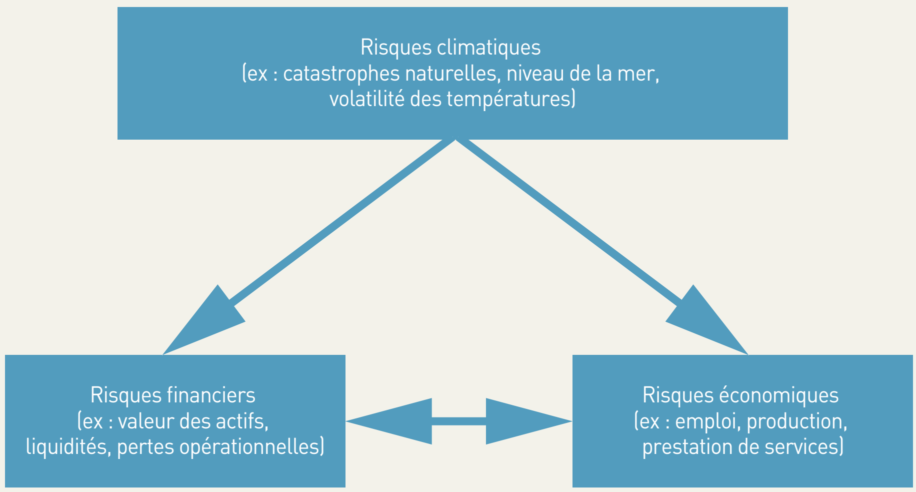
ainsi de devenir le leader des fonds d'investissements durables[101]. En 2018, le Luxembourg détient la première part de marché des fonds d'investissements durables en Europe avec 35 % des actifs sous gestion (graphique 1). En décembre 2018, l'Union européenne recensait 2 816 fonds d'investissement durable avec un encours bilanciel de 496 milliards d'euros. Ces fonds européens sont devenus de plus en plus attractifs pour les investisseurs, conduisant ainsi à une croissance annuelle des encours des actifs de 13 % depuis 2016. Le total d'actifs durables a quasiment doublé depuis 2012.

L'attrait suscité par les investissements intégrant des critères responsables a favorisé la création du label indépendant « ESG LuxFLAG » au Luxembourg afin de certifier les fonds d'investissements répondant aux critères environnementaux, sociaux et de gouvernance (ESG) tout au long du processus d'investissement, devançant alors l'Union européenne dans la mise en place de critères écologiques pour un label européen. La barre des 100 milliards d'euros d'actifs sous gestion labélisés « LuxFLAG » a été dépassée en mars 2020, avec une croissance de 167 % sur les 12 derniers mois[102]. Parallèlement, la Bourse de Luxembourg a lancé la Luxembourg Green Exchange (LGX) en septembre 2016, qui est devenue la première plateforme mondiale dédiée exclusivement aux instruments financiers écologiques dits « verts ». La LGX a permis au Luxembourg de devenir le leader mondial sur les cotations en obligations « vertes » (ou « green bonds »), avec près de la moitié des obligations dans le monde qui sont cotées au LGX (121 milliards de dollars d'obligations vertes émises sur la LGX en décembre 2018). Néanmoins, en dépit de sa grande expertise dans le secteur de la finance durable, le Luxembourg doit être attentif à la résilience climatique de ses activités, et considérer le risque climatique comme pouvant avoir un impact significatif sur la stabilité de la place financière (graphique 2).

L'évaluation du risque climatique et de son impact potentiel sur la stabilité financière est devenue ces dernières années une problématique principale des autorités publiques et notamment des banques centrales[103]. Au Luxembourg, cette question est abordée sous différents angles[104]

Cette étude propose d'évaluer l'impact du risque climatique sur le secteur financier au Luxembourg. Les effets du risque physique climatique au Luxembourg sont analysés dans

Graphique 2
Lien entre les risques climatiques, économiques et financiers



Source : Banque de France

101 Voir à ce propos la page dédiée à la finance durable du cluster « Luxembourg For Finance » disponible à l'adresse : https://www.luxembourgforfinance.com/fr/la-place-financiere/finance-durable/
102 Voir le communiqué de presse de LuxFLAG (2020) disponible sous ce lien : www.luxflag.org/media/pdf/press_releases/LuxFLAG_Press_Release_AuM_of_labelled_products_exceeds_100_billion_mark_3103201.pdf
103 Voir à ce propos les multiples travaux menés à l'échelle européenne : Commission européenne (2018), Parlement européen (2013) ou par d'autres banques centrales (Banque de France, 2019).
104 À titre d'exemple, voir le rapport du cluster Luxembourg For Finance (2018).

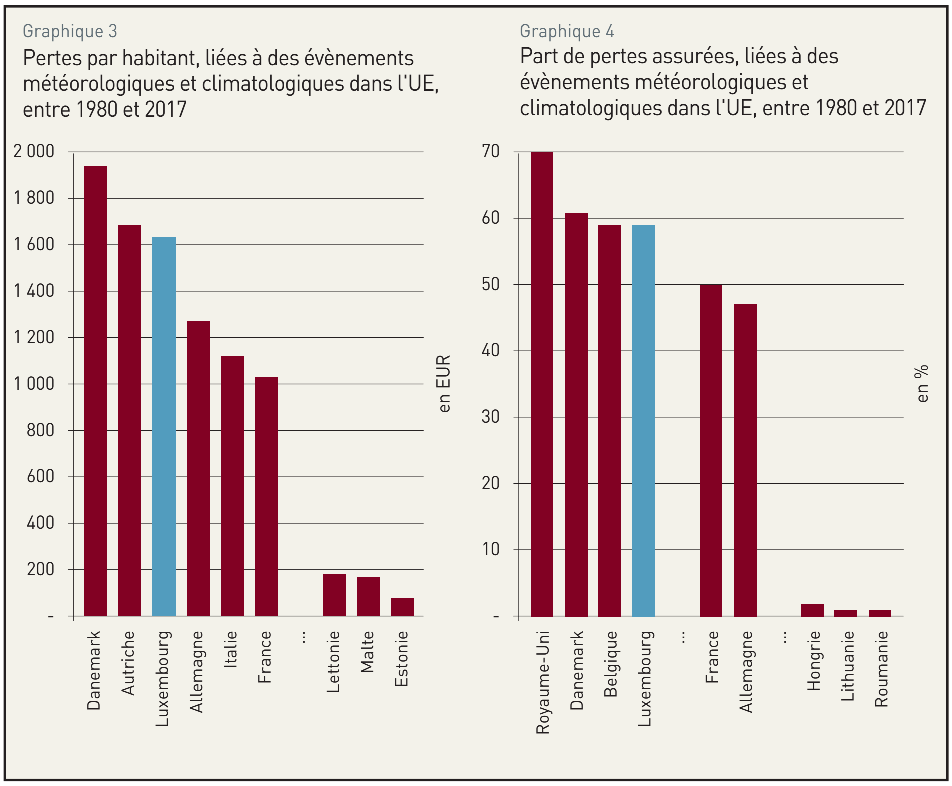
un premier point ; tandis que les conséquences potentielles du risque de transition au Luxembourg sont détaillées dans un deuxième point.

1. EFFETS LIMITÉS DU RISQUE PHYSIQUE CLIMATIQUE AU LUXEMBOURG

Le risque physique climatique désigne les pertes directes potentielles dues aux phénomènes climatiques. Nonobstant les importantes variations qui caractérisent les données, les pertes économiques provoquées par les risques naturels dans l'Union européenne (UE) sont en constante augmentation depuis les années 1980. Pour les 28 États membres de l'UE, sur la période 1980-2017, les pertes causées par des évènements météorologiques ou climatologiques représentaient 83 % des pertes totales dues à des risques naturels, soit 426 milliards d'euros[105].

Les pertes sont relativement faibles pour le Luxembourg en termes de montants, avec 718 millions d'euros de pertes mais il est le troisième pays le plus impacté de l'UE si l'on se réfère au ratio par habitant, avec une perte de 1 627 euros par habitant (graphique 3). Le Luxembourg n'est donc pas épargné par les risques liés aux changements climatiques. Néanmoins, la grande majorité des pertes au Luxembourg sont assurées (59 %), ce qui lui permet d'être le quatrième pays le mieux couvert des pays de l'Union européenne en cas d'évènements météorologiques ou climatologiques (graphique 4).

Au Luxembourg, les principales banques semblent très peu exposées au risque physique climatique dans la mesure où leurs expositions sont principalement concentrées dans des zones géographiques faiblement vulnérables aux phénomènes climatiques extrêmes. Ainsi, le montant total des expositions pondérées par les risques (RWA) des banques au Luxembourg a légèrement varié autour des 200 milliards d'euros entre mars 2015 et décembre 2018, avant de connaître une forte progression en 2019, jusqu'à atteindre 227 milliards d'euros en décembre 2020 (graphique 5). Ces expositions sont globalement situées dans des pays à climat tempéré, et donc peu susceptibles d'être impactées par le changement climatique. Ainsi, près de 70 % des expositions sont localisées en Europe en 2020, dont 21 % au Luxembourg et 21 % dans les pays limitrophes que sont l'Allemagne et la France (graphique 6). Les États-Unis constituent le premier pays extra-européen dont la valeur des expositions pondérées par les risques est la plus forte avec moins de 6 % du total de RWA des banques au Luxembourg.



Source: Agence européenne pour l'environnement

105 Source : Agence européenne pour l'environnement

Actuellement, le secteur bancaire au Luxembourg semble peu exposé au risque physique mais son impact n'est pas à sous-estimer car certains phénomènes climatiques surviennent de façon soudaine et dévastatrice.

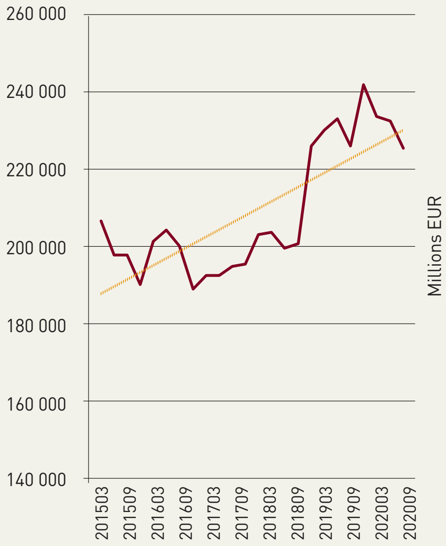
2. IMPACT SIGNIFICATIF DU RISQUE DE TRANSITION AU LUXEMBOURG

Le risque de transition désigne les impacts potentiels qu'occasionneraient sur la stabilité financière une période de transition rapide ou brusque vers une économie « moins-carbonée », afin de limiter les impacts du changement climatique. Cette transition pourrait être mise en place par des contraintes légales visant à limiter les émissions de carbone (taxation énergétique, fixation d'un prix carbone, etc.). Les établissements bancaires sont particulièrement sensibles à ce type de risque en raison de leurs expositions aux sociétés non financières (SNF) des secteurs carbonés.

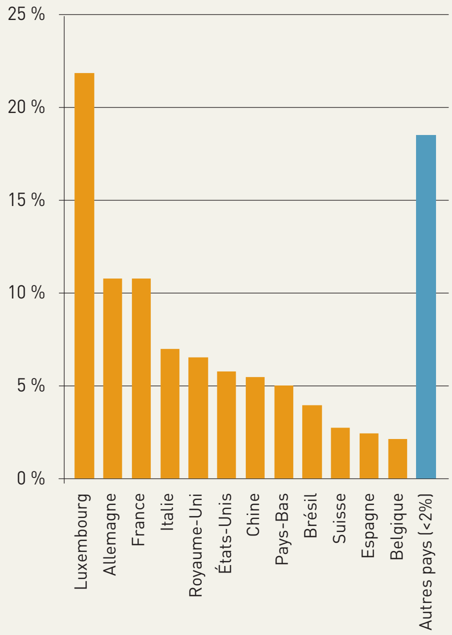
A) EXPOSITIONS DES BANQUES AU LUXEMBOURG AUPRÈS DU SECTEUR NON FINANCIER

L'analyse des prêts accordés aux sociétés non financières montre une progression relativement constante des montants octroyés par le secteur bancaire luxembourgeois aux secteurs économiques « carbonés »[106], passant de

Graphique 5
Évolution des expositions totales pondérées par les risques des banques au Luxembourg depuis 2015

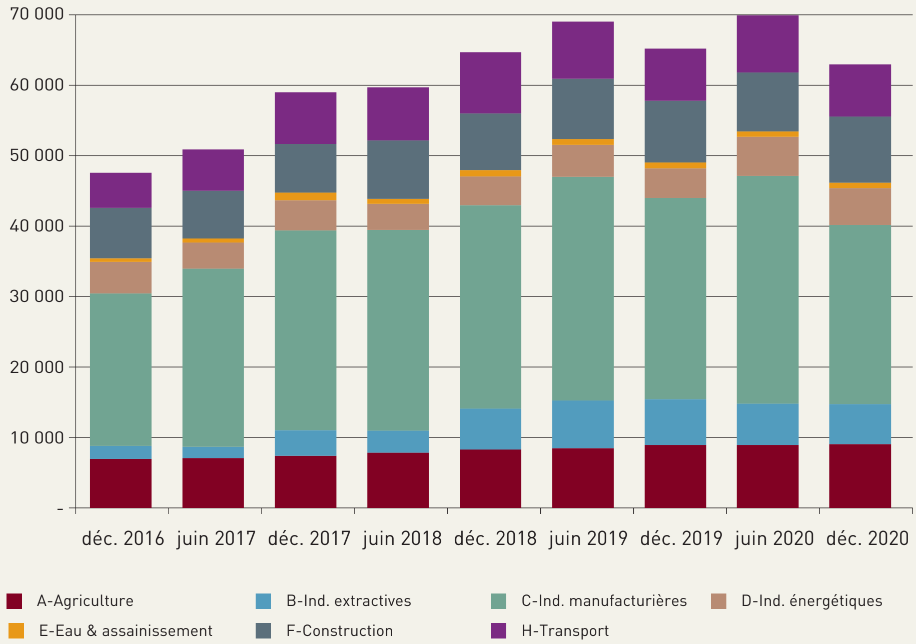


Graphique 6
Répartition géographique des expositions pondérées par les risques des banques au Luxembourg, en décembre 2020



Source : CSSF

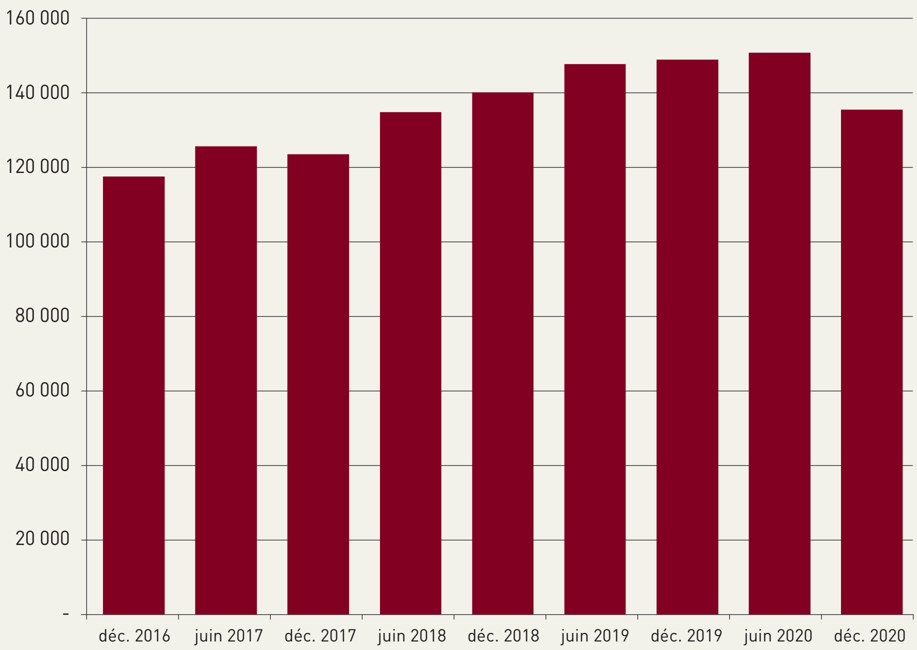
Graphique 7
Répartition sectorielle des prêts bancaires au Luxembourg octroyés aux sociétés non financières « carbonées »



Source : CSSF

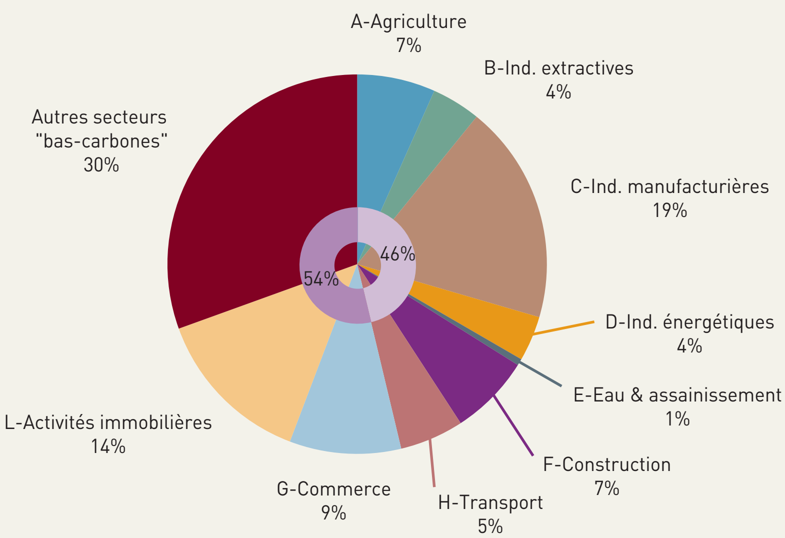
106 *Les secteurs économiques sensibles à un risque de transition ont été sélectionnés sur base de l'intensité de gaz à effets de serre (GES) par valeur ajoutée émise en 2017 par les sociétés non financières dans l'Union européenne :* agriculture, industrie extractive & manufacturière, production et distribution d'électricité, gaz & d'eau, construction et transports.

Graphique 8
Total des prêts accordés par les banques au Luxembourg aux sociétés non financières
(en Millions EUR)



Source : CSSF

Graphique 9
Répartition des prêts des banques au Luxembourg envers les sociétés non financières, par secteur économique, en décembre 2020



Source : CSSF

47 milliards d'euros en décembre 2016 à 63 milliards d'euros en décembre 2020, soit une croissance de 32 % (graphique 7).

Sur l'ensemble, l'analyse des prêts par secteur économique révèle également une progression constante des montants octroyés par les banques au Luxembourg aux sociétés non financières, passant de 117 milliards d'euros en décembre 2016 à 135 milliards d'euros en décembre 2020, soit une croissance de 15 % sur la période (graphique 8).

Cette hausse traduit une part plus importante des prêts « carbonés » en 2020 (46 % en décembre 2020, contre 40 % en décembre 2016) par rapport au total des prêts au secteur non financier, même si la proportion est plutôt stable depuis 2018.

Au niveau de l'ensemble des prêts envers les sociétés non financières, l'industrie manufacturière est le secteur économique le plus représenté, avec une part de 19 % du total des prêts accordés aux SNFs en décembre 2020 (graphique 9), suivie par les secteurs des activités immobilières (14 %) et du commerce (9 %).

Au Luxembourg, il semblerait qu'il n'y ait pas d´ajustements significatifs du secteur bancaire vers une réduction du risque climatique.

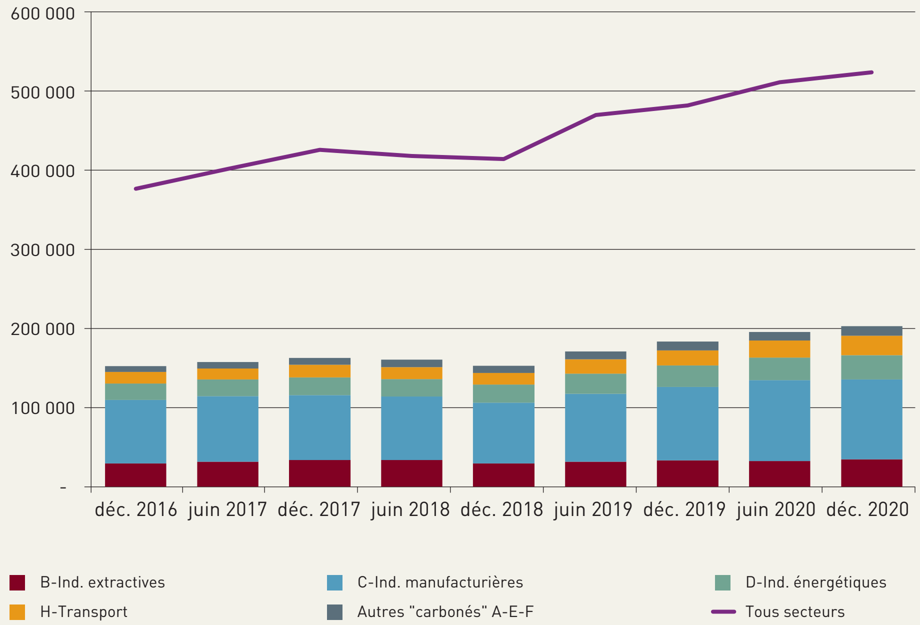
B) EXPOSITIONS DES FONDS D'INVESTISSEMENT AU LUXEMBOURG À L'ÉGARD DU SECTEUR NON FINANCIER

L'examen des bilans des fonds d'investissement permet d'étudier les secteurs économiques auxquels le secteur financier au Luxembourg est significativement exposé et l'impact de ces expositions sur ces fonds en cas de transition vers une économie décarbonée. La dynamique des principaux actifs détenus par les fonds d'investissement et émis par le secteur non financier est analysée.

L'analyse des titres de créance montre une croissance des expositions à l'égard du secteur non financier « carboné », au Luxembourg passant de 154 milliards d'euros en décembre 2016 à 206 milliards d'euros en décembre 2020, soit une croissance de 33 % sur la période (graphique 10). Sur l'ensemble des secteurs économiques, l'étude des titres de créance émis par le secteur non financier montre également une croissance de 39 % sur la période, passant de 382 à 532 milliards d'euros en décembre 2020.

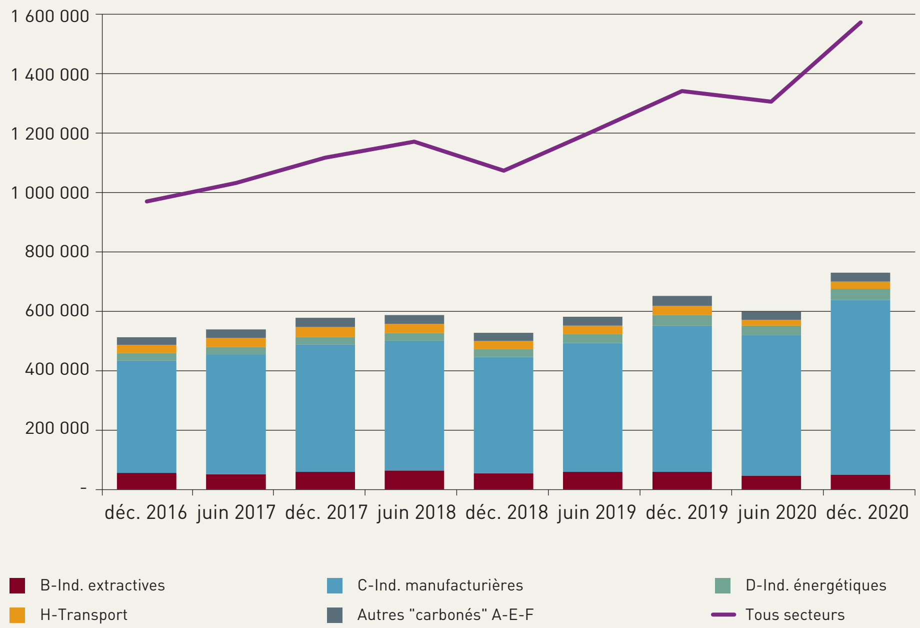
Cette augmentation, légèrement plus accentuée pour tous secteurs confondus, traduit une part plus faible des titres émis par des secteurs « carbonés » en 2020 (44 % en décembre 2020, contre 45 % en décembre 2016) par rapport au total des titres de créances détenus par le secteur non financier. L'évolution des titres de participation est semblable à celle des titres de créances, avec une croissance des titres des sociétés non financières des secteurs « carbonés » détenus par les fonds d'investissement

Graphique 10
Répartition sectorielle des titres de créance des sociétés non financières des 7 secteurs « carbonés » détenus par des fonds d'investissement
(en Millions EUR)



Source : BCL

Graphique 11
Répartition sectorielle des titres de participation des sociétés non financières des 7 secteurs « carbonés » dans le portefeuille des fonds d'investissement
(en Millions EUR)



Source : BCL

de 43 %, passant de 519 milliards d'euros en décembre 2016 à 740 milliards d'euros en décembre 2020 (graphique 11).

Sur l'ensemble des secteurs économiques, l'étude des titres de participation des sociétés non financières montre également une croissance de 62 %, passant de 984 à 1 596 milliards d'euros entre décembre 2016 et décembre 2020.

3. CONCLUSION

Les acteurs de la place financière luxembourgeoise semblent faiblement exposés au risque physique climatique dans la mesure où leurs expositions proviennent principalement, soit de zones géographiques moins vulnérables, soit des pays à haute résilience climatique. Toutefois, l'étude sectorielle des expositions des banques et des fonds d'investissement semble indiquer que l'évolution des stratégies vers des secteurs « bas-carbone » est encore relativement timide, voire inexistante pour le secteur bancaire, ce qui suppose qu'un risque de transition pourrait impacter de manière significative la place financière en cas de durcissement des politiques et des mesures environnementales. Les risques climatiques faisaient a priori partie des indicateurs de surveillance des risques par les banques avant la prise de conscience récente sur la question climatique. Or, la combinaison des risques de changements climatiques (risque physique) et celui induit par la mise en œuvre d'une politique de transition vers une économie bas-carbone (risque de transition) sont difficiles à évaluer en raison de la complexité sous-jacente aux interactions des deux risques, mais aussi de l'absence de données et d'expériences équivalentes. Dans ce contexte, il est nécessaire que les analyses des risques climatiques s'appuient sur plusieurs scénarios hypothétiques, mais vraisemblables, qui seraient susceptibles d'exprimer conjointement les trajectoires futures possibles du climat, de la dynamique de transition ainsi que leur potentiel impact sur les sphères réelle et financière.

Dans ce contexte, il est essentiel que les autorités publiques et de surveillance agissent de manière coordonnée afin de s'assurer que les acteurs financiers du pays développent des outils adaptés pour l'évaluation et le suivi des risques climatiques sur leurs activités et sur leurs portefeuilles d'actifs. Dans ce cadre, il y a lieu de rappeler que le secteur financier peine à intégrer les effets du changement climatique dans ses modèles et analyses de risques. En outre, il est nécessaire de mettre en place des collectes régulières et granulaires de données dont l'objectif est d´analyser et/ou de quantifier le risque de transition qui découlera de la mise en place d'un modèle économique bas-carbone.

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2. OPTIMAL LEVELS OF BORROWER-BASED MEASURES IN THE PRESENCE OF MORTGAGE DEFAULT

Ibrahima Sangaré[107]

ABSTRACT

This study investigates the optimal calibration for borrower-based measures in Luxembourg in the framework of a DSGE model with mortgage default and two borrowing constraints (LTV and DSTI). Using a welfare-based approach, we find that the optimal values for the LTV and DSTI ratios in the context of the COVID-19 pandemic are 85 % and 32 %, respectively. We also find that the optimal macroprudential policy welfare-dominates the non-optimal policy. Moreover, the optimal policy stabilizes mortgage lending and output more effectively than the policy based on the current average data. Finally, our findings suggest that an LTV limit calibrated above its optimal level increases mortgage default risk while a relatively high DSTI limit has no noticeable effects on the mortgage default risk under COVID-19-related shocks.

1. INTRODUCTION

In recent years, the Luxembourg residential real estate market has been strongly dynamic, characterized by a rapid growth in both house prices and mortgage loans leading to high and increasing household indebtedness. The residential property prices were continuing to rise at the beginning of 2021. The real and nominal residential property prices in Luxembourg respectively rose by 16.08 % and 16.71 % in annual terms in the last quarter of 2020. This ongoing increase in RRE prices is driven by both excess of demand for housing and supply limitations. The persistent low interest rate environment, in combination with high dwelling prices, has fuelled the increase in household indebtedness levels.

Households' indebtedness in Luxembourg is at a high level, even compared to other European countries, and continues to increase. The country features ratios of household debt-to-disposable income and mortgage debt-to-disposable income at above 100 % and continue to have a strong growth in mortgage loans that has often been driven by loosening lending standards. In particular, mortgage debt-to-disposable income amounted to 132 % in 2020Q4 while household debt-to-disposable income reached 167 % in the same quarter. The latter largely exceeds the average European countries household debt-to-income ratio of 104.46 % in 2020Q4.

These developments, forming the main vulnerabilities in the residential real estate market in Luxembourg, taken in combination with adverse economic or financial conditions could pose risks to financial stability risks both from the perspective of households' debt sustainability as well as housing affordability. In the absence of demand-side policy actions accompanying the supply-side policies, these vulnerabilities could have adverse effects for the real economy.

Therefore, in June 2019, the European Systemic Risk Board (ESRB) issued a recommendation for remedial actions on medium-term residential real estate vulnerabilities to Luxembourg, among five other EU countries[108]. More specifically, the ESRB has recommended to Luxembourg to establish a legal framework for borrower-based measures (such as LTV, DSTI, DTI and maturity limits) and to activate them as well as to curb the structural factors that have driven the vulnerabilities identified in Luxembourg.

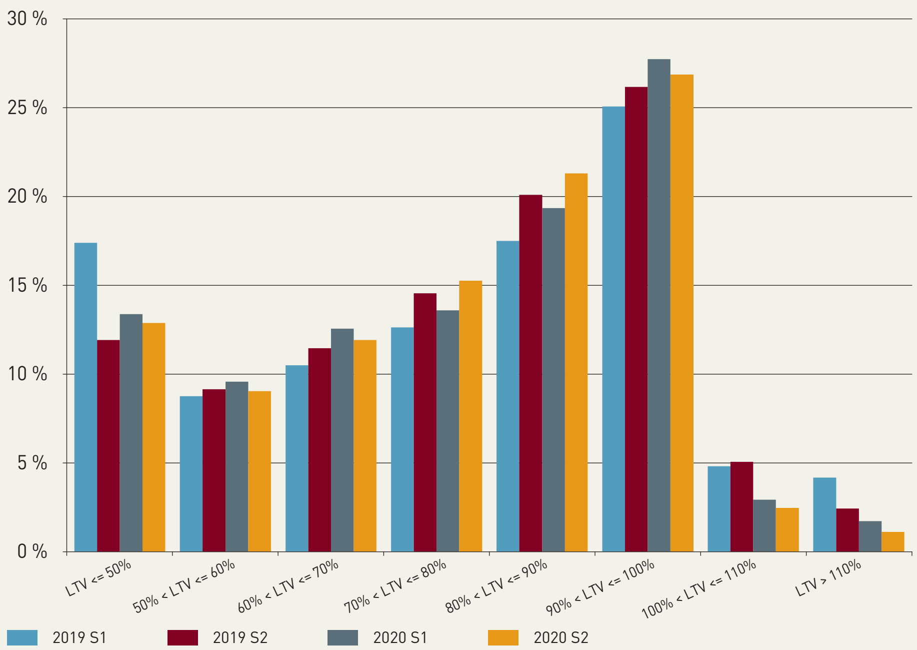
107 Financial Stability and Macroprudential Surveillance Department, Banque centrale du Luxembourg.
108 Recommendation/ESRB/2019/6.

Consequently, the legal framework for borrower-based measures in Luxembourg has been adopted by the Luxembourg parliament in November 2019, rendering these demand-side instruments legally available in the national macro-prudential policy toolkit. It has followed a recommendation issued by the *Comité du Risque Systémique* (the Luxembourg macroprudential authority) in November 2020 toward the *Commission de Surveillance du Secteur Financier* (CSSF) for activating the LTV limits in Luxembourg[109]. Accordingly, among borrower-based measures, only legally-binding LTV limits have been activated with differentiated limits according to borrower categories and entered into force on 1 January 2021. Especially, a maximum LTV limit is set to 100 % for first-time buyers acquiring their primary residence. For borrowers other than first-time buyers acquiring a primary residence, the LTV limit is 90 %. To enable flexibility, lenders may issue 15 % of the portfolio of new mortgages granted to these borrowers with an LTV above 90 % but below the maximum of 100 %. For all other borrowers, including for the buy-to-let segment, the LTV cap is set to 80 %.

However, before the legal activation of the LTV limits, Luxembourg banks applied various LTV and DSTI limits depending on their own assessment of household creditworthiness as illustrated by the distribution of new loans granted by LTV and DSTI in Figure 1 and Figure 2. Figure 1 and Figure 2 show that the amount of new loans with a

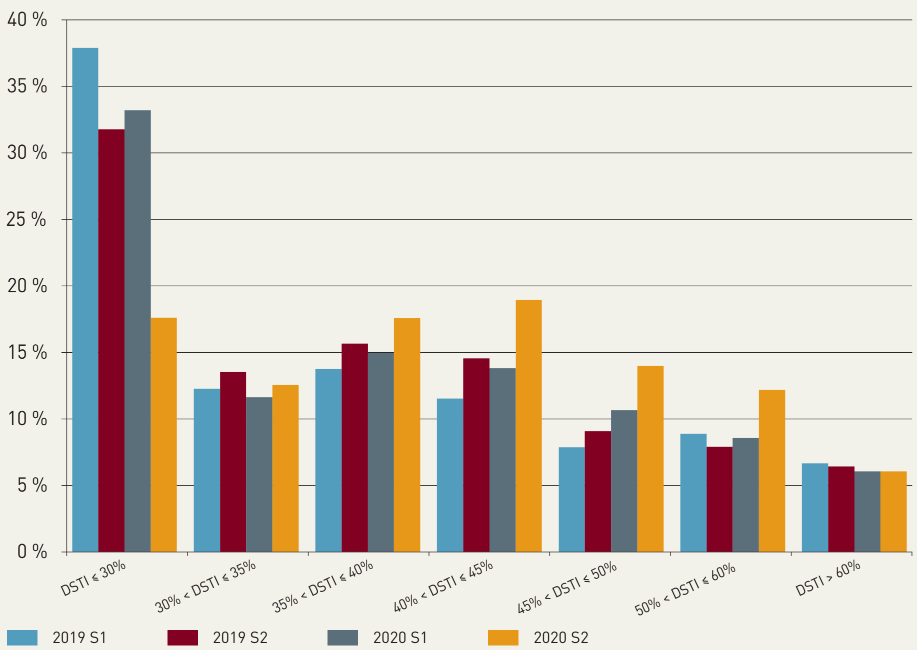
109 For more details, see Recommendation/CRS/2020/005 and CSSF Regulation N° 20-08.

Figure 1
Distribution of new loans granted by LTV



Source: CSSF

Figure 2
Distribution of new loans granted by DSTI



Source: CSSF

LTV higher than 80 % has decreased from 53.3 % in the second semester of 2019 to 51.3 % in 2020S2. However, in the same period, the amount of new loans with the debt service cost (DSTI) higher than 40 % has increased from 38.4 % to 51.7 %.

As only the LTV cap is legally binding, lenders would continue to extend new loans with varieties of DSTI caps depending on their own assessment of borrowers.

Therefore, there is a need to assess the effectiveness of the combined legally-binding LTV and DSTI in addressing vulnerabilities in the residential real estate market, especially in the context of the pandemic crisis.

This study addresses the question of what is the optimal calibration of borrower-based measures in the context of the coronavirus pandemic. To this end, we use a DSGE model to determine the optimal levels of LTV and DSTI, in the presence of loan default. The macroeconomic effects of such a combination of macroprudential measures is also assessed.

There are two specific objectives of this work. On the one hand, we search for optimal levels of borrower-based measures taken in combination in order to help supporting potential policy actions and to assist in their optimal calibration if it becomes necessary to activate them in combination. Current empirical and theoretical evidence suggests that combinations of macroprudential instruments are more effective in targeting potential risks than the implementation of a single instrument[110]. In addition to providing guidance on the possible calibration of borrower-based measures, this work also provides some insights into the relationship between borrower-based measures and mortgage risk from households.

More specifically, we build a DSGE model with mortgage default and two macroprudential borrower-based instruments namely LTV and DSTI limits. The model is designed to assess the optimal limits of these instruments based on a welfare analysis and is calibrated using Luxembourg data.

Our main findings can be summarized as follows. Using a welfare metric, we first find that, in a context the COVID-19 pandemic characterized by simultaneous adverse demand and supply shocks, the optimal values of LTV and DSTI ratios are 85 % and 32 %, respectively. Second, we find that the optimal macroprudential policy welfare-dominates the non-optimal policy. Moreover, the optimal policy better stabilizes mortgage loans and output than the policy based on the average values of the observed policy instruments. Finally, our findings suggest that a higher levels of both LTV and DSTI limits implies a higher mortgage default risk compared to the optimal calibration of these instruments. This reflects the fact that the main driver of household default risk in the presence of a COVID-19 related shock is the LTV limit.

The rest of the analysis is organised as follows. Section 2 reviews the related literature. Section 3 describes the model and Section 4 presents the model calibration. Section 5 presents the optimal macroprudential policy stance and provides the optimal values of LTV and DSTI limits for Luxembourg as well as the dynamics of the main macro-financial variables in the COVID-19 context. Section 7 concludes.

110 See Crowe *et al.* (2013), Cassidy and Hallissey (2016) and Grodecka (2017) for more details.

2. LITERATURE REVIEW

This work is related to four strands of literature. First, the existing studies using the dynamic stochastic general equilibrium (DSGE) modelling approach for analysing the real estate dynamics in Luxembourg are rather limited. Sangaré (2019) studies the optimal macroprudential policy for Luxembourg using a DSGE model with a housing sector and a borrowing constraint. Therefore, the novelty of the current work compared to the previous one is to analyse the optimal macroprdential policy for a combination of borrower-based measures within a DSGE framework that incorporates mortgage default and two borrowing constraints.

This work is also related to numerous papers that model the housing sector with a borrowing constraint in a dynamic stochastic general equilibrium framework (e.g. Iacoviello (2005), Iacoviello and Neri (2010), Gerali *et al.* (2010), Mendicino and Punzi (2014), Rubio and Carrasco-Gallego (2014), Brzoza-Brzezina *et al.* (2017), Guerrieri and Iacoviello (2017)). However, few studies among the mentioned papers explicitly model the banking sector and they do not include mortgage default or study the effectiveness of macro-prudential policy. We address this gap by considering a DSGE framework in which banks are explicitly modelled in a monopolistic competitive market and we also include a mortgage default mechanism.

This study is also related to the growing body of literature on the effectiveness of macroprudential policies. Several papers have explored the effectiveness of macroprudential policies using stochastic general equilibrium models, including Lubello and Rouabah (2017) and Fève and Pierrard (2017). However, their models do not account for the housing sector and only consider individual macroprudential instruments without mortgage default modelling.

Few studies with a housing sector have been interested in exploring the optimality of macroprudential policies (Rubio and Carrasco-Gallego (2014), Mendicino and Punzi (2014), Punzi and Rabitsch (2018)). Although they assess optimality, these studies do not focus on the interaction between macroprudential instruments and they do not include either mortgage default or several borrowing constraints. Moreover, most of these papers analyze optimal interactions between the monetary policy and macro-prudential policy rather than assessing the optimal combinations of macroprudential instruments.

Some studies (Lambertini *et al.* (2017), Pataracchia *et al.* (2013), Forlati and Lambertini (2011), Clerc *et al.* (2015), Mendicino *et al.* (2018)) do explicitly model mortgage default but they do not include an optimality framework or the combination of macroprudential instruments. Other works, such as those of Rubio and Carrasco-Gallego (2014), Mendicino and Punzi (2014), Punzi and Rabitsch (2018), Mendicino *et al.* (2018) investigate the optimality of macroprudential instruments but the instruments are taken in isolation and not in combination. These authors do not explore the impact of mortgage default.

Finally, our study fits into the literature on combinations of macroprudential instruments. This strand of literature mainly addresses the combination of borrower-based instruments using empirical techniques adopted by Kelly *et al.* (2018) and Albacete *et al.* (2018). Some exceptions include Chen and Columba (2016), Grodecka (2017) and Greenwald (2018) who analysed the combination of borrower-based instruments using a DSGE modelling approach but without default. Benes *et al.* (2016) use a DSGE model for studying the combination of a capital buffer and a borrower-based measure (LTV ratio) but without any optimality analysis.

The current study considers the optimal combination of borrower-based macroprudential instruments (LTV and DSTI) in a DSGE model with mortgage default. To the best of our knowledge, the only work existing in the literature on macroprudential policies that fits our methodology is the one from Aguilar *et al.* (2019). However, the latter paper focuses on combination of capital-based macroprudential measures rather than borrower-based measures.

3. MODEL[111]

We develop a DSGE model with a housing sector, two borrowing constraints (LTV and DSTI ratios) and a mechanism for mortgage defaults. The only source of mortgage default in the model is an idiosyncratic shock that affects the house value. We assume that income-related risks (i.e., household unemployment) do not trigger mortgage default[112].

Two groups of households populate the economy: patient households and impatient households and each group has unit mass. Patient households are savers and have higher discount factors than impatient households who are borrowers ($\beta_P > \beta_I$).

This heterogeneity in agents' discount factors generates positive fund flows in equilibrium: patient households make positive deposits and do not borrow, while impatient households borrow a positive amount of loans. Patient households consume, work and accumulate capital and housing. Impatient households consume, work and accumulate housing. As impatient households are considered to be borrowers, they are constrained by having to collateralize the value of their house which introduce some financial frictions in the economy, to allocate a constant fraction of their income to debt services and by the occurrence of default.

We introduce a monopolistically competitive banking sector *à la* Gerali *et al.* (2010). Banks intermediate the funds that flow from patient households to impatient households. Banks issue loans to impatient households and firms by collecting deposits from patient households and accumulating their own capital out of reinvested profits. Banks face the risk of defaults from their borrowers. Another financial friction is introduced in the model by assuming that banks are subject to a risk weighted capital requirement constraint that translates into an exogenous target for the leverage ratio, the deviation from which implies a quadratic cost.

On the production side, monopolistically competitive intermediate-goods-producing firms produce heterogeneous intermediate goods using physical capital, bought from capital goods producers, and labour supplied by households against flexible wages. The prices of intermediate goods are set in a staggered fashion *à la* Rotemberg (1984). Final goods- producing firms, who bundle intermediate goods into final goods, capital and housing producers operate in perfectly competitive markets.

Finally, a government covers its expenditures by levying lump-sum taxes on households and by collecting the share of defaulting households' wealth that is seized and paid to the government's insolvency agency. The monetary authority follows a standard Taylor-type interest rate rule.

111 We only present here a brief summary of the model. The more detailed presentation of the model is in a technical appendix available upon request.

112 This assumption is made in order to simplify the model.

3.1. HOUSEHOLDS

The economy is composed of two types of agents: patient and impatient households. The only difference between these agents is that the discount factor for impatient households (β_I) is less than the discount factor for patient households (β_P). Both types of households derive utility from consumption, $c_{z,t}$, housing services, $h_{z,t}$ and the number of hours worked, $n_{z,t}$. Households have identical expected discounted utility functions that corresponds, in real terms, to:

$$E_0 \sum_{t=0}^{\infty} \beta_z^t U(c_{z,t}; h_{z,t}; n_{z,t}) = E_0 \sum_{t=0}^{\infty} \beta_z^t \left[A_{c,t}(1-a)\ln\left(c_{z,t} - a.C_{z,t-1}\right) + A_{h,t}\chi_h \ln\left(h_{z,t}\right) - \frac{\chi_n n_{z,t}^{1+\gamma}}{1+\gamma} \right] \quad (1)$$

where z = {I,P} with I and P respectively standing for impatient (borrowers) and patient (savers) households. The current individual consumption depends on the lagged smoothed aggregated consumption, $a.C_{z,t-1}$, where the parameter a, denotes the degree of habit formation in consumption for non-durable goods. The parameter χ_h is the weight on housing services, χ_n denotes the weight on hours worked and γ is the elasticity of labour substitution. $A_{c,t}$ and $A_{h,t}$ are two preference shocks to consumption and housing demands, respectively, and both follow an AR(1) process.

A) Patient households

The representative patient household maximises their expected utility (1) and is subject to the following real budget constraint[113]:

$$\begin{aligned} c_{P,t} + q_{h,t}\left[h_{P,t} - h_{P,t-1}\right] + d_t + q_{k,t}[k_t - (1-\delta_k)k_{t-1}] \\ = w_{P,t}n_{P,t} + \frac{R_{t-1}}{\Pi_t}d_{t-1} - T_{P,t} + \Lambda_t + Div_t + \frac{r_{k,t-1}k_{t-1}}{\Pi_t} \end{aligned} \quad (2)$$

where $q_{h,t}$ and $q_{k,t}$ are the respective prices for housing stock, $h_{P,t}$, and physical capital, k_t which depreciates at the rate, δ_k. Patient households receive the wage rate, $w_{P,t}$, for supplying hours of work and earn R_{t-1} on the last period risk-free deposit, d_{t-1} and $r_{k,t-1}$, the rental rate on the physical capital that they own, which depends on gross inflation, $\Pi_t = \frac{P_t}{P_{t-1}}$. Patient households receive a profit Λ_t from both intermediate consumption and capital goods producers and a dividend Div_t from monopolistically competitive banks. Finally, they pay a lump-sum tax, $T_{P,t}$, to the government.

113 The first order conditions derived from the maximization problem of patient households are in a technical appendix available upon request.

B) Impatient households

The representative impatient household faces two borrowing constraints.

(i) LTV constraint

In each period, t, households' borrowing is subject to the regulatory LTV constraint defined in real terms as:

$$R_{I,t}^{L} l_{I,t} \leq LTV q_{h,t} h_{I,t} \tag{3}$$

where *LTV* denotes the loan-to-value ratio fixed by the macroprudential authority and $R_{I,t}^{L}$ is the mortgage lending rate.

(ii) DSTI constraint

In addition, the borrowing in period, t, is limited by a regulatory DSTI constraint expressed in real terms as:

$$R_{I,t}^{L} l_{I,t} \leq DSTI w_{I,t} n_{I,t} \tag{4}$$

For simplification purposes, we assume that only the value of housing is subject to an idiosyncratic shock triggering mortgage default. In other words, the risk of mortgage default is only related to the value of house and not to the borrowers' income. This assumption implies that there is only one source of mortgage default in the model (i.e., house value).

We assume that in $t + 1$, each impatient household faces an idiosyncratic shock to its house value ω_{t+1}, which follows a uniform distribution with the lower and upper bounds, $(\underline{\omega},\overline{\omega})$[114]. The shock ω_t is i.i.d. and it has positive support with cumulative distribution, $F(x) \equiv prob(\omega_t \leq x)$, with mean $\mu_{\omega,t}$, variance σ_{ω}^{2} and density function $f(\omega_t)$.

The borrower is solvent if and only if $\omega_{t+1} \geq \widetilde{\omega}_{t+1}$ where $\widetilde{\omega}_{t+1}$ is the threshold or cutoff point such that, in real terms:

$$R_{I,t}^{L} l_{I,t} = \widetilde{\omega}_{t+1} E_t q_{h,t+1} h_{I,t} \Pi_{t+1} \tag{5}$$

Default occurs when the expected real value of the impatient household's house at $t + 1$ falls below the amount that needs to be repaid, that is when $E_t(\omega_{t+1} q_{h,t+1} h_{I,t} \Pi_{t+1}) < R_{I,t}^{L} l_{I,t}$.

From (5) and (3), the cutoff point is determined endogenously as:

$$\widetilde{\omega}_{t+1} = LTV \frac{q_h}{E_t q_{h,t+1} \Pi_{t+1}} \tag{6}$$

The default threshold is therefore driven by the LTV ratio and the deviation of the nominal house price from expectations.

114 Impatient households face an identical uniform distribution for the shock.

When default occurs, households cannot repay the loan and the bank can seize, in real terms, $\omega_{t+1} q_{h,t+1} h_{I,t} \Pi_{t+1}$, where $q_{h,t+1}$ denotes the house real price in period, t + 1. The bank then pays the fraction 1 - μ of what is seized to the government's insolvency agency.

The bank's participation constraint can be written in real terms as:

$$R^L_{I,t} l_{I,t} = \Phi(\widetilde{\omega}_{t+1}) q_{h,t+1} h_{I,t} \Pi_{t+1} \tag{7}$$

where $\Phi(\widetilde{\omega}_{t+1}) \equiv (1-\Theta) \mathrm{G}_{t+1}(\widetilde{\omega}_{t+1}) + \widetilde{\omega}_{t+1} \int_{\widetilde{\omega}_{t+1}}^{\overline{\omega}} f(\omega_{t+1}) \mathrm{d}\omega_{t+1}$ with $1-\mu = \Theta \in [0,1]$ and $\mathrm{G}_{t+1}(\widetilde{\omega}_{t+1}) \equiv \int_{\underline{\omega}}^{\widetilde{\omega}_{t+1}} \omega_{t+1} f(\omega_{t+1}) \mathrm{d}\omega_{t+1}$ is defined as the expected house value accrued to the bank when default occurs.

The budget constraint of the representative impatient household is given, in real terms, by:

$$c_{I,t} + q_{h,t} h_{I,t} + \frac{R^L_{I,t-1}}{\Pi_t} l_{I,t-1} = w_{I,t} n_{I,t} + l_t - T_{I,t} + [1 - \Theta \mathrm{G}_t(\widetilde{\omega}_t)] q_{h,t} h_{I,t-1} \tag{8}$$

The representative impatient household maximises (1) subject to the budget constraint (8), the regulatory DSTI constraint (4) and the bank participation constraint (7)[115].

3.2. BANKS

A monopolistically competitive banking sector extends loans to impatient households and collect deposits from patient households. Banks are subject to an adjustment cost. As in Gerali *et al.*(2010), we assume that the representative bank has a target τ for their capital-to-risk-weighted-assets ratio and pays a quadratic cost whenever it deviates from that target. The target can be interpreted as an exogenous regulatory capital requirement constraint that imposes the amount of own resources to hold. The existence of a cost for deviating from τ implies that bank leverage affects credit conditions in the economy.

The representative bank's real expected profit is:

$$E_t\left[\Lambda^r_{B,t+1}\right] = E_t[RE^r_{t+1}] - R_t\left(l_{I,t} - k_{B,t}\right) - \frac{\zeta_B}{2}\left(\frac{k_{B,t}}{rwr.\,l_{I,t}} - \tau\right)^2 k_{B,t} \tag{9}$$

where *rwr* denotes the regulatory risk weight on mortgage lending and $E_t[RE^r_{t+1}]$ is the expected real return from lending to impatient households which can be written as:

$$E_t[RE^r_{t+1}] = R^L_{I,t} l_{I,t} - l_{I,t} E_t\left(\frac{q_{h,t+1}\Pi_{t+1} h_{I,t}}{l_{I,t}}\right) \int_{\underline{\omega}}^{\widetilde{\omega}_{t+1}} (\widetilde{\omega}_{t+1} - \mu\omega_{t+1}) f(\omega_{t+1}) \mathrm{d}\omega_{t+1}.$$

The representative bank chooses the optimal loan supply in order to maximise its real expected profit (9). Solving the maximisation programme leads to the following first order condition:

$$R^L_{I,t} = R_t - \zeta_B\left(\frac{k_{B,t}}{rwr.\,l_{I,t}} - \tau\right)\left(\frac{k_{B,t}}{rwr.\,l_{I,t}}\right)^2 rwr + \rho^L_t \tag{10}$$

115 Note that the LTV constraint (3) is included in the household maximization problem through the bank participation constraint (7) as the default threshold, $\widetilde{\omega}_t$, already incorporates the LTV constraint. Furthermore, the first order conditions derived from the maximization problem of impatient households are in a technical appendix available upon request.

where $l_{I,t} = \frac{L_{I,t}}{P_t}$ denotes the real loan and ρ_t^L is the mortgage finance premium, defined as:

$$\rho_t^L = E_t\left[\frac{q_{h,t+1}\Pi_{t+1}h_{I,t}}{l_{I,t}}\right]\int_{\underline{\omega}}^{\widetilde{\omega}_{t+1}}(\widetilde{\omega}_{t+1} - \mu\omega_{t+1})f(\omega_{t+1})\mathrm{d}\omega_{t+1} \quad (11)$$

The mortgage finance premium that compensates loan losses is determined by the expected ratio of the real value of houses to the real value of total loans as well as the degree of cross-sectional uncertainty in the economy.

Bank capital is accumulated out of reinvested profits.

3.3. FIRMS

Final goods producers operate under perfect competition, buy differentiated intermediate goods produced by intermediate goods producers. The latter operate under monopolistic competition and are indexed by $j \in [0,1]$. The intermediate goods firm j relies on the following technology:

$$y_t(j) = A_{F,t}(k_{t-1}(j))^{\alpha}\left[(n_{I,t}(j))^{\eta}(n_{P,t}(j))^{1-\eta}\right]^{1-\alpha} \quad (12)$$

where α is the share of capital in total production, n is the share of impatient households' labour in the total labour input and $n_{I,t}(j)$ and $n_{P,t}(j)$ stand for labour supplied by impatient and patient households respectively. $A_{F,t+1}$ is an aggregate productivity shock.

Each intermediate producer j solves its cost minimization problem subject to (12), which provides the real cost of production factors. Price rigidities are introduced in the model following the New Keynesian literature. Firms are subject to Rotemberg price-setting and the optimal price is found by solving their dynamic problem of profit maximization[116].

Finally, in each period, perfectly competitive capital investment-goods producers purchase last-period undepreciated capital at price $q_{k,t}$ from patient households and capital investment goods from final-goods firms at a relative price of one, and produce the new capital goods. This increases the effective installed capital, which is then sold back to patient households at $q_{k,t}$. This transformation process is subject to adjustment costs in the change in investment. Lastly, $q_{k,t}$ is derived from the capital goods producers' maximization of their expected profits.

3.4. MONETARY POLICY AND GOVERNMENT SPENDING

The central bank sets monetary policy according to a Taylor-type rule. It is assumed that government spending is exogenous and represents a constant fraction of the steady state output.

3.5. MARKET CLEARING CONDITIONS

The model's equilibrium is defined as a set of prices and allocations such that households maximize their discounted present value of utility, banks maximize their real expected profit, and all firms maximize the discounted present value of profits subject to their constraints, and all markets clear.

116 As in Rotemberg (1984), it is assumed that price changes are costly with quadratic adjustment costs.

4. CALIBRATION OF THE MODEL

In order to simulate the model, we have selected the values for the model parameters based on both Luxembourg data and literature. Table 1 presents the calibrated values of the various parameters.

We set the discount factor of patient households, β_P, to 0.995 in order to match the average annual real risk free interest rate of 2 %. The discount factor of impatient households, β_I, is assumed to be 0.90 so that the two borrowing constraints are binding.

The degree of habit formation in consumption, a, is set to the estimated value of 0.5 in Sangaré (2019). The capital share in output, α, is equal to 0.3, corresponding to the share of labour income to GDP of 0.7 as per Luxembourg data. The share of impatient households' income of total labour income, η, is set to 0.6 based on the results in Alpanda and Zubairy (2017) and the fact that the BCL's Household Finance and Consumption Survey for Luxembourg (HFCS, 2014) reports a small share of income of wealthier households (top deciles) over the total income declared.

We set the non-residential capital depreciation rate, δ_K, to 0.01 also based on Luxembourg data. The loan-to-value (LTV) ratio, *LTV*, is 0.90 and the debt service-to-income (*DSTI*) ratio is 0.40, which are in line with the CSSF survey. The goods substitution elasticity, ϵ, is set 6, implying the steady-state markup of 20 % as in Chen and Columba (2016) and Hristov and Hülsewig (2017). The inverse Frisch elasticity is γ=1.15 in following with the estimates in Sangaré (2019).

We fix the steady-state ratio of capital-to-risk weighted assets to 12 %, which is inferred from a normalization using the Basel III regulatory rule and data. The regulatory risk weight on mortgage loans, *rwr*, taken from Luxembourg data, is 0.19. The dividend policy parameter, v = 0.9, is endogenously determined at the steady state. The banking leverage adjustment cost parameter, ζ_B, is set to 0.66 corresponding to the estimate in Sangaré (2019). The parameters of adjustment costs related to goods prices (ζ_P) and business capital (ζ_K) are respectively set to 10 and 2. These values are broadly consistent with the literature (Hristov and Hülsewig (2017) for ζ_P, Clerc *et al.* (2015) for ζ_K). Bank capital depreciates at the rate of δ_B=0.1 as in Gerali *et al.* (2010).

The weights for housing preference (χ_h) and labour disutility (χ_n) in the utility function are respectively 0.5 and 1, following Clerc *et al.* (2015).

The fraction of the actual house value seized by the bank in case of default, μ, is set to 95 % implying insolvency proceeding costs of 5 %, which is the approximate average value in the literature.

The steady state values of the lower and upper bounds of the idiosyncratic housing value shock are respectively $\underline{\omega}$ = 0.6 and $\overline{\omega}$ = 2.4, such that the two borrowing constraints in the model are binding and the model is well determined for reasonable values of LTV. Therefore, the steady state value of the probability of mortgage default is in the range from 1 % to 5 %.

The ratio of public spending over GDP is 0.2 based on Luxembourg data. The monetary policy rule has a smoothing parameter of 0.8, a response to inflation about 2, and a response to the output gap of 0.4 following Gerali *et al.* (2010).

Finally, we use 0.8 for the coefficients of the autoregressive parts of the shock processes.

Table 1:
Calibration of the model parameters

β_P	Discount factor of Patient households	0.995
β_I	Discount factor of Impatient households	0.9
a	Degree of habit formation in consumption	0.5
α	Capital share in output	0.3
η	Share of Impatient households' income in labour income	0.6
δ_K	Non-residential capital depreciation rate	0.01
LTV	LTV ratio	0.90
$DSTI$	Debt service-to-income ratio	0.40
γ	Inverse of Frisch elasticity	1.15
τ	Ratio of Capital-to-Risk weighted assets	0.12
ζ_B	Banking leverage adjustment cost	0.66
δ_B	Banking capital used in banking activity	0.1
rwr	Regulatory Risk weight on mortgage loans	0.19
v	Banks' dividend policy parameter	0.9
ζ_P	Parameter of goods price adjustment cost	10
ζ_K	Parameter of business capital-investment adjustment cost	2
ϵ	Goods substitution elasticity	6
μ	Fraction of the house value that seized by banks in case of default	0.95
θ	Fraction of the house value seized to cover insolvency proceeding cost	0.05
χ_h	Weight of housing in the utility	0.5
χ_n	Weight of labour in the utility	1
g	Government spending to GDP ratio	0.2
ϕ_R	Taylor rule smoothing coefficient	0.8
ϕ_Π	Taylor rule coefficient on inflation	2
ϕ_Y	Taylor rule coefficient on output	0.4
$\underline{\omega}$	Lower bound of the idiosyncratic housing shock	0.6
$\overline{\omega}$	Upper bound of the idiosyncratic housing shock	2.4
ρ_c	AR consumption preference shock	0.8
ρ_h	AR housing preference shock	0.8
ρ_b	AR banking capital shock	0.8
ρ_f	AR productivity shock	0.8
ρ_r	AR monetary policy shock	0.8
ρ_k	AR capital-investment shock	0.8
ρ_g	AR government spending shock	0.8
ρ_p	AR risk premium shock	0.8

Source: calculs BCL.

5. OPTIMAL CALIBRATION OF LTV AND DSTI MEASURES

5.1. OPTIMAL POLICY FRAMEWORK

An optimal policy analysis aims at identifying optimal calibration values for the policy instruments that maximize the objective function of the macroprudential authority. Therefore, determining the optimal levels of policy instruments requires defining the objective of the macroprudential policy authority and then defining the optimality criteria.

It is challenging to model the objective of macroprudential policy within a DSGE model context since vulnerabilities in the financial system can arise in various forms and from various sources. Furthermore, there is no specific proxy or widely accepted definition of such policy objectives in macro models.

Given the commonly accepted definition of the objective of the macroprudential authority, which is to safeguard financial stability, some authors such as Rubio and Carrasco-Galego (2014) and Angelini *et al.* (2012) assume that there exists a loss function for the macroprudential authority. This loss function is assumed to depend on a set of weighted variable volatilities and the policy authority minimizes this function subject to the equilibrium conditions of the model. This approach is similar to the monetary economics approach in which the monetary policy authority minimizes its loss function.

However, using loss functions in a DSGE context is generally an approximation of the social welfare analysis. The reason is that the loss function is derived from a second order approximation to the expected utility function of the representative household in the basic New Keynesian (NK) model in the absence of real and financial frictions (only taking price stickiness into account)[117]. The authority's loss function therefore represents an average welfare loss and depends on the variability of some endogenous variables[118]. Moreover, the economic rationale behind the use of the welfare loss function as a policy objective function, which depends on the volatilities of variables, is that the volatility has an impact on welfare. For example, from a financial stability perspective, lower volatility of credit growth can smooth borrowers' consumption, thereby improving their welfare.

For these reasons, we follow a welfare-based approach by assuming that the maximization of social welfare is a proxy for the

117 See for instance, Gali (2008), Gali and Monacelli (2005, 2008).
118 The monetary policy authority's loss function depends for instance on the variability of both the output gap and the rate of inflation (See Gali (2008) for more details).

objective of the macroprudential authority. We therefore define the optimal macroprudential policy as that which maximises the social welfare of the economy.

We perform a grid search for values of LTV and DSTI that maximise social welfare. This provides an assessment of the benefits of implementing different macroprudential policies. We follow Schmitt-Grohe and Uribe (2007) by computing the conditional welfare of agents using the second order approximation of the model[119].

The welfare loss/gain is computed for each type of household (savers and borrowers) under each policy regime using optimal policy ratios.

To make the welfare results more intuitive, we define a welfare metric in terms of consumption equivalents. This consumption equivalent welfare measure is the constant fraction of steady-state consumption that households are willing to give away in order to obtain the benefits of the macroprudential policy[120].

5.2. OPTIMAL VALUES OF LTV AND DSTI RATIOS WITH COVID-19 RELATED SHOCKS

We search for the values of the LTV and DSTI ratios that provide the highest conditional mean of social welfare under a second order approximation of the model. The optimal LTV and DSTI values are found by searching over a grid defined on [0; 1.2] and [0; 1] respectively[121]. We determine separately the optimal values of the LTV and DSTI caps in such a way that conditional social welfare is maximized. The optimization setup consists of searching for the optimal value of each ratio while taking the other ratio as given and calibrated to its actual data value.

Table 2 presents the optimal and current data values of LTV and DSTI as well as the volatilities and the welfare gains/losses generated by the respective values in a context of simultaneous negative shocks to both demand and supply (i.e., a COVID-19-related shock).

Table 2:

Optimal LTV and DSTI ratios under a COVID-19-related environment

	DATA (AVERAGE)	OPTIMAL LEVELS
LTV	90	85
DSTI	40	32
σ_l	2.9450	2.4816
σ_y	5.6297	5.5779
Social welfare (cost/gain)	-0.1060	-0.1044
Impatients (Borrowers)	0.0820	0.0821
Patients (Savers)	-0.2936	-0.2905

Note: The volatilities and values of macroprudential instruments are expressed in %. The welfare metric used is the conditional welfare, computed conditionally on the initial state being the deterministic steady state of the model. The welfare losses/gains are expressed in terms of their percentage of consumption equivalents. This is the same across scenarios. A second order approximation is used for solving the model and providing the quantitative results.

119 Second order approximation methods have a particular advantage of accounting for effects of volatility of variables on the mean levels. See among others Schmitt-Grohe and Uribe (2004).
120 An analytical expression of the welfare measure is available upon request.
121 These intervals are chosen in order to ensure the determinacy of the model steady state and to use economically reasonable values.

Under recessionary shocks, the optimal LTV limit is found to be 85 % while the optimal DSTI cap is about 32 %. The optimal values of the policy instruments imply welfare gains for borrowers (i.e., impatient households) while savers (i.e. patient households) face welfare losses.

Overall social welfare is negative as a consequence of stronger welfare losses for savers. The welfare metric displays a concave curve as a function of DSTI and LTV. For a given DSTI, increasing the LTV ratio loosens the collateral constraint, implying more mortgage lending to borrowers who increase their asset (house) holdings, which improves their welfare. However, this implies stronger adverse effects resulting from the recessionary shocks on their consumption, thereby reflecting higher debt service charges. The overall impact of increasing LTV on borrowers' welfare is detrimental. For savers, the increase in LTV leads them to save more at the expense of consumption while their house values improve as a result of the higher asset valuation and their increasing return from saving. Therefore, the net effect of increasing LTV is beneficial for savers as their welfare improves. Overall, the social welfare of the whole economy follows a concave path as a function of the LTV values[122].

Comparing the optimal policy scenario to the outcomes provided by the current average data suggests that optimal levels of policy instruments welfare-dominate their non-optimal levels. Furthermore, in terms of stabilization properties, the optimal policy better stabilizes mortgage credit growth and output than the non-optimal policy in the presence of the considered recessionary shocks.

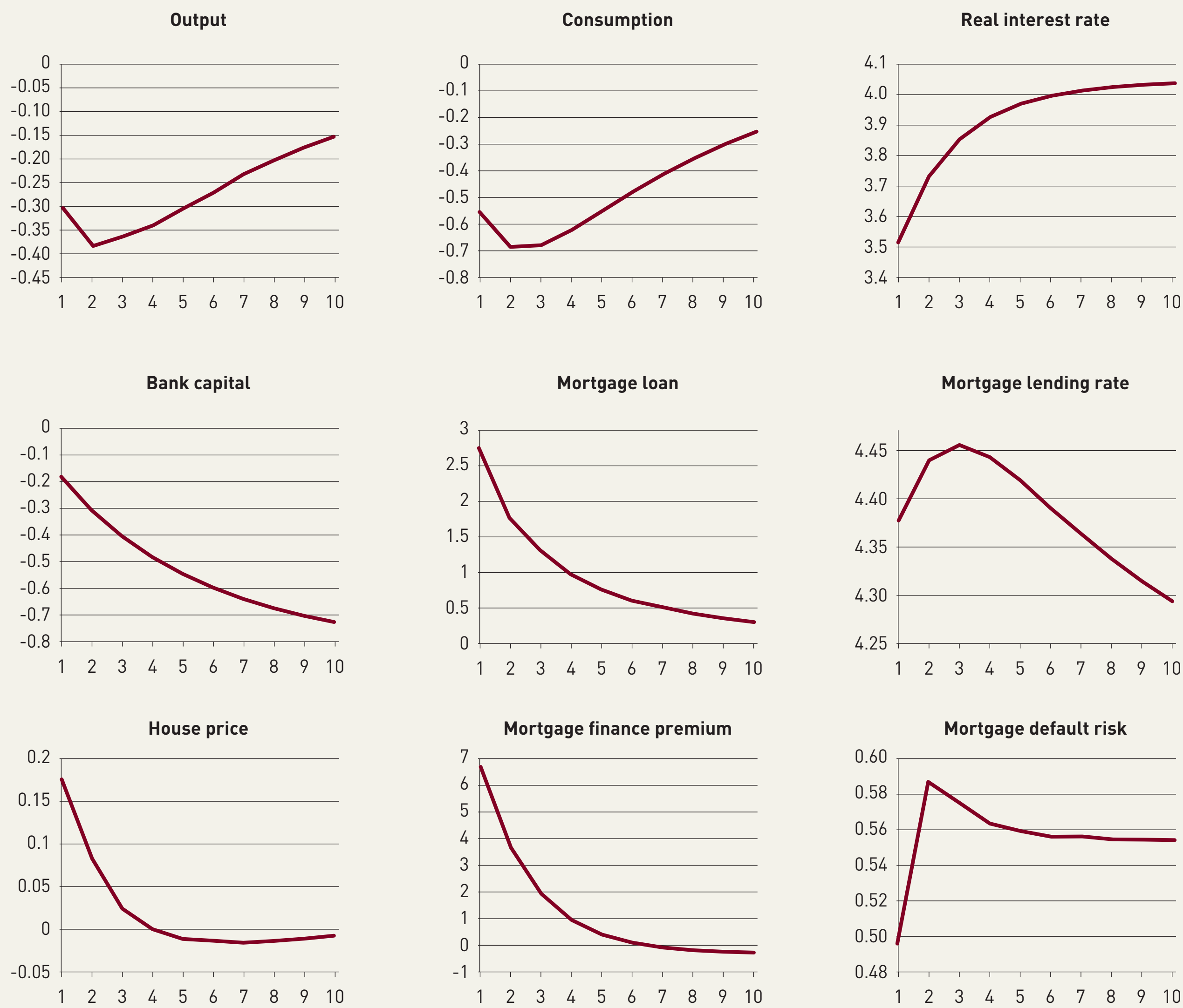
5.3. EFFECTS OF COVID-19-RELATED SHOCKS UNDER THE OPTIMAL POLICY CALIBRATION

We assume that simultaneous negative demand and supply shocks, triggered by the COVID-19 pandemic, hit the economy. The demand shock is a consumption preference shock, while the supply shock is defined by a productivity shock. Figure 3 shows the effects of a simultaneous negative 1 % demand and supply shock on the main macro-financial variables of the economy subject to the optimal limits of LTV and DSTI. These shocks directly reduce consumption of households (borrowers and savers) and output. As a consequence, savers increase their saving and borrowers' preference for house holding increases. Banks, facing a balance sheet (equilibrium) constraint as deposits have increased, respond to credit demand from borrowers by increasing mortgage loans with higher interest rates. The shocks therefore lead to a rise in mortgage loans and lending rates. House prices increase, reflecting the upward trend in both borrowers' preference for housing and mortgage loans. LTV and DSTI ratios, having been set to their tighter optimal limits, have an adverse impact on mortgage loans and subsequently house prices increase less as it would be the case in the absence of these levels of policy instruments.

Facing these recessionary COVID-19-related shocks, the mortgage default risk declines following the impact of shocks before increasing in the medium and long term. This, combined with the higher expected house values, increases the mortgage finance premium, which in turn raises mortgage lending rates. The negative prospects for banking profits and lending activities deplete bank capital. Finally, these recessionary shocks bring the monetary policy rates down, leading to a decrease in real interest rates.

122 A similar analysis applied to changing DSTI values, when LTV limit remains given, explains the concave path of the overall economy's welfare in function of DSTI.

Figure 3
Effects of COVID-19-related shocks on the main variables of the economy

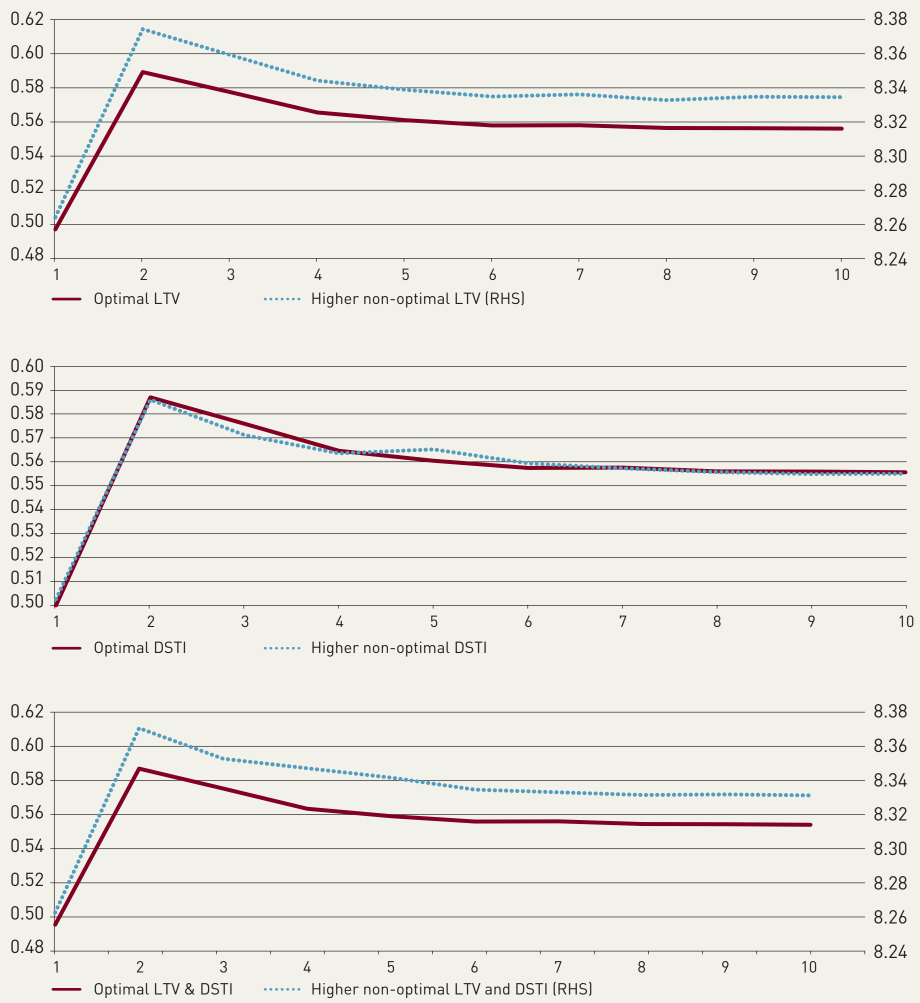


Note: Time, measured in quarters, is on the horizontal axis. All variables are measured in % deviations from steady state, except the mortgage default risk expressed in % levels and the real interest rate and the mortgage lending rate measured in % annualized levels.

5.4. INVESTIGATING THE INTERPLAY BETWEEN LTV AND DSTI AND MORTGAGE DEFAULT RISK

We assume that the macroprudential authority exogenously sets the values of both LTV and DSTI caps to their optimal levels. We perform a counterfactual (i.e., a sensitivity) analysis by assessing the impacts of choosing alternative non-optimal values of DSTI and LTV on the mortgage default risk. We compare the optimal calibration of instruments (LTV=85 % and DSTI=32 %) against three policy scenarios. First, the scenario in which only the LTV limit is modified and set to a higher non-optimal level (LTV=95 %) compared to its optimal value (higher non-optimal LTV scenario). Second, the scenario with higher non-optimal DSTI in which only DSTI has increased (DSTI=50 %) compared to its optimal value and the third scenario assumes that both LTV and DSTI are set to higher values (LTV=95 % and DSTI=50 %) relative to the optimal calibration. We consider a COVID-19-related shock which comprises both contractionary demand and supply shocks.

Figure 4
Effects of the COVID-19-related shocks on mortgage default risk under different policy (LTV and DSTI) scenarios



Notes: Time, measured in quarters, is on the horizontal axis. Mortgage default risk is expressed in % levels.

Figure 4 displays the impacts of simultaneous 1 % negative shocks to households' preference for consumption and total factor productivity under the three policy scenarios. It is clear that LTV and DSTI limits that are higher than their respective optimal values amplify the effects of the shocks on mortgage default risk. In particular, a higher LTV limit increases the risk of mortgage default compared to the optimal LTV cap. The reason is straightforward. Increasing the LTV cap increases the default threshold, which is directly driven by the LTV ratio in the modelling framework. When LTV increases, mortgage loans also increases, thereby leading to the increase in mortgage default risk.

However, Figure 4 shows that, contrary to the LTV cap which affects the probability of mortgage default, the increase in the DSTI limit has a negligible impact on default risk. Consequently, an increase in both LTV and DSTI limits results in greater mortgage default risk compared to the optimal calibration. This reflects the fact that the main driver of default risk in our modelling framework when the COVID-19 related shock occurs is the LTV limit[123].

6. CONCLUSIONS

The objective of this work is to quantitatively determine the optimal calibration values of two borrower based measures for Luxembourg within the framework of a DSGE model with mortgage default. The first contribution of this study is to build a DSGE model that contains a housing sector with mortgage default, two borrowing constraints (LTV and DSTI) and a monopolistically competitive banking sector. The second contribution consists of determining the non-joint optimal values of the LTV and DSTI limits for Luxembourg.

Based on a welfare analysis, we find that the (non-joint) optimal values of LTV and DSTI ratios in the presence of a Covid-19 related adverse shock are 85 % and 32 %, respectively. We also find that the optimal macroprudential policy welfare-dominates the non-optimal policy. Moreover, the optimal policy calibration better stabilizes mortgage lending and output compared to the policy based on the actual data. Finally, our findings suggest that a simultaneous increase in both the LTV and DSTI limits implies a higher mortgage default risk compared to the optimal calibration of these instruments. This reflects the fact that the main driver of default risk in the presence of a COVID-19 related shock is the LTV limit.

As possible extensions of this work, we plan to assess the optimal interactions between LTV, DSTI and the bank capital requirement ratio. It is worth noting that another potential research topic would be to expand the DSGE model with default by introducing an explicit differentiation between the mortgage debt stock and flow, which can facilitate the analysis of amortization requirements and the subsequent macro-financial implications.

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123 This result reflects the assumption made in the modelling framework that the only source of mortgage default is a shock that affects the house value and that income-related risks do not trigger mortgage default.

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3. HOUSEHOLD INDEBTEDNESS IN LUXEMBOURG

Lucas Hafemann[124]

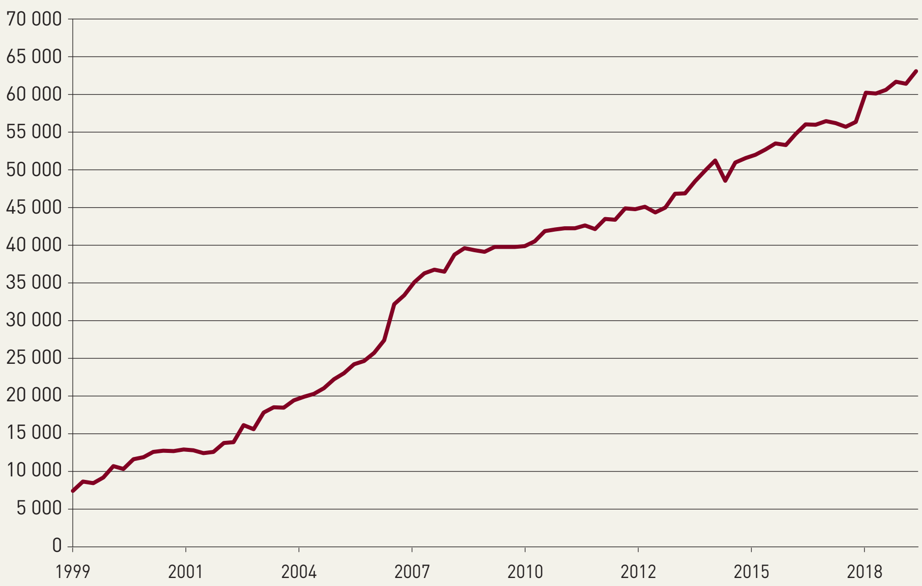
ABSTRACT

Household debt in Luxembourg has increased to historically unprecedented levels raising questions about (i) the driving forces behind this process, (ii) its sustainability and (iii) the possible role of (macroprudential) policymakers. We identify potential variables that drove household indebtedness in Luxembourg via an OLS and a VECM estimation and find that increases in house prices, the Loan-to-Value ratio and the share of mortgage credit with a variable rate lead to higher household indebtedness levels. Based on the VECM and ad-hoc fixed thresholds, we identify the maximum amount of household debt that is in line with economic fundamentals. We then compare this amount with Luxembourg's current household debt levels and conclude that they might be unsustainable. Based on our estimates, average Loan-to-Value ratios should decrease by at least 3.3 percentage points to reach "sustainable" debt levels.

1. INTRODUCTION

The Great Recession highlighted that an unsustainable level of household indebtedness can severely and adversely affect the real economy and the stability of the financial system. Cross-country analyses suggest that the recession was more substantial in countries with high household debt-to-income levels (Glick and Lansing, (2010)). In a similar vein, Jordà, Schularick and Taylor (2013) and Cuerpo *et al.* (2013) present evidence that the likelihood of a financial crisis increases when household debt is high. Finally, higher debt-to-income ratios amplify shocks as households' sensitivity to changes in interest rates and expected income increases, (Chmelar (2013)).

Figure 1
Household debt per capita



Source: BCL calculations. The chart displays household debt per capita at constant prices (Euros in 2015).

Against this backdrop, we analyze the current household debt situation in Luxembourg. By the end of the first quarter of 2020, Luxembourg's economy featured an historically high level of real household debt per capita (Figure 1). This is also mirrored by the sharp increases in debt-to-disposable income ratios since 1999 (Figure 2). Indeed, among the euro area member states, Luxembourg had the second-highest household debt-to-income ratio in 2018, at 174 %, while the average euro area ratio was 94 %.[125]

The evolution of household debt does not directly yield information

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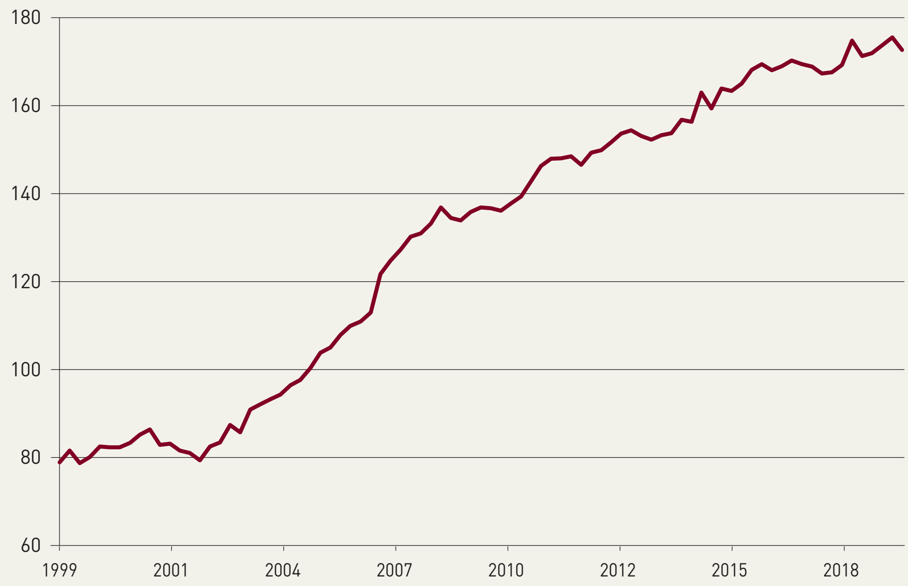
125 The corresponding data set comes from Eurostat.

on its sustainability. The debt level may be considered as unsustainable if it permanently exceeds a value justified by economic fundamentals. Although we address the question of household debt sustainability in this analysis, the results should be interpreted with caution, as the calibration of the sustainable debt level is highly uncertain.

Our contribution in this work is threefold. First, we find the maximum amount of household debt that is "sustainable" for Luxembourg. We derive this maximum amount via empirical models and *ad-hoc* fixed thresholds. Second, we determine which factors influence household debt by relying on two distinct empirical models. We validate our OLS findings with a Vector Error Correction Model (VECM) that yields time-varying sustainable debt levels directly and is better suited to differentiate between long-run and short-run effects. We find that household debt levels in Luxembourg are primarily driven by house prices and the average Loan-to-Value (LTV) ratio, while disposable income is not able to explain the increase in household indebtedness. The results suggest that current debt deviates from its long-run level. These results can help to provide some guidance on potential macroprudential policy responses. Thus, we estimate how much average LTV ratios have to decline so that household debt converges towards its "sustainable" level. Given the time series used, the effects of the differentiated LTV measure that was implemented in January 2021 are not present in the data.

Figure 2

Household debt-to-disposable income



Source: BCL calculations. The chart shows the development of debt-to-disposable income in %.

Our findings relate to at least three strands of the literature. First, they contribute to the literature identifying variables that determine the level of household debt. Second, they add to the discussion on household debt sustainability. Finally, our paper is related to the literature on policies to address household indebtedness.

For individual households, the life-cycle hypothesis (LCH) by Modigliani and Brumberg (1954) links an agent's age and income to their personal debt stock. Typically, agents borrow before working-life and, as their age and income increase, they repay this debt and save part of their income for retirement. Barnes and Young (2003) apply a LCH model to US data. They find that changes in interest rates, future income and demographics can explain increases in the debt-to-income ratios during the 1990's. In dynamic stochastic general equilibrium (DSGE) models that account for housing and household debt, agents use debt to smooth consumption so that real debt increases when price levels, or the interest rate, decrease or house prices or the LTV ratio increase (Iacoviello (2005), Gerali *et al.* (2010) and Iacoviello (2015)). Iacoviello and Pavan (2013) combine the life-cycle hypothesis with the business-cycle one and find that household debt is procyclical.

Turinetti and Zhuang (2011) empirically analyze the factors underlying US household debt using an OLS approach. They find that housing prices and consumer confidence are positively associated with the debt service ratio, while the unemployment rate, disposable income per capita, and the interest rate display a negative relationship. Additionally, they provide evidence that age structure and socioeconomic factors such as education level also play a role in household indebtedness.

Relying on household survey data for the US, Dynan and Kohn (2007) arrive at a similar conclusion. The authors find that house prices, financial innovations and demographic factors were responsible for increases in household indebtedness from 1983 until 2004. Meng, Hoang and Siriwardana (2013) examine the determinants of household debt in Australia with a Cointegrated Vector Autoregression (CVAR) model. Their results suggest that housing prices, GDP and the number of new dwellings (interest rates, the unemployment rate and inflation) increase (decrease) household debt. Similarly, Meniago *et al.* (2013) employ a VECM for South Africa. They find that GDP, deflation, increases in consumption and the prime rate are primarily responsible for higher debt levels. Uusküla (2016) studies private debt in the euro area. Panel regressions suggest that household debt is driven by real GDP, economic sentiment, house prices and a crisis dummy variable. Rinaldi and Sanchis-Arellano (2006) focus on the share of non-performing loans. For a panel of six euro area countries, they assess relationships through an error correction model and find that although higher debt to income ratios are positively correlated with arrears, the underlying mechanism is more complex. More specifically, they find that when the increase in the debt-to-income ratio accompanies an increase in disposable income, the negative effect on debt sustainability is compensated.

Barnes and Young (2003) determine a "sustainable" level of household debt using an overlapping generations model. According to their model, current and expected income and interest rates, as well as demographic factors, give rise to sustainable debt levels. Furthermore, they show that US' debt-to-income ratios were above fundamental values at the beginning of the 2000's. Tudela and Young (2005) apply the same methodology to UK data but find no evidence that household indebtedness deviates from its long-term level. Lindquist (2012) identifies "sustainable" household debt levels based on an accounting identity. Assuming that households want to consume a fixed amount, debt is considered as "sustainable" when debt service payments (i.e., interest and principal payments) are low enough that households do not have to cut their consumption. Emanuelsson, Melander and Molin (2015) calculate "risky" levels of debt-to-income ratios. This "risky" debt-to-income ratio provides guidance on how much debt the economy can support if the underlying economic conditions deteriorate to historically extreme levels.

For a panel of the fifty US states, Albuquerque, Baumann and Krustev (2014) utilize an error correction model to estimate time-varying debt-to-income levels. They identify one cointegration relationship and outline that household debt has been above its equilibrium value since 2001. However, since 2009 the gap between actual and sustainable debt-to-income ratios has been slowly decreasing. Juselius and Drehmann (2015) quantify sustainable private debt-to-GDP ratios via a CVAR model. They show that two cointegration relationships can provide indications of debt sustainability.[126] While one relationship suggests that debt evolves with assets in the long-run, the other suggests that debt service costs must be constant in the long-run. They find that their model is able to predict the Great Recession based on real-time data, as private debt deviated from its long-term level prior to the crisis in the US.

126 Juselius *et al.* (2017) add a third cointegration relationship. They impose that the spread between the mortgage and the policy rate is constant in the long-run as they focus on the role of monetary policy in the financial cycle. However, estimating sustainable debt levels is not directly related to this third cointegration relationship.

This paper differs from previous work along three dimensions. First, we exclusively focus on household debt in Luxembourg.[127] Second, we take into account the LTV ratio and the share of adjustable rate mortgages since theory suggests potential linkages between household debt and these variables. Third, we account for the fact that the underlying variables might themselves not be at "sustainable" levels. If debt levels are positively correlated with house prices, then high household debt levels may be observed during house price booms that also deviate from economic fundamentals.

Structural models demonstrate that macroprudential policies can influence household indebtedness when collateral constraints are present (Iacoviello (2005)). Macroprudential policies, such as caps on the LTV ratio, directly influence the collateral constraint, which determines the amount of debt. Alpanda and Zubairy (2017) rely on a DSGE model to analyze those policies best suited to reduce household debt and they compare monetary with fiscal and macroprudential policy. According to their estimates, tightening of LTV caps and reducing mortgage interest rate deductions are the most effective tools to reduce household debt. Turdaliev and Zhang (2017) study the Canadian case in a small open economy DSGE model. They also find that macroprudential policies exhibit less negative side effects than monetary policies when policymakers aim for lower household debt levels. Drawing on panel data sets, Cerutti, Classens and Laeven (2017) and Akinci and Olmstead-Rumsey (2018) provide empirical evidence that macroprudential policy measures can influence household credit.

According to the literature, low interest rates, financial liberalization, and house price appreciation are the main factors that increase household debt. Our estimation results suggest that house prices are among the main determinants of household debt, while the role of interest rates is of minor importance in Luxembourg. Disposable income is a possible factor that increases household debt, but our results suggest that in Luxembourg disposable income and household indebtedness are only weakly related. The estimation results also provide evidence that declining LTV ratios have a negative influence on debt. Hence, the use of macroprudential policy measures, such as borrower-based measures, that decrease LTV ratios can reduce household debt.

In this study, we address the question of how much LTV ratios must be reduced to reach a level of debt that we identify as being "sustainable" for Luxembourg.

The remainder of the paper is organized as follows. Section 2 provides an overview of the variables that explain household debt and defines *ad-hoc* fixed thresholds to distinguish between "unsustainable" and "sustainable" levels of household debt. Section 3 introduces the data set. Section 4 analyses the research questions using an OLS model, and Section 5 provides the results from a VECM model. Section 6 addresses the nexus between household indebtedness and the loan-to-value ratio. Section 7 concludes.

2. HOUSEHOLD DEBT IN THEORY

As outlined above, household debt has increased considerably in Luxembourg since 1999. Before identifying which variables drive this trend, we first assess possible contributing factors.

127 Büyükkarabacak and Valev (2010) claim that indebtedness of households is a better risk indicator than indebtedness of the corporate sector.

One contribution of our analysis is that we assess whether the current level of household indebtedness in Luxembourg deviates from its long-run "unsustainable" level. To do so we compare the current household debt level with the maximum amount of debt that is "sustainable". When the current debt level is below (above) this threshold, it is considered as "sustainable" ("unsustainable"). Various methods are used to identify this threshold.

2.1 DETERMINANTS OF HOUSEHOLD DEBT

The life cycle hypothesis (LCH), the permanent income hypothesis (PIH) as well as real business cycle (RBC) and DSGE models are approaches that explain household debt development from a theoretical viewpoint. The LCH by Modigliniani and Brumberg (1954) and the PIH by Friedman (1957) state that households seek to smooth consumption over their life cycle. Income can be thought of as an "inverted U-shaped" function of age, because it is low before working-life and during retirement. Hence, agents borrow before working-life, when current income is below their desired consumption (e.g., through student loans). During working-life, they first pay back these loans and then begin to save for retirement. However, the linkage between household debt and age is primarily relevant at the individual household level. Since we take a macroeconomic perspective, where overlapping generations are present, the age effects of individual agents are assumed to be negated, on average, at any point in time.

Nevertheless, the LCH and the PIH help to explain how aggregate household debt develops when the underlying macroeconomic variables change. In fact, all four theories state that agents aim to maximize intertemporal utility by smoothing their consumption path. They use debt to decouple consumption from current income levels. If current income falls while expected future income remains stable, agents borrow to partly offset the drag on consumption resulting from a negative income shock (Barba and Pivetti (2009)). However, in the real world, where frictions are present, the relationship between debt and income is more complex. For a lender, an agent's disposable income also serves as an indicator of whether the borrower can repay their debt. Hence, borrowers are able to take on higher debt levels when disposable income is high. The two opposing effects of income on household debt can be disentangled by considering different time horizons. In RBC models, reductions in disposable income only lead to more debt if they are temporary. In contrast, the lender focuses on debt sustainability, which is a long-run concept. In the analysis below, we use an HP-filter to disentangle short-run deviations from the long-run trends in disposable income.

Interest rates may also play a key role. Since debt financing is cheaper when interest rates are low, the level of new loans is inversely related to the interest rate. Besides this effect on new loans, the interest rate also affects existing loans with adjustable-rate mortgages (ARM). Increases in the interest rate lead to a higher debt burden for those households that hold mortgage debt with a variable rate, (Meng, Hoang and Siriwardana (2013)). This means that the sign of the overall interest rate semi-elasticity is theoretically unclear. In Section 4.2, we will disentangle the two channels by the implementation of an interaction term that considers the product of the interest rate and the ARM share.

As the majority of household debt in Luxembourg is mortgage debt[128], house prices also play an important role in Luxembourg household debt dynamics. When house prices rise, the amount of debt needed to purchase a house increases, if households do not have the necessary funds to purchase a dwelling outright. Furthermore, homeowners can increase their debt level if the value of their collateral

128 In Luxembourg, the share of mortgage debt to total household debt has increased from 61 % in 2000 to 80.3 % % in 2020Q4. Household mortgage debt-to-disposable income was 132.1 % in 2020Q4.

increases, (Wadhwani (2002)). Analogously, an increase in households' assets, and therefore available collateral, can also lead to higher debt levels.

Finally, in some cases, financial deregulation has also boosted household debt levels (Rinaldi and Sanchis-Arellano (2006)). On an individual household level, fewer households reach their borrowing constraint. On an aggregate basis, households were able to increase their debt levels, although their income and asset levels remained unchanged. This translates into higher LTV ratios.

2.2 "SUSTAINABLE" DEBT LEVELS

For the purpose of this work, the maximum amount of "sustainable" debt can be derived from either empirical or theoretical models (e.g. accounting identities) or via *ad-hoc* thresholds. In this section, we adopt a number of ad-hoc thresholds taken from the literature on household debt that can help to identify "sustainable" debt-to-income ratios. In Section 5.1, we further apply an empirical model that also yields a time-varying sustainable debt level.

The Macroeconomic Imbalance Procedure Scoreboard (MIPS) suggests a threshold for private sector debt-to-GDP of 133 % as a "sustainable" level. The threshold is set at 133 % based on the upper quartile of the distribution of the ratio of private sector debt-to-GDP of all EU Member States during the period from 1995 to 2007, i.e., before the beginning of the financial crisis (European Commission (2012) and European Commission (2018)). This translates into a value of household-debt-to-disposable income of 77.49 % for Luxembourg when averages of the disposable income-to-GDP ratio and the household-to-total private debt ratio over that period are considered.[129]

The 1995-2007 data period omits the recent low interest rate environment. Following the argumentation above, low interest rates may potentially increase the level of sustainable debt. We therefore calculate a threshold that is based on the 1995Q1-2020Q1 sample. In this period, the upper quartile of the distribution of the ratio of private sector debt-to-GDP of all EU Member States is 158 %, so that the threshold increases to 83.35 %.[130]

Bouis, Christensen and Cournède (2013) and Cuerpo *et al.* (2013) suggest relying on pre-housing boom values. Building on the MIPS' threshold, Cuerpo *et al.* (2013) define country-specific thresholds by computing the upper quartile of the distribution of the ratio of private sector debt-to-GDP on a national basis during the period 1994-2007. Following their approach, the "sustainable" debt threshold resulting from an upper quartile of the debt-to-disposable income in Luxembourg during the years from 1999 to 2007 is 104.59 %.

Bouis, Christensen and Cournède (2013) consider debt-to-GDP values in 2000 "sustainable". According to their approach, household debt-to-disposable income in Luxembourg must be below 82.43 % to be "sustainable". Alternatively, one can take a cross-country perspective. In 2018, the average debt-to-disposable income ratio in the euro area was 93.52 %. The upper quartile for euro area Member States is 114.06 %.[131] Cuerpo *et al.* (2013) further consider a leverage perspective. They suggest that debt is only "sustainable" if it moves in tandem with assets since the latter can serve as a buffer. In this respect, financial assets can be sold and mortgages can serve as collateral. They assume that the debt-to-assets

129 The data comes from the BCL website and Statec.
130 The MIPS calculation is based on a sample that excludes Croatia, as it entered the EU in 2013. To be consistent, we also exclude Croatia in the construction of the value for the 1995-2020 sample.
131 Due to data availability, Greece and Malta are not included in the sample.

level was "sustainable" in 2000, i.e., before the housing boom. Under their definition of "sustainable", debt-to-asset ratios should not exceed 32.01 % in Luxembourg. From 2001Q1 to 2020Q1, this ratio would have been reached, if the debt-to-disposable income ratio was 119.29 % on average.

Table 1:

"Sustainable" Debt-to-disposable income ratios in Luxembourg

MEASURE	DEBT-TO-DISPOSABLE INCOME IN %
Upper quartile of the distribution of the ratio of private sector debt-to-GDP of all EU Member States from 1995 to 2007 (2020).	77.49 (83.35)
Upper quartile of the debt-to-disposable income ratio in Luxembourg from 1999 to 2007 (2020).	104.59 (160.25)
Debt-to-disposable income in Luxembourg in 2000.	82.43
Average debt-to-income ratio in the euro area in 2018.	93.52
Upper quartile of debt-to-income ratios of euro area member states in 2018.	114.06
Sustainable debt-to-asset ratio in Luxembourg.	119.29

Below, we compare actual debt-to-income values with the "sustainable" levels from Table 1. While the upper quartile of debt-to-income ratios of euro area member states in 2018 provides a cross-country view, the upper quartile of the debt-to-disposable income ratio in Luxembourg from 1999 to 2007 provides a national perspective. Finally, the leverage perspective is considered based on debt-to-asset ratios.

3. DATA

The data used in this study stems from several sources. All variables are measured in real terms and are seasonally adjusted, if applicable. The sample considered varies according to the underlying variables. The LTV ratio is the limiting factor for the data period. Whenever it is included, the sample starts in 2005Q1 and ends in 2020Q1. For models omitting the LTV ratio, the sample begins in 1999Q1.

Household debt and assets, as well as total private debt, are taken from the BCL database. Data for household disposable income, the share of adjustable rate mortgages and the house price index are BCL estimates. The mortgage rate is from the ECB Statistical Data Warehouse. For LTV ratios, we merge BCL estimates with data from the Commission de Surveillance du Secteur Financier (CSSF). Data on population size was obtained from Statec Luxembourg. Some variables deserve further attention. Household debt is a stock variable, while disposable income is a flow variable. When considering debt-to-income levels, the vast majority of the literature uses annual income levels. For comparability reasons, disposable income is annualized when we refer to debt-to-disposable income.

As outlined in Section 2.1, the impact of disposable income on household debt depends on whether income changes are permanent or transitory. For the OLS estimations, we disentangle permanent from transitory changes with the HP-filter. We set λ to 400,000 as this describes the credit cycle (ESRB (2014)). To account for the fact that changes in the population size can influence the amount of disposable income, we focus on per capita values. Furthermore, the log of per capita income is considered. In this manner, the coefficient associated with the trend in Section 4.2 provides the sensitivity of the dependent variable to per capita income increases.

As described above, ARMs mean that debt obligations from previous periods vary according to the current interest rate. However, the available time series provides the share of new loans. We therefore have to construct a series that represents the share of ARM out of the stock of debt.[132]

Two assumptions are needed to construct this time series. Figure 3 shows how the ARM share of new loans evolves over time. From 2003 until 2012Q2 the ARM share was relatively stable at around 85 %. After this period, the time series displays a negative trend as well as more volatility. The first assumption is that at the beginning of the sample, i.e., in 2003Q1, the share of ARMs in the stock of mortgage debt was 85 %. The total amount of new loans is the aggregate of the flow of mortgage debt and the amount of credit that has been repaid. The former is derived by taking differences of the stock variable, while the latter calls for a second assumption. More precisely, we assume that the average maturity of the stock of mortgage debt is 15.3 years throughout the sample. The value corresponds to the average maturity in the Household Finance Consumption Survey's third wave. With these variables, we construct a weighted average for the ARM share according to Equation (1). Hereafter, ARM_t^{stock} (ARM_t^{nl}) is the ARM share for the stock of debt (new loans) at time *t*. NL_t and $Amort_t$ are the amount of new loans and the absolute size of the amortization, respectively.

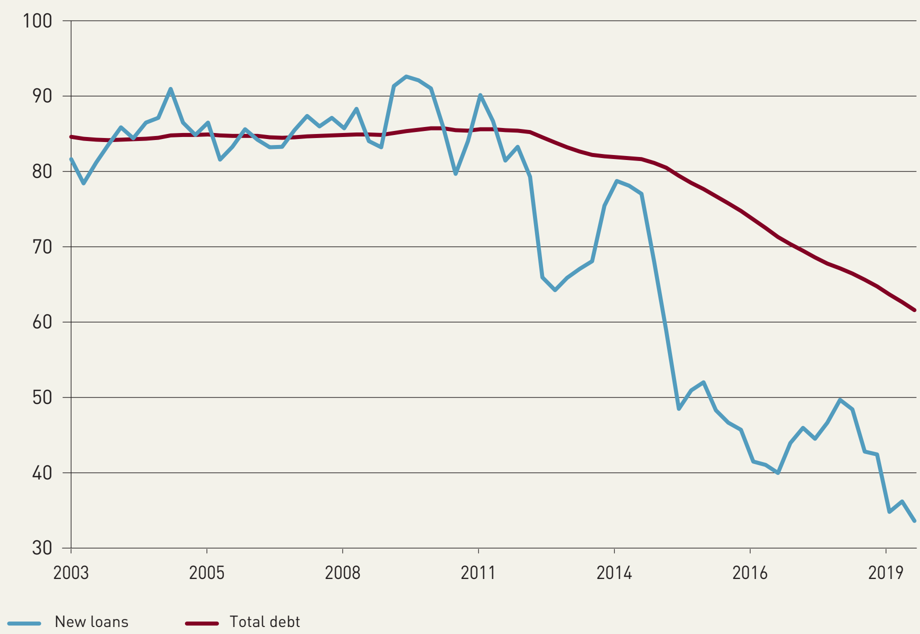
$$ARM_t^{stock} = \frac{ARM_{t-1}^{stock}\,(Debt_{t-1}^{stock} - Amort_t) + ARM_t^{nl} * NL_t}{Debt_{t-1}^{stock} - Amort_t + NL_t} \qquad (1)$$

Juselius and Drehman (2015) show that the mortgage rate of the stock of mortgage debt is better suited to estimate long-run relationships in a VECM. They obtain a stock mortgage rate by smoothing the flow series using an auto-regressive component of 0.7. They argue that this rate closely matches the U.S. effective lending rate from the Bureau of Economic Analysis data. When we use the VECM in Section 5.2, we follow their approach.

Regarding LTV, data from the banks are the preferred option. However, data reported to the CSSF is limited. In fact, only three data points are available on a bi-annual frequency, those are the second semester of 2018 and 2019 and the first semester of 2019. This data set is merged with the LTV ratio from internal BCL estimates to obtain a longer time series, at a quarterly frequency from 2005Q1 to 2020Q1. Both variables show similar movements among the data points available. Starting from 2018S2, we first observe a drop in the LTV ratio before it increases in 2019S1. We combined the two sources as follows. First, we always assign the LTV ratios from the CSSF to the second quarter within a semester. Second, we fill the two gaps between the three assigned values by a

132 Due to the autoregressive structure of the ARM share for new loans, the results shown below are similar for both ARM shares.

Figure 3
Share of adjustable rate mortgages



linear interpolated value. Third, we rebase the values of the BCL estimates with the ratio provided by the CSSF in 2018S2.

4. EMPIRICAL EVIDENCE FROM AN OLS APPROACH

Our main objectives are (i) to analyze if household debt is "sustainable", (ii) to identify which variables influence household debt and (iii) to relate levels of household debt to LTV ratios. We start with unit root and cointegration tests that check whether household debt is in line with economic fundamentals. In Section 4.2, we rely on an OLS model to analyze whether we find empirical support for the aforementioned debt-related hypotheses.

4.1 INCOME AND LEVERAGE PERSPECTIVE

Household indebtedness can be considered as "unsustainable" if it deviates from its long-run value that is justified by economic fundamentals. From an income perspective, debt can be considered as "unsustainable" if the discounted future disposable income is insufficient to pay all debt. Alternatively, debt and disposable income should be cointegrated. We perform Johansen tests[133] with log per capita debt and log disposable income per capita as the only variables.[134] Table 2 displays the eigenvalues for different estimates. None of the null hypotheses can be rejected at the 5 % significance level. This suggests that per capita debt and disposable income per capita are not cointegrated in Luxembourg.

Table 2:
Johansen Cointegration tests

NO. OF CE(S)	INTERCEPT, NO TREND		INTERCEPT, LINEAR TREND	
	1 LAG	4 LAGS	1 LAG	4 LAGS
None	0.049	0.048	0.081	0.269
At most 1	0.020	0.010	0.043	0.042

*Source: BCL. The numbers represent eigenvalues. ***, ** and * display eigenvalues that are different from zero on a 1 %, 5 % and 10 % significance level. We consider MacKinnon-Haug-Michelis (1999) p-values and always display the lower p-value from the trace test or the maximum eigenvalue test.*

From a leverage perspective, debt is "unsustainable", if it increases more than households' assets for a prolonged period of time. Figure 4 shows the development of the debt-to-assets ratio in Luxembourg. This ratio shows an increasing trend over time. An Augmented Dickey-Fuller (ADF) test[135] confirms that it is not stationary around a constant.

4.2 DRIVERS OF HOUSEHOLD DEBT IN LUXEMBOURG

In this section, we identify the determinants of household debt. In Model I (Model II), household debt to disposable income (per capita debt) serves as the regressand. For the assessment, we use the OLS estimation shown in Equation (2). The endogenous variable, Y_t, is explained by its lagged value and a set of lagged exogenous variables, X_{t-1}. The list of explanatory variables includes (log) house prices, the mortgage rate, an interaction term of the mortgage rate with the ARM share, the ARM share separately, the LTV ratio and the squared LTV ratio. For Model II, the trend and the cyclical component of disposable

133 The test is outlined in Johansen (1991) and Johansen (1995).
134 Note that cointegration is a long-run concept. It is therefore unnecessary to differentiate between the cyclical and the trend component of income.
135 The ADF test roots on Dickey and Fuller (1979).

income complete the set of explanatory variables. We apply Newey-West standard errors to address issues related to endogeneity and serial correlation.

$$Y_t = \alpha + \Lambda X_{t-1} + \beta Y_{t-1} + \varepsilon_t \quad (2)$$

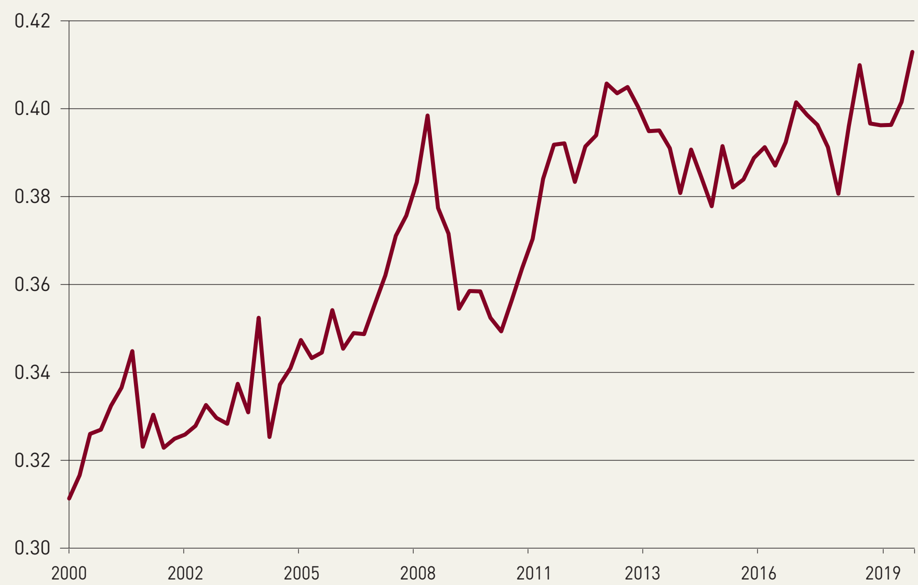
Table 3 outlines the regression results for both models. In line with theory, real house prices and the lag of the dependent variable explains the evolution of household debt in both regressions. This result is significant at the 5 % level. While the coefficient for LTV is positive, the negative coefficient of LTV^2 suggests a non-linear influence of LTV ratios. The two coefficients are only significant in Model II, which generally shows more plausible results. In Section 6, we further discuss the role of the LTV ratio. The regression results also suggest that a higher share of ARMs increases debt. This finding is significant at the 10 % level in both Models.

The mortgage rate and the interaction term display the expected signs and are significant for Model II. Lower interest rates have two effects. They reduce debt service payments for those households holding mortgage debt with a variable rate contract. However, lower interest rates increase the incentive for households to take on more debt. In Table 3, the interest rate effect for households with an ARM contract is captured via the interaction term, while the mortgage rate provides incentives for households to take on new debt. The semi-interest elasticity shows that the former effect dominates the latter effect. Moreover, if the interaction term is omitted, the coefficient for the mortgage rate is positive for both models.

At a first glance, the coefficients in Modell I seem counterintuitive. However, the dependent variable is a ratio and interest rates are likely to affect both the numerator and the denominator. The positive coefficient on the mortgage rate likely stems from a negative reaction of disposable income to the mortgage rate. Changes in the monetary policy stance can potentially explain this negative relationship. In this respect, declines in the interest rates boost output and thereby disposable income. Furthermore, the inflation component in the real interest rate might play a role. In theory, debt as well as income are both negatively affected by an increase in inflation (Debelle (2004)). When the effect on disposable income is disproportionally strong, e.g., due to the bracket creep effect[136], higher inflation rates increase the debt-to-disposable income ratio. On average, the interest rate

136 The bracket creep describes a situation when inflation pushes households into higher income tax brackets although their real earnings before tax have not increased at a similar pace.

Figure 4
Debt-to-assets ratio



Source: BCL Calculations

semi-elasticity is 0.59 in Model I and 0.40 in Model II. However, as outlined above the ARM share has decreased considerably over the last decade. In fact, it was 0.61 in 2020Q1, yielding semi-elasticities of 2.77 and -1.17 in Models I and II.

We find that the two aforementioned interest rate channels exist in Model II. The overall effect of interest rate changes strongly depends on the ARM share. However, it is unlikely that declining interest rates are the primary source for the increases in debt. As expected, households are able to accumulate more debt when they rely on contracts with an adjustable rate, although the coefficient is not significant. The fact that neither the trend nor the cyclical component of disposable income is significant in Model II. This is in line with our findings from Section 4.1 and adds to the discussion that household indebtedness deviates from its long-run value. The lag of the dependent variable is incorporated in the regression's RHS and alone explains 97.9 % of the variations of the dependent variable in Model I.

Table 3 :

Regression Results: ***The left (right) panel describes the results of Model I (Model II)***

DEP. VARIABLE: HH DEBT/DISP. INC.		
VARIABLE	COEFFICENT	P-VALUE
Const	-292.90	0.020
LTV	4.121	0.170
LTV^2	-0.026	0.196
Mortgage Rate	10.119	0.049
Mo. Rate*Share of ARM	-0.120	0.054
Share of ARM	0.276	0.049
House Pr. (log)	0.308	0.002
Hh Debt/Disp. Inc.	0.787	0.000
Inter. Rate Semi-Elasticity	0.590	0.041
(Assumption: Share of ARM equals its average (79.69))		
R^2	0.991	

DEP. VARIABLE: HH DEBT PER CAPITA (LOG)		
VARIABLE	COEFFICENT	P-VALUE
Const	-3113.64	0.106
LTV	7.481	0.002
LTV^2	-0.048	0.004
Mortgage Rate	-6.455	0.081
Mo. Rate*Share of ARM	0.086	0.062
Share of ARM	0.366	0.053
House Pr. (log)	0.365	0.000
Hh Debt per Capita (log)	0.465	0.001
Disp. Income Cycle (per Capita)	0.013	0.944
Disp. Income Trend (per Capita)	3.063	0.111
Inter. Rate Semi-Elasticity	0.398	0.161
(Assumption: Share of ARM equals its average (79.69))		
R^2	0.995	

Source: BCL.

5. LONG-RUN EFFECTS

After establishing some preliminary empirical findings in Section 4, we now turn to a VECM model. The advantage of the VECM is that it directly identifies short-term and long-term relationships between the underlying variables. In this manner, we are able to assess how the considered variables have contributed to increasing household debt levels. Furthermore, the VECM approach allows us to identify time-varying "sustainable" debt levels.

5.1 METHODOLOGY

The VECM is a restricted Vector Autoregression (VAR) model that is capable of dealing with non-stationary variables when they are cointegrated. Consequently, under the requirement that at least one cointegration relationship exists, all time series can enter as endogenous variables. Hence, we first check for stationarity in all variables that enter the VECM. Afterwards we rely on the Johansen test to detect how many cointegration relationships, *r*, are present.

As described above, the VECM combines short-run with long-run relationships of the endogenous variables. After establishing a long-run equilibrium, it outlines how deviations from this equilibrium feed back on the dependent variables. This feedback-loop ensures that the variables will adjust to the equilibrium again. Equation (3) describes the VECM.

$$\Delta Y_t = \nu + \mathbf{\Pi} Y_{t-1} + \sum_{i=1}^{p-1} \Gamma_i \Delta Y_{t-i} + \varepsilon_t, \tag{3}$$

where Y_t is a K x 1 vector of endogenous variables and Δ is the difference operator. The vector *v* is for constant effects. The vector Γ_i captures the effects of lagged changes in the endogenous variables. The parameter *p* fixes the number of lags in the underlying VAR.[137] The error term ε_t has zero mean and is iid. The special feature of the VECM is the matrix **Π**, which determines long-run relationships. The number of cointegration relationships yields the rank *r* of the matrix. A valid VECM requires $0 < r < K$. The matrix **Π** can be decomposed into two K x r matrices α and β, i.e., **Π**=**αβ'**. The cointegration relationship is given by **β**'Y_t and α describes how the model adjusts to deviations from the long-run equilibrium.

However, the VECM needs to be uniquely identified. In fact, it requires at least r^2 restrictions. Those restrictions can either be imposed on **α** or on **β**. We will discuss the restrictions we impose in the next section.

5.2 "SUSTAINABLE" DEBT LEVELS FROM A VECM

As mentioned in Section 2, we now compare the thresholds for "sustainable" debt stemming from *ad-hoc* values from the literature with those from a VECM. The underlying theory closely follows Juselius and Drehmann (2015). They claim that two long-run relationships help to identify "sustainable" debt levels, i.e., leverage and the debt service burden. Under the leverage hypothesis from above, debt and house prices (or assets) have to move in tandem over the long-run.

The debt service burden is closely related to the income perspective. Expected future income has to be high enough to service future interest payments and amortizations. When the interest rate applicable to the debt stock increases, agents find it more difficult to pay back their debt.[138] Therefore, debt levels have to decrease in the long-run. This shows that there exists a cointegration relationship between debt and interest rates, according to which the two variables negatively influence one another. Put differently, the debt service burden has to be constant in the long-run. It follows that debt is only "sustainable" when both long-run relationships hold.

137 The lag length of this VECM notation is one period shorter than that of conventional VARs as we use the difference operator.
138 Juselius and Drehmann (2012) find that the debt service ratio is a good indicator for an upcoming financial crisis.

Table 4 :

Cointegration tests

	4 VARIABLES VECM			3 VARIABLES VECM		
OLS	OLS	FE	OLS	FE	FE	FE
r=0	0.1947	0.0439	0.3774	0.1451	0.1426	0.2640
r≤1	0.1779	0.0622	0.1441	0.0982	0.2667	0.2033
r≤2	0.1076	0.1924	0.1963	0.0005	0.8204	0.8204
r≤3	0.0119	0.2993	0.2993			

Source: BCL.

As outlined above, we need two cointegration relationship conditions to differentiate between the leverage and the debt service burden view. In this section, we use both a three and a four variable VECM. In the three variable model, the household debt-to-disposable income ratio, the mortgage rate on the debt stock and the (log) house price index are the endogenous variables. In the four variable model, we substitute the debt-to-income ratio with the two underlying time series. Hence, we add (log) per capita household debt and disposable income to the list of variables. We focus solely on real variables.

We look at the number of cointegration relationships within the VECM as displayed in Table 4. The four variable VECM points to two cointegration relationships when a 10 % significance level is applied and the lag length of the underlying VAR, p, is set to three as suggested by the Akaike information criteria.[139] The hypotheses of no, and at most one, cointegration relationship is rejected when applying the trace test. Hence, we conclude that two cointegration relationships describe the model reasonably well. In contrast, the three variable model does not suggest any cointegration. Therefore, we retain the four variable model.

The two cointegration relationships in the four variable VECM describe the leverage and the debt service burden perspective. This means we have to impose at least four restrictions on **α** and **β** from Equation (3). In line with Juselius and Drehmann (2015), we only restrict **β**. Let β_{lev} and β_{dsb} be the first and second column in β and let β_{lev} (β_{dsb}) describe the leverage perspective (the debt service burden perspective). Equation (4) lists our set of restrictions stemming from the following theoretical considerations. Juselius and Drehmann (2015) look at debt-to-GDP levels and restrict them to one. Since we focus on "sustainable" household debt levels, we restrict the coefficients on debt, i.e. β_{lev} and β_{dsb}, to one. However, when we consider the two hypotheses, we have to ensure that debt is not increasing due to increases in income. Hence, we restrict the coefficients in β_{lev} and β_{dsb} that correspond to income to zero as well. Two further restrictions are necessary to disentangle the two perspectives. They directly follow from Juselius and Drehmann (2015). Therefore, the parameter describing the mortgage rate (the house price index) has to be zero in β_{lev} (β_{dsb}). This leaves us with the following specification of **β**, where β_{lev}^{hpi} and β_{dsb}^{rate} are parameters that the model estimates.[140]

$$\boldsymbol{\beta}' Y_t = \begin{pmatrix} \beta_{lev} \\ \beta_{dsb} \end{pmatrix} Y_t = \begin{pmatrix} 1 & 0 & 0 & \beta_{lev}^{hpi} \\ 1 & 0 & \beta_{dsb}^{rate} & 0 \end{pmatrix} \begin{pmatrix} debt_{t-1} \\ income_{t-1} \\ rate_{t-1} \\ hpi_{t-1} \end{pmatrix} \quad (4)$$

The upper panel of Table 5 displays the coefficient estimates for the cointegration vectors β_{lev} and β_{dsb}. The coefficients β_{lev}^{hpi} and β_{dsb}^{rate} have signs that are in line with the leverage and the debt service burden

139 The results are not sensitive to changes in the lag length.
140 The variables in Y_t are household debt, disposable income, the mortgage rate of the debt stock and the house price index.

perspective. Both coefficients are statistically different from zero. We obtain a high interest rate semi-elasticity, because we consider real interest rates where the inflation rate does not crowd out the effects. The coefficient β_{lev}^{hpi} shows plausible results. When real house prices increase by 1 %, household debt per capita rises by 1 % in the long-run.

The lower panel in Table 5 outlines the short-run dynamics of the model. As we are primarily interested in long-run effects, we present evidence of the two co-integration relationships. We label deviations from the two cointegration relationships $\widetilde{lev}$ and $\widetilde{dsb}$. The model is only valid when debt reacts to deviations from the equilibrium relationships in a way that it approaches equilibrium long-run. Hence, deviations from the leverage and the debt service burden vector should negatively impact changes in debt for given mortgage rates and house prices. Put differently, a positive leverage or debt service gap depresses credit growth. Indeed, we find a negative coefficient for the leverage vector (first column). For the debt service burden vector, we observe a statistically insignificant coefficient.

The impact of the error correction terms on the other variables matches Juselius and Drehmann's (2015) estimates. In particular, they find that $\widetilde{lev}$ does not significantly affect any of the other variables and that debt service burden deviations significantly affect interest rates negatively. They argue that this reflects monetary policy responses to elevated debt levels.

Table 5:
VECM Results of the four variable Model

PANEL A: COINTEGRATION EQUATIONS					
COINTEGRATING EQ:	$debt_{t-1}$	$income_{t-1}$	$rate_{t-1}$	hpi_{t-1}	Const.
β_{lev}	1	0	0	-0.987	-622.29
T-statistic				[-17.302]	
β_{dsb}	1	0	29.895	0	-1112.13
T-statistic			[3.636]		

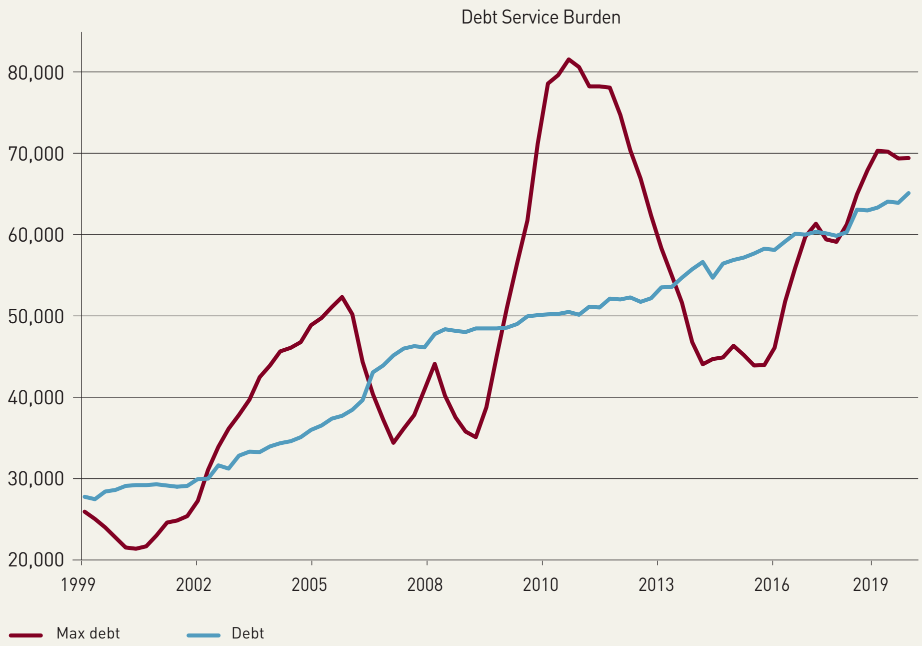
PANEL B: SHORT-TERM DYNAMICS					
ERROR CORRECTION:	$\Delta(debt_t)$	$\Delta(income_t)$	$\Delta(rate_t)$	$\Delta(hpi_t)$	
$\widetilde{lev}$	-0.1142	-0.0149	0.0005	-0.0153	
T-statistic	[-4.012]	[-0.913]	[0.238]	[-0.831]	
$\widetilde{dsb}$	0.0022	0.0047	-0.0025	-0.0038	
T-statistic	[0.242]	[0.891]	[-3.426]	[-0.632]	

With the estimates from Equation (4), we can now evaluate whether current household debt levels are "sustainable". We therefore compare the actual (log) per capita household debt levels with those resulting from the two cointegration relationships as in Equations (5) and (6). Note that we multiply β_{lev}^{hpi} by sustainable real house prices provided by Ferreira Filipe (2018) in order to correct for the overvaluation of house prices. The reason is that "sustainable" debt levels could be artificially high when house prices are overvalued, i.e. they are higher than justified by economic fundamentals, see Cuerpo (2013).

$$\widehat{debt}_{lev,t}^{max} = -const_{lev} - \beta_{lev}^{hpi} hpi_t \tag{5}$$

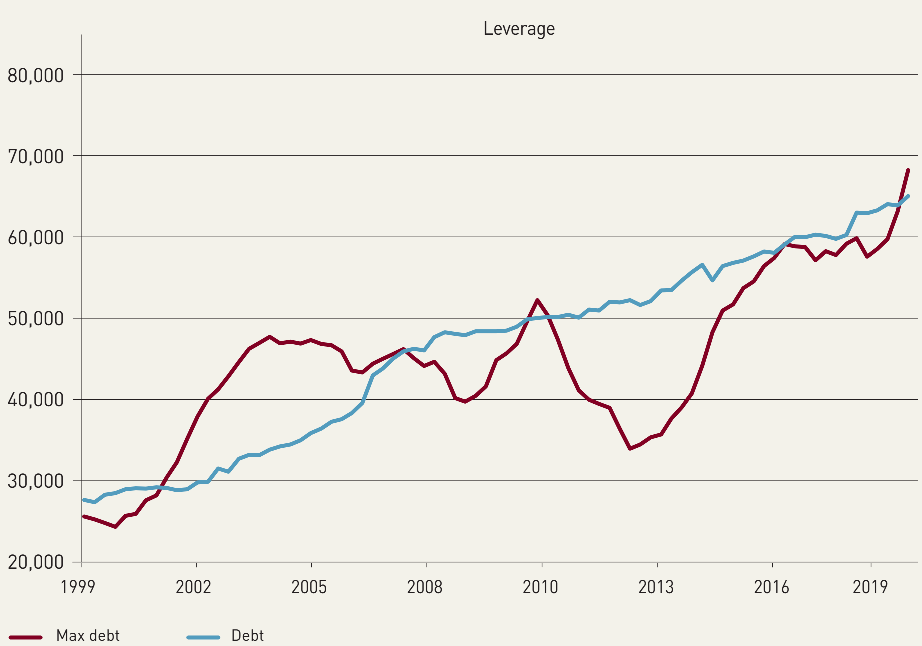
$$\widehat{debt}_{dsb,t}^{max} = -const_{dsb} - \beta_{dsb}^{rate} rate_t \tag{6}$$

Figure 5
"Sustainable" Debt Levels from a VECM



Source: BCL calculations.

Figure 6
"Sustainable" Debt levels from the leverage approach



Source: BCL calculations.

Figures 5 and 6 show the development of the two cointegration relationship equations and the (log) per capita debt over time. Figure 5 shows the maximum "sustainable" level of debt according to the debt service burden while figure 6 shows the maximum amount of leverage relationship. Recall that household debt may be "unsustainable" when one of the two cointegration equations deviates from the long-term value. We observe that under the leverage perspective, debt levels until 2019Q4 were indeed "unsustainable". However, in 2020Q1, household debt converged towards its fundamental value for the first time since 2011Q1. The debt service burden suggests that debt is still close to, but below, its maximum "sustainable" amount. Moreover, Figure 5 shows that there had also been periods where the debt service burden was "unsustainable". Most notably, both variables were at "unsustainable" levels before and during the Great Recession as well as during the subsequent European Sovereign Debt Crisis.

5.3 IDENTIFYING OTHER VARIABLES CONTRIBUTING TO RISING DEBT LEVELS

In Section 4.2, we found that household debt was driven by reductions in the LTV ratio. We now reevaluate our findings with a VECM framework. We again rely on a model where (log) per capita debt and (log) disposable income are separately integrated in the model.

Table 6 :

ADF tests for additional variables

	CONSTANT		CONSTANT & TREND	
	LEVEL	1ST DIF	LEVEL	1ST DIF
Loan-to-Value Ratio				
Lags	0	0	0	0
Test stat.	-1.7283	-9.3668	-2.6463	-9.3804
Prob.	0.4121	0.0000	0.2622	0.0000
Mortgage Rate (New Loans)				
Lags	0	0	1	0
Test stat.	-2.4411	-11.827	-3.5374	-11.855
Prob.	0.1322	0.0000	0.0388	0.0000
ARM share				
Lags	1	1	1	1
Test stat.	1.1818	-0.8533	-0.1169	-3.2923
Prob.	0.9978	0.7969	0.9936	0.0765

Table 6 outlines the unit root test for the additional variables. While the LTV ratio and the mortgage rate are also trend-stationary. The ARM share is only I(1) when a trend is added.[141]

We introduce two more variables to obtain a six variable model. We perform Johnansen tests to identify the number of possible cointegration relationships, as shown in Table 7. In line with the Akaike information criterion, we account for the loss of degrees of freedom associated with the higher number of variables by reducing the lag length to two. The Maximal Eigenvalue Test points to one cointegration relationship at the 95 % confidence level. The results of the Trace Test are less clear. The underlying theory requires us to have one or two cointegration vectors. We estimate the models for *r*=1, treating the results with caution as a different number of cointegration relationships is not implausible.

Table 7:

Cointegration tests five and six variable models

NO. OF CONITEGRATIONS	EIGENVALUE	6 VARIABLES VECM P-VALUE (TRACE TEST)	P-VALUE (MAX. EIGENVALUE TEST)
r=0	0.5227	0.0010	0.0234
r≤1	0.3593	0.0273	0.3317
r≤2	0.3349	0.0579	0.1474
r≤3	0.2086	0.2214	0.4011
r≤4	0.1393	0.2847	0.3118
r≤5	0.0213	0.2642	0.2642

141 Note that in 4.2, we also disentangled the effects of interest rate changes on new loans from their effects on the stock of debt with an interaction term. Specifically, the interaction term is the product of the mortgage rate and the ARM share. We refrain from the interaction term now as its long-run path is already determined by the long-run reaction of the mortgage rate and the ARM share.

As before, we need two restrictions to ensure that the increases in debt are not due to a contemporaneous increase in income. The impact of all other variables remains unrestricted. With this specification, the model closely resembles the OLS model in 4.2.

$$\beta' Y_t = \left(1\ 0\ \beta_{dsb}^{ltv}\ \beta_{dsb}^{rate}\ \beta_{dsb}^{arm}\right) \begin{pmatrix} debt_{t-1} \\ income_{t-1} \\ ltv_{t-1} \\ rate_{t-1} \\ arm_{t-1} \\ hpi_{t-1} \end{pmatrix} \tag{7}$$

Table 8 presents the results of the six variable VECM model.[142] The estimates from both models are qualitatively similar to our findings from Section 4. As before, we see that house price increases are positively associated with household debt. In addition, higher LTV ratios lead to higher debt levels. The real mortgage rate positively affects per capita debt. This is in line with the positive semi-interest rate elasticity observed in 4.2. Recall, that the interest rate affects debt through two distinct channels. Rising interest rates increase the costs for new mortgages, thereby reducing the total amount of mortgage debt. At the same time, debt increases for households that currently have a mortgage credit with a variable interest rate. We observe that the latter effect predominates. Consequently, the recent increase in household indebtedness is not primarily due to the low interest rate environment. Moreover, the ARM share is positively related to debt. All these effects are significant. Most importantly, positive deviations from the cointegration vector negatively affect debt so that a steady state is reached.

Table 8:

VECM Results from the Six Variable Model

PANEL A: COINTEGRATION EQUATIONS							
COINTEGRATING EQ:	*debt_(t-1)*	*income_(t-1)*	*ltv_(t-1)*	*rate_(t-1)*	*arm_(t-1)*	*hpi_(t-1)*	*Const.*
β	1	0	-1.558	-2.687	-2.602	-2.006	171.28
T-statistic			[-5.443]	[-4.025]	[-8.218]	[-9.847]	

PANEL B: SHORT-TERM DYNAMICS							
ERROR CORRECTION:	Δ(debt_t)	Δ(income_t)	Δ(ltv_t)	Δ(rate_t)	Δ(arm_t)	Δ(hpi_t)	
$\widetilde{\text{coint}}$	-0.2159	-0.0019	-0.0504	0.0229	-0.0023	0.0818	
T-statistic	[-3.891]	[-0.047]	[-1.101]	[1.114]	[-0.365]	[1.697]	

Finally, we check whether the time-varying debt levels hold when we consider the six variable model instead of the four variable VECM from Equation (4). Equation (8) yields the maximum "sustainable" debt level. Again, we correct for the overvaluation of house prices.

$$\widehat{debt}_t^{max} = -const - \beta^{ltv} ltv_t - \beta^{rate} rate_t - \beta^{arm} arm_t - \beta^{hpi} hpi_t \tag{8}$$

142 As before, for the short-run dynamics we only present evidence of the cointegration relationship in Table 8.

Figure 7 displays the corresponding maximum debt levels. The results suggest that household indebtedness in 2020Q1 is above the maximum debt level from the model. Specifically, household indebtedness in 2020Q1 is 1 % above the maximum "sustainable" level. Taking into account the estimates from the OLS model, we show by how much the average LTV ratio has to decline to reduce household indebtedness by 1 %.

6. THE ROLE OF LOAN-TO-VALUE RATIOS

Building on the results from the OLS model in Section 4, we now analyze the nexus between household indebtedness and the loan-to-value ratio. According to Table 3, there is a positive but decreasing effect of the LTV ratio on household debt. In 2020Q1, the average LTV ratio was 78.1 %. Figure 8 shows how different average LTV ratios lead to different debt-to-disposable income ratios while Figure 9 shows log household debt per capita levels along with average LTV values.[143] We assume that all other explanatory variables are at their historical mean in the analyzed sample. Figure 8 displays the nexus between the average LTV ratio and Luxembourg households' debt-to-disposable income in the long-run. Figures 8 and 9 therefore show by how much the LTV ratio would have to decrease to reach "sustainable" debt-to-disposable income and debt-per-capita levels, respectively.

143 We refer to the historical mean so that the comparison with the VECM conducted in Section 5 is straightforward.

Figure 7
Sustainable Debt Levels form a seven variable VECM

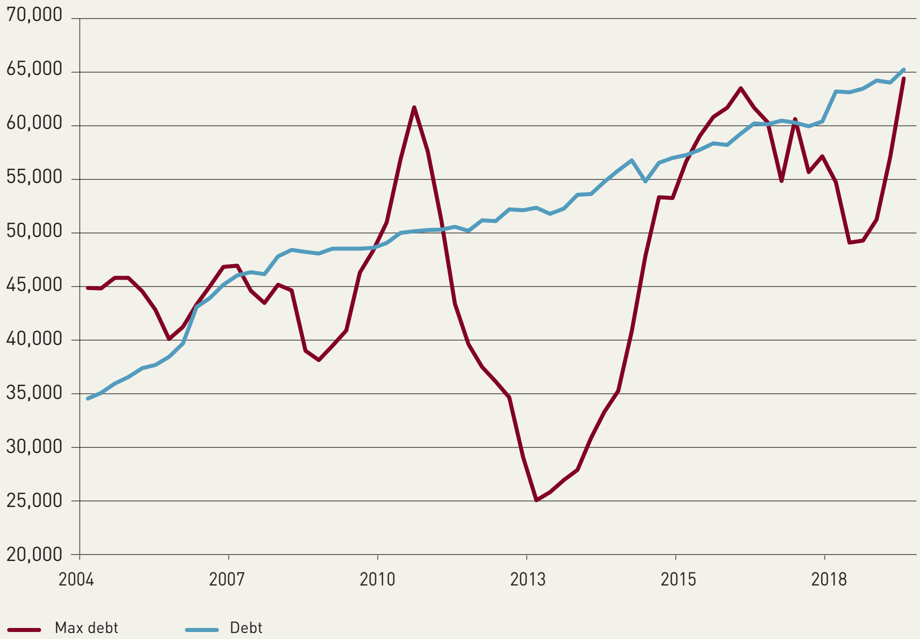
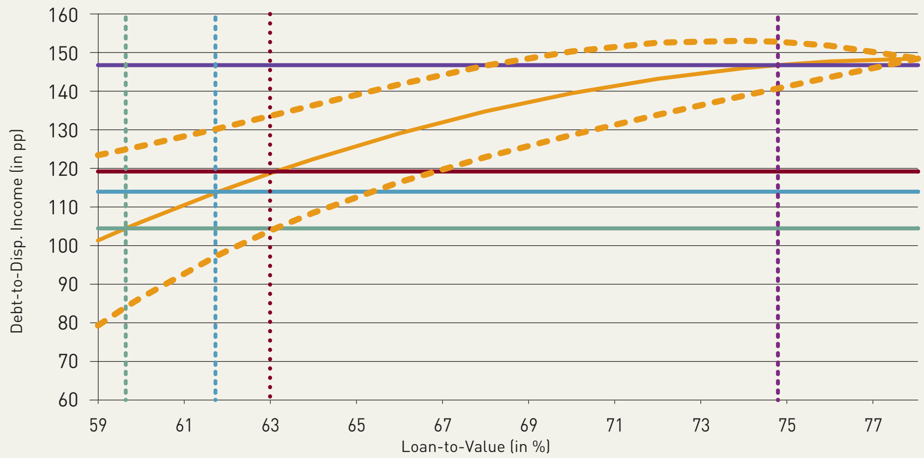
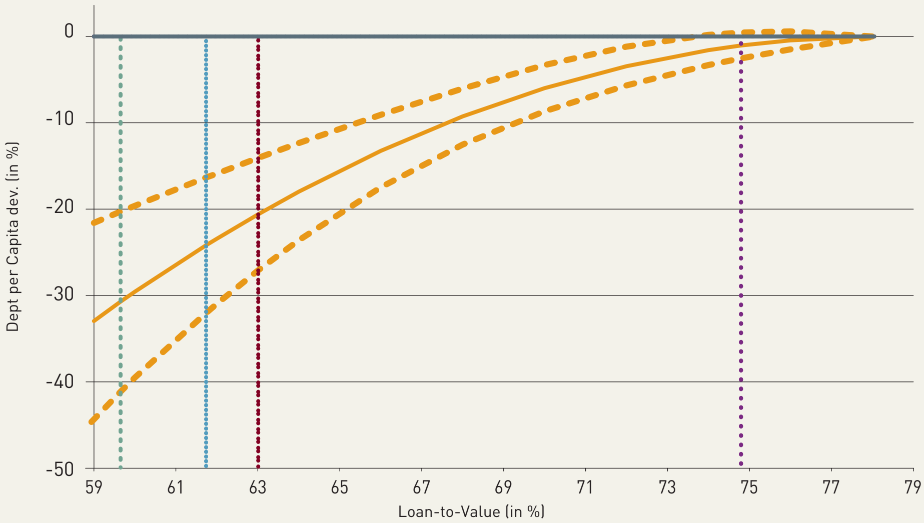


Figure 8
Debt-to-Disposable Income



Source: BCL calculations. Nexus between LTV and debt-to-disposable income in the long-run. The solid orange line indicates the estimated mean response to deviations from this LTV ratio. The dashed orange lines are the 95% confidence bands around the mean. The horizontal purple line displays the "sustainable" debt level from the VECM. To be "sustainable", debt-to-disposable income needs to decline by 1.7 pp from the 2020Q1 observed value of 172.6% to the purple line at 146.8%. Correspondingly, the average LTV ratio should decline by 3.3 pp from the observed 78.1% to 74.8% as indicated by the intersection of the orange and purple lines. The red, blue and green solid lines indicated sustainable debt levels established in the literature. The green line displays the upper quartile of the debt-to-disposable income ratios in Luxembourg from 1999 to 2007. The blue line is the upper quartile of debt-to-income ratios of euro area member states in 2018. The red line indicates the sustainable level from the leverage-perspective.

Figure 9
Debt per Capita



Source: BCL calculations. The dashed lines highlight which LTV ratios correspond to sustainable debt levels identified in the literature and the VECM. These are 59.61%, 61.73%, 63% and 74.8% for the green, blue, red and purple line, respectively. The results derive from Model II where the log of per capita debt is the dependent variable. The solid orange line outlines by how many percent per capita debt increases or decreases if the economy's average LTV ratio changes in comparison to the 2020Q1 observed value. According to the dashed green, blue, red and purple lines, "sustainable" debt levels are reached when per capita debt decreases by 30.71%, 24.17%, 20.59% and 0.99%, respectively.

According to the upper quartile of the debt-to-disposable income ratios in Luxembourg from 1999 to 2007, the average LTV ratios must be lowered to at least 59.65 % in order for debt to be considered as "sustainable" based on the fixed thresholds from the literature. When setting the threshold based on the upper quartile of debt-to-income ratios of euro area member states (the leverage approach), the LTV ratio must not exceed 61.73 % (63 %). Hence, a reduction of 18.41, 16.32 or 15.05 percentage points from the 2020Q1 average ratio is required for "sustainability" when based on the thresholds from the literature.

According to the VECM results shown in Figure 8, for the household debt level to be below the threshold, the average LTV ratio needs to decline by 3.3 pp. This corresponds to a debt-to-disposable income ratio of 146.8 %, which is the time-varying threshold from the VECM and 1.7 pp. below observed household debt –to-disposable income levels in 2020Q1 (172.6 %). Consequently, for household debt levels to be considered "sustainable", our results suggest that the LTV ratio has to decline by at least 3.3 pp from the observed 78.1 % to 74.8 % shown in the figure.

Figure 9 shows how the (log) per capita debt would change if these lower LTV ratios were met. Accordingly, the LTV reductions to 59.61 %, 61.73 %, 63 % and 74.8 % result in a decline in per capita debt of 30.71 %, 24.17 %, 20.59 % and 0.99 %, respectively.

However, these results have to be interpreted with caution. As the three fixed thresholds have been adopted from the literature, they do not specifically correspond to Luxembourg's economy. In addition, they do not result from a model estimation and are time-invariant.

7. CONCLUSION

Since 1999, household debt per capita has more than doubled in Luxembourg. This paper identifies the driving forces of this rapid increase via OLS estimations and a VECM model and evaluates whether current debt levels are considered as "sustainable". We find that strong and sustained house price increases and higher LTV ratios are the major contributors to the increases in household indebtedness in Luxembourg. Low interest rates only play a minor role, as two opposing channels almost offset each other during the period considered in this analysis. On the one hand, new loans are more attractive to households when interest rates are low. On the other hand, lower interest rates decrease repayment obligations for households that signed mortgage debt contracts with an adjustable rate. Additionally, we find no evidence that increases in disposable income contribute to increasing household debt levels.

In particular, the fact that household disposable income has not increased at a similar pace as household indebtedness raises potential policy considerations. Cointegration tests suggest that the two variables do not follow a common trend. Juselius and Drehmann (2015) highlight that not only income levels, but also households' assets are important determinants of debt sustainability. In this respect, an ADF test suggests that Luxembourg households' debt-to-assets ratio is non-stationary. We further assess household debt levels by comparing current debt-to-disposable income values with pre-specified fixed thresholds and observe that household debt levels are above these thresholds. Finally, we apply a VECM that also suggests that current household debt levels can be considered as high.

To evaluate how macroprudential policymakers can address rising household debt levels, we examine the linkage between debt and the aggregate LTV ratio. We observe a positive but decreasing relationship. To lower household debt levels, the results of this work suggest that average LTV ratios in Luxembourg should decline by 3.3 percentage points.

Several extensions of the analysis are of interest, but are beyond the scope of this paper. First, we identify "sustainable" household debt levels via fixed ad-hoc thresholds and empirical models. A natural extension is to determine these thresholds using structural models. Second, although high household debt levels result in increased vulnerability to shocks, we do not address this question for Luxembourg households. Third, the work could be extended by taking into account the effects related to tax regimes.

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4. THE IMPACT AND EFFECTIVENESS OF MACROPRUDENTIAL CAPITAL BUFFERS: EVIDENCE FROM LUXEMBOURG

Boubacar Diallo[144]

ABSTRACT

In this contribution, we examine several key questions such as: How effective are macroprudential capital buffers in Luxembourg? What are their effects on bank lending, risk-taking and efficiency in Luxembourg, if any? To answer these questions, we use the introduction of the capital conservation buffer (CCoB) and the other systematically important institutions (O-SII) capital buffer to investigate their individual effects on the relevant banks' total lending, mortgage lending, lending to non-financial corporations, lending to households and inter-bank lending activities. We also assess the effects of these buffers on banks' risk-taking and efficiency. Applying the difference-in-differences (DID) methodology to an unbalanced panel of 141 banks in Luxembourg over the period 2011-2018, we find the following results. The O-SII capital buffers decreased total lending and boosted bank soundness, as measured by the z-score; as well as bank efficiency. However, our results also suggest that the introduction of the CCoB in Luxembourg did not have any significant effect on lending. Robustness checks using several resampling approaches and the propensity score matching (PSM) suggest that the findings are corroborated.

INTRODUCTION

Macroprudential capital buffers are intended to increase bank resilience thereby allowing banks to absorb losses while maintaining the smooth supply of credit to the economy during crisis periods. On the research side, Cerutti *et al.* (2017), Jiminez *et al.* (2017), Altunbas *et al.* (2018), Cizel *et al.* (2019), Fraisse *et al.* (2020) among others, have published papers on the effectiveness of macroprudential policies with respect to both capital buffers and borrower-based measures at the country, regional and monetary union levels. However, experience with assessing their effects on different types of lending, bank soundness and efficiency remains limited. Therefore, the main goal of this contribution is to address this gap by providing answers to the following questions. What are the effects of macroprudential capital buffers in Luxembourg and what are their more specific effects on bank lending, risk-taking and efficiency? To answer these questions, we use the introduction of the capital conservation buffer (CCoB) and other systematically important institutions (O-SII) capital buffer and assess their effects on total lending, mortgage lending, lending to non-financial corporations households and other banks. In addition, we examine their potential effect on risk-taking and bank efficiency using an unbalanced panel of 141 banks over the period 2011-2018.

In Luxembourg, the capital conservation buffer (CCoB) and the other-systematically important institutions (O-SII) capital buffer were implemented in 2014 and 2016, respectively. The primary objective of the CCoB is to ensure that banks have sufficient capital to draw on in the event that they incur losses. This buffer helps to ensure that banks are able to avoid breaches of the minimum capital requirement because if a bank breaches the buffer it is subject to automatic restrictions on the amount of dividend and bonus payments.

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In Luxembourg, the CCoB has been effective as of January 1, 2014 when it was set at 2.5 percent of Common Equity Tier 1 (CET1).[145] However, there is an exception from these requirements for small and medium-sized investment firms. Small and medium-sized investment firms are defined as those with a number of employees fewer than 250 persons, which have an annual income not exceeding 50 million euros or a total annual balance sheet not exceeding 43 million euros. In the analysis that follows, we exploit this heterogeneity and measure the ex-post effects of the CCoB on bank lending, risk-taking and efficiency.

The European regulation also foresees the activation of O-SII capital buffers in order to address the negative externalities associated with the failure of a systemically relevant bank and to protect the economy as a whole. According to the European Banking Authority (EBA), O-SIIs are institutions that are most likely to create risks and financial instability because of their systemic importance. In their search to maximize private benefits, these institutions may impose negative externalities on the banking sector and contribute to market failures. In following with the EBA guidelines, the O-SII capital buffers are calculated using a scoring method based on size, importance, complexity and interconnectedness in Luxembourg. The O-SII buffer rates were first effective on January 1, 2016. The Central Bank of Luxembourg (BCL) also applies an extended methodology to identify O-SIIs that may have important interconnections with the investment fund sector. The extended methodology complements the EBA approach and calculates scores that take into account the importance of a given bank in relation to its interlinkages with the Luxembourg investment fund sector.

Using the difference-in-differences (DID) empirical methodology we find that the introduction of the O-SII capital buffers decreased total lending for banks operating in Luxembourg. More precisely, the O-SII capital buffer decreased the total loan growth rate by roughly 20 percentage points over the period 2011-2018 (during which the CCoB was activated in 2014 and the O-SII buffer in 2016) compared to a scenario with no O-SII buffers. However, applying the same methodology to the implementation of the CCoB requirements suggests that the CCoB has not had any significant effect on bank lending. Importantly, O-SII capital buffers also increased bank soundness, as measured by the z-score, and bank efficiency. These results hold in the presence of several robustness tests to account for selection bias issues.

Our study is motivated by several strands of the literature on macroprudential policy. First, many papers in the literature have focused on the effects of capital requirements on lending. Using a panel data set covering 2800 banks across 48 countries over the period 2000-2010, Claessens *et al.* (2013) investigate the effectiveness of macroprudential policies on banks' balance sheets. Taking into account endogeneity concerns, they showed that, as macroprudential tools, borrower-based measures have a significant but limited impact on credit growth. In similar work, De Jonghe *et al.* (2020) look at how time-varying bank capital requirements affect balance sheet adjustments and lending standards for the non-financial corporate sector. Additionally, Fraisse *et al.* (2020) analyze the effect of bank capital requirements on firms' borrowing and investment, finding that a one percentage point increase in capital requirements reduces lending by 10 percent. However, bank capital requirements did not affect consumer loans.

Using the countercyclical capital buffer (CCyB) introduced in Switzerland in 2012, Auer and Ongena (2019) study the effects of macroprudential regulation on residential and commercial lending. Their findings suggest that the introduction of the CCyB for Swiss banks increased the growth in commercial lending for small firms. However, interest rates and fees charged to these small firms also increased. Conversely, in Spain, Jimenez *et al.* (2017) investigated the effects of provisioning and countercyclical

145 The implementation of the CCoB in Luxembourg is based on Article 59-5 of the Law of 5 April 1993 on the financial sector (LFS). The CCoB was activated in January 2014 and the exemption for small and medium-sized investment firms took place in 2015.

buffers on credit growth, finding little impact. Nevertheless, they found that countercyclical buffers help to reinforce the solvency of the banking sector. Gropp *et al.* (2018) identify the effect of higher capital requirements on firm lending, investment and growth using a difference-in-differences matching method. They use the 2011 European Bank Authority (EBA) capital exercise as well as the June 2011 stress test to assess the effect of these requirements in euro area countries. The objective of the stress test exercise was to ensure that banks had sufficient capital to insure against unexpected losses. They find that banks in the EBA sample increased their capital ratios by reducing their credit supply. In addition, the observed reduction in credit supply negatively affected investment and sales growth of firms.

With respect to the existing literature, our study adds several contributions compared to previous studies. First, it uses the implementation of the capital conservation and O-SII buffers in Luxembourg to assess the effectiveness of two macroprudential capital buffers, unlike previous studies. Second, it focuses specifically on Luxembourg, a financial center in which banks originating from different countries and in which a large continuum of business models operate. The results suggest that the O-SII buffer requirements result in a decrease in total lending growth over the period considered compared to a scenario in which no O-SII buffer was implemented.

Other studies look at how macroprudential policies can help to decrease bank risk-taking. For example, Altunbas *et al.* (2018) investigate the effects of macroprudential policies on bank risk-taking using a large panel of banking institutions operating in 61 advanced and emerging economies. Their findings suggest that macroprudential policies have a significant impact on bank risk-taking. Interestingly, the effects of these macroprudential policies on risk-taking depend on banks' characteristics, suggesting that small, weakly capitalized banks and institutions with important wholesale funding dependencies react more strongly to changes in macroprudential tools. Cappelletti *et al.* (2019) assess the impact of higher capital buffers on banks' risk-taking behavior in Europe. Using the EBA framework they study the effects of higher bank O-SII capital buffers on banks' lending and risk. Their results suggest that banks identified as O-SIIs reduced their credit supply to households and the banking sector in the short-term, and thereby shifted their lending to less risky counterparts within the non-financial corporate sector. Additionally, in the medium-term the soundness of O-SII banks increased. Lubello and Rouabah (2017) embedded a shadow-banking sector within a DSGE framework to investigate the effects of macroprudential policies on financial stability. They find that the introduction of capital requirements and caps to securitization are effective instruments for decreasing volatility in the financial system through the stabilization of output volatility. Our present research also looks at this question and estimates the effects of the CCoB and O-SII capital buffers on bank risk-taking measured by the z-score. Our results show strong and positive effects of the O-SII capital buffers on bank soundness. Consequently, unlike previous papers, we also investigate for the first time the effects of macroprudential policies on bank efficiency. These results also show consistent and positive effects of O-SII capital buffers in enhancing bank efficiency. This result is in contradiction with the findings of Curi *et al.* (2013) and Barth *et al.* (2013) who have both shown that strict banking regulation and supervision are negatively and significantly associated with bank efficiency.

Another strand of the literature in the effectiveness of macroprudential tools tries to disentangle their effects on lending according to a country's level of economic development. For instance, Cerutti *et al.* (2017) study the effects of several macroprudential tools on credit growth and house prices according to a country's level of economic development. More precisely, they define an aggregate measure of macroprudential instrument consisting of 12 specific tools from the Global Macroprudential Policy Instruments (GMPI) survey of the IMF. They find that macroprudential policies have significant mitigating effects on credit growth. However, these effects were much stronger for developing and emerging economies. Cizel *et al.* (2019), who showed that macroprudential instruments had a significant impact on bank credit growth in both advanced and emerging market economies, also obtained similar findings. In addition, they found some substitution effects for non-bank credit in advanced economies, thereby reducing the policies' effects on total credit. Lim *et al.* (2011), using a sample of 49 countries, find that macroprudential instruments reduced procyclicality. More specifically, macroprudential policies helped decrease the sensitivity of credit to GDP growth. Olszak *et al.* (2019) studied the effects of several macroprudential measures on bank lending for a sample of 60 countries, showing that macroprudential policies decrease the procyclical impact of capital and lending during both normal and bad times. Yet, the effects of these policies were stronger for larger banks. To alleviate concerns related to omitted variables issues, because of the observed heterogeneity across countries, focusing on a financial center such as Luxembourg allows us to obtain estimates that are not likely to suffer from this heterogeneity and measurement error given the absence of data issues such as different reporting requirements. More importantly, focusing on one country allows us to deal with the endogeneity related to national discretion as policymakers could use their supervisory judgment in implementing macroprudential tools as well as classifying a bank as an O-SII independent of its score.

On the effects of macroprudential policies in alleviating housing bubbles, Krznar and Morsink (2014) use Canadian data and find that the implementation of macroprudential policy tools decreases mortgage credit, and house price growth. Calem *et al.* (2017) analyze the effects of macroprudential policies on credit supply in the U.S., finding that the 2011 Comprehensive Capital Analysis and Review (CCAR) stress test had a negative effect on the share of jumbo mortgage originations and approval rates of banks participating in the stress test. They further found that banks with worse capital positions were more significantly and negatively impacted. Using a sample of 28 European countries over the period 1990-2018, Poghosyan (2019) investigated the effectiveness of lending restriction policies, namely loan-to-value (LTV) and debt-service-to-income ratios (DTI) on credit and house prices. The author found that, overall, lending restrictions have significant effects on credit and house prices. However, these effects are delayed and reached their peaks only after three years. Our results suggest that there was no specific impact of the CCoB or O-SII capital buffers on mortgage lending, thus validating the importance of implementing borrower-based macroprudential tools in order to address rising household indebtedness in relation to residential real estate vulnerabilities in Luxembourg.

In terms of data, Budnik and Kleibl (2018) built a new and comprehensive database on macroprudential policies for 28 EU countries over the period 1999-2014. This new database, named the Macroprudential Policies Evaluation Database (MaPPED), provides a detailed overview of the life-cycle of macroprudential policy tools, and classifies these instruments according to their macroprudential versus microprudential nature. Their findings indicate that capital buffers, lending restrictions and caps on maturity mismatches have significant impacts on the supply of credit to the non-financial private sector across EU countries.

Another line of research has recently suggested that there may be leakages associated with the effects of macroprudential policies. Ongena *et al.* (2013) are the first to show that tighter restrictions on bank activities and higher minimum capital requirements in domestic markets are associated with lower bank lending standards abroad. Aiyar *et al.* (2014b) and Reinhardt and Sowerbutts (2015) all show that the implementation of macroprudential tools by home authorities for domestic banks increases foreign borrowing. Precisely, Aiyar *et al.* (2014b) investigate the leakage effects of macroprudential policies in the U.K. They provide evidence that both types of regulated banks, i.e. UK-owned banks and foreign subsidiaries, decrease their lending in response to the introduction of macroprudential tools. However, unregulated banks, i.e. resident foreign branches, increase lending in response to tighter capital requirements. Still in the U.K., Danisewicz *et al.* (2017) studied the effects of cross-border spillovers of macroprudential measures on the organisational structure of banks' foreign affiliates. Their empirical results suggest that after a tightening of capital buffer requirements, branches of multinational banks reduce interbank lending growth by 6 percentage points relative to subsidiaries of the same banking group. However, there were no differences for non-bank lending. Interestingly, they found that a tightening in lending standards at home does not have differential effects on either interbank or non-bank lending in the U.K. This is in line with the findings of Cerutti *et al.* (2017) who provided some evidence on the effects of macroprudential policies on cross-border lending. Goodhart (2008) and the IMF also argue that increasing bank capital requirements may be associated with growth of the non-bank sector. In this study, to account for potential spillovers of macroprudential policies, we use data on foreign lending in the euro area by banks operating in Luxembourg. Our results do not show evidence for outward spillovers in lending.

The next section of this research deals with the identification methodology for O-SII banks. The remainder of this study is as follows. Section 2 presents the empirical approach. Sections 4 and 5 deal with the results and robustness tests, respectively. Finally, section 5 concludes and provides some potential guidance for decision-making.

O-SIIS IDENTIFICATION METHODOLOGY

The methodology in the EBA Guidelines allows the relevant authorities to identify O-SIIs and require each institution identified to maintain an O-SII buffer of up to 2 percent of the total risk exposure amount, consisting of Common Equity Tier 1 capital. The O-SII framework is based on a loss given default (LGD) approach, which is intended to reduce the negative externalities associated with the failure of a systemically important institution. In other words, it is intended to address losses in case of default and the scoring approach focuses on the various activities of banks rather than the amounts held. The Guidelines proposed by the EBA consist of a two-step identification process. During the first step, quantitative information on banks' size, interconnectedness, relevance for the economy and complexity are collected by the national authorities and classified in terms of scores that determine a bank's systemic importance.

Accordingly, banks scoring above a certain threshold (upper threshold) will be identified as O-SIIs, and those scoring below the threshold (lower threshold) will not be identified as OSIIs. In the second step, national authorities can still designate O-SIIs using their judgment. For example, judgment can be used to: (i) designate an institution as an O-SII (when appropriate) if its score is below the threshold , (ii) move a bank to a higher loss absorbency bracket (where appropriate), and (iii) remove a bank from the list (i.e. reverse previous judgment) if appropriate. The O-SIIs identification process in Luxembourg started in 2015 and repeats on an annual basis. The CET1 O-SII buffer requirement is reassessed on an annual basis.[146]

IDENTIFICATION STRATEGY

This section discusses the difference-in-differences (DID) econometric models. Because bank capital ratios and their capital levels prior to the implementation of macroprudential capital buffers might be correlated with other bank characteristics including lending, risk-taking and efficiency, we use the implementation of new macropudential tools in relation to pre-existing capital requirements to assess

146 For more details see the EBA score guidelines available at: https://eba.europa.eu/regulation-and-policy/own-funds/guidelines-on-criteria-to-to-assess-other-systemically-important-institutions-o-

their effects on bank lending, soundness and efficiency. First, we focus on the effects of the CCoB on banks in Luxembourg. More precisely, we define a dummy variable called Treat for treatment, which takes the value of 1 for all banks affected by the CCoB and 0 for small and medium-investment firms. We also define another dummy variable called Post that takes the value of 1 for the period following its implementation. One can now estimate the model as follows:

$$Bank\ Outcome_{i,t} = \beta_0 + \beta_1 Treat + \beta_2 Treat \times Post + X_{i,t-1} + \eta_t + \rho_i + \theta_i + \epsilon_{i,t} \qquad (1)$$

where *i,t* denote bank and period, respectively. The variable Bank Outcomeit consists of total, mortgage, non-financial corporation, household and bank loan growth rates; bank soundness i.e. insolvency and efficiency measured respectively by the z-score and the DEA approach[147] of bank *i* in period *t*. β_0 is the average of the outcome variable of the control group during the pre-treatment period. Therefore, this coefficient captures the average of the outcome variable for small and medium investment firms that are not affected by the CCoB. β_1 is the average of the outcome variable of the treatment group in the pre-treatment era minus the average of the outcome variable of the control group in the pre-treatment period. Put differently, *β*1 gives the coefficient of the mean difference in the outcome variable between the treatment and control groups prior to the implementation of the CCoB. β_2 is the average of the outcome variable of the control group in the post-treatment era minus the average of the outcome variable of the control group in the pre-treatment period. It is the expected mean change in the outcome variable from before to after the implementation of the CCoB implementation for the control group. β_3 is the coefficient of interest and is often called the DID estimate. It measures the true effect of the treatment and provides information on whether the expected mean change in the outcome variable from before to after the implementation of the CCoB is different in the two groups.

$X_{i,t-1}$ are lagged control variables at the bank and country levels consisting of bank size, capital and equity ratios, diversification, GDP and inflation. n_t controls for year-fixed effects, ρ_i and θ_i are banking business model and country of origin fixed effects, respectively. Banking business models are captured by six dummy variables, namely universal, retail and commercial banks, custodian and investment funds, private, corporate banking and others. In a similar vein, country of origin fixed-effects are measured by seven geographical dummy variables for Luxembourg, German, French, Swiss, Italian and Chinese and other segments, respectively.

Second, we follow the same approach as above and define two new dummy variables for the O-SII capital buffers. We define a dummy variable called "Treat" for treatment, which takes the value of 1 if a given bank is subject to an O-SII capital buffer in 2015, 2016, 2017 and 2018, respectively; and 0 otherwise. Since the O-SII capital buffers were effective as of January 1 2016, we define another dummy variable called "Post" that takes the value of 1 for the period following the intervention i.e. after 2015. The second econometric model is as follows:

$$Bank\ Outcome_{i,t} = \alpha_0 + \alpha_1 Treat \times Post + X_{i,t-1} + \eta_t + \rho_i + \theta_i + \epsilon_{i,t} \qquad (2)$$

Again, our coefficient of interest is α1, which measures the change in the outcomes of O-SII banks compared to other banks, conditional on a set of controls at the bank and country levels. With this model, one cannot add the single variables Treat and Post since the treatment takes the value of 1 when a bank is classified O-SII and only after the implementation of the policy. This suggests that the treatment occurs at different period of time, which leads to a variation in timing as argued by Goodman-Bacon (2018).

147 Diallo (2020) uses this approach to calculate bank efficiency for the Luxembourg banking sector.

Estimation method. To estimate equations (1) and (2), we use the population-averaged panel data model. This method fits generalized linear models and allows one to specify the within-group correlation structure for the panels. This technique deals with error correlations across individuals and groups due to the grouping of banking institutions. Furthermore, according to Bertrand *et al.* (2004) simple DID estimates and their standard errors generate many spurious correlations if one does not account for this serial correlation. In our case, we assume that the correlation structure follows an AR(1) process as in Bertrand *et al.* (2004). In order to get efficient estimates of the parameters of interest, we use the bias-corrected bootstrapped standard errors for statistical inference. More specifically, we use 1000 bootstrap replications to get the bias corrected estimates. The use of a large number of replications is motivated by the findings of Hall (1986) and Andrews and Buchinsky (2000, 2001) who showed that to obtain unconditional coverage probabilities of the estimates one needs to uses a large number of bootstrap repetitions.

Selection bias. Some challenges must be addressed before presenting the results of the DID technique. The most important one is the selection bias for the empirical specifications. The selection bias mostly refers to the fact that in order to be able to estimate the causal effects of macroprudential policies one must show that the evolution in the outcome variables for the treatment and control groups follow similar patterns before the changes occur. However, there is no specific econometric tool to test this assumption. Therefore, in our case we perform mean-comparison tests of the outcome variables, namely bank lending, soundness and efficiency before the implementation of the macroprudential tools. In terms of results, we do not find a statistically significant difference in the means of total, mortgage, non-financial corporation, household and bank lending, bank soundness and efficiency. For example, we find *p-values* of 0.197 and 0.846 for total lending using the CCoB and O-SII capital requirements, respectively. In addition, we employ two procedures to identify any potential concerns regarding the selection bias. The first approach to deal with the selection bias issue consists of using two resampling approaches. Moreover, we randomly construct the treatment group within banks in the sample and re-estimate the empirical models. Alternatively, since we have data on banks that are no longer operating in Luxembourg, we use these banks as a treatment group in the second robustness exercise and re-estimate the econometric model. The main idea is that we should find no effect if the selection bias is not a concern. Second, we follow the literature and use the propensity score matching approach. This approach allows us to match treated banks in relation to macroprudential policies with non-treated banks that may have a similar probability to be treated. Consequently, we compare pairs of banks that are exposed to a similar probability of being treated according to the buffers, respectively using bank-level characteristic variables. We match banks in the treatment group with banks in the control group based on the neighbor matching estimator with respect to several bank characteristics. Additionally, to control for changes in credit demand, our empirical strategies control for time, bank fixed-effects and GDP growth (Borio and Gambacorta (2017)). The inclusion of these effects permits us to take into account the demand-side bias and it increases the efficiency of the estimates

Data. The outcome variables consist of several types of annual loan growth rates, bank soundness and efficiency. We sequentially use the growth rates of total, mortgage, non-financial corporation, and household and bank loans, respectively. For bank soundness, we measure it using the z-score, which has been widely applied in the banking literature.[148] Specifically, it measures a bank's insolvency risk by taking the ratio between the sum of equity capital as a percent of assets and the return on assets and the standard deviation of the return on assets as a proxy for return volatility. Therefore, a higher z-score implies a lower probability of insolvency. Bank efficiency is calculated using the non-parametric Data

148 See for instance Boyd and Runkle (1993); Beck *et al.* (2007); Demirguc-Kunt *et al.* (2008); Laeven and Levine (2009), Cihak and Hesse (2010) and Diallo and Al-Mansour (2017).

Envelopment Analysis (DEA) method.[149] Besides these variables, we control all empirical specifications by adding a range of bank characteristic variables. More precisely, we include the lagged variables of the logarithm of total assets and its square to control for size, capital and equity ratios in terms of total assets, non-interest income in terms of total assets as a proxy for diversification, a measure of bank concentration in terms of total assets using the Herfindahl-Hirschmann index (HHI) and a measure of bank funding proxied by the ratio of total deposits to liabilities. At the macro level, we control for the lagged variables of the logarithm of per-capita GDP and the consumer price index for Luxembourg, respectively. The introduction of these two variables controls for demand-side effects as well as inflation. The introduction of the covariates is useful to capture the comparability between the treated and untreated groups before the implementation of the macroprudential capital buffers (Mayer (1995)). The data come from the Banque centrale du Luxembourg (BCL) and we use the GDP deflator of Luxembourg in 2010 for variables expressed in nominal terms. The final sample consists of 815 unbalanced bank-year observations over the period from 2011-2018. Taking the lag of the covariates and using the bootstrapping procedure decreases the size of the final sample according to the outcome variables.

149 Diallo (2020) provides detailed bank efficiency estimates for Luxembourg.

RESULTS

Capital Conservation Buffers (CCoB)

This section presents the main findings for the capital conservation buffer. In Table 1, we first estimate the main model by adding the confounding variables. Recall that the confounding variables are the first lag of the logarithm of total assets and its square, the capital and equity ratios in terms of total assets, bank concentration measured by the HHI index and diversification captured by the ratio of non-interest income and total assets, funding measured by the ratio of total deposits and liabilities, the logarithm of per-capita GDP and the consumer price index (CPI). In addition, we also add country of origin, banking business model and year fixed-effects. We can see that the coefficient of the interaction term remains negative for the lending outcome variables but is still statistically insignificant. This suggests that the CCoB requirements did not have any effect on lending, soundness and efficiency for banks operating in Luxembourg. Next, we present the results obtained for the O-SII capital buffers.

Table 1:

CCoB: Effects of macroprudential policies on bank lending, risk-taking and efficiency with confounding variables

	TOTAL LOANS	MORTGAGE	NON FIN. CORP.	HOUSE-HOLDS	BANKS	Z-SCORE	EFFICIENCY
Treat	-0.2237	-0.8660**	0.5252	0.7718***	0.0782	0.4013	-0.0109
	(0.1872)	(0.4327)	(1.1756)	(0.2860)	(0.0922)	(0.5235)	(0.0178)
Post	-1.5467	0.9748	-0.1985	-1.2030	-1.8049***	0.1657	0.0235
	(1.1423)	(2.1385)	(4.4414)	(2.5941)	(0.6371)	(0.6385)	(0.0309)
Treat×Post	-0.1484	0.0000	-0.8242	-0.4859	-0.0988	0.0799	0.0015
	(0.2027)	(0.0000)	(1.4512)	(0.3603)	(0.0935)	(0.2820)	(0.0098)
lag size	-0.7033**	1.6840	-2.7677*	-0.4435	-0.2947	0.1698	-0.0214
	(0.3352)	(1.1980)	(1.5993)	(0.7416)	(0.1967)	(0.6300)	(0.0442)
lag size^2	0.0217**	-0.0502	0.0800*	0.0152	0.0084	-0.0009	0.0006
	(0.0101)	(0.0355)	(0.0466)	(0.0223)	(0.0060)	(0.0196)	(0.0014)
lag capital ratio	0.0027	-0.4303	0.7513	-1.4156***	-0.1662	-0.2562	-0.0064
	(0.2802)	(0.2988)	(1.1903)	(0.5264)	(0.1181)	(0.2949)	(0.0145)
lag equity ratio	0.5214	-1.0447	-1.2059	2.1067	0.7388***	0.1443	0.0952**
	(0.4925)	(1.7067)	(1.6746)	(1.4396)	(0.2710)	(0.9143)	(0.0442)
lag HHI assets	0.5153**	0.1142	1.5547	0.5108	0.0518	-0.0638	-0.0264
	(0.2573)	(5.7543)	(1.0849)	(0.5416)	(0.2325)	(0.3018)	(0.0166)
lag diversification	0.3614	-1.7240	-8.7299	3.2360	0.3129	1.0019	-0.0848
	(1.4896)	(6.6991)	(10.9183)	(3.5191)	(1.0313)	(2.9790)	(0.0998)
lag funding	0.3136	-0.9263	-0.6050	0.5460	0.1824	-0.4476	0.0176
	(0.2701)	(1.5275)	(0.9830)	(0.6131)	(0.1468)	(0.6932)	(0.0314)
lag GDP	0.1466	-0.0440	0.2741	0.0211	-0.0087	0.0096	0.0041
	(0.1485)	(0.3793)	(0.7235)	(0.3975)	(0.0945)	(0.0590)	(0.0056)
lag CPI	0.1900	-0.0955	0.1931	0.1225	0.1311	-0.0275	-0.0011
	(0.1391)	(0.3147)	(0.6031)	(0.3543)	(0.0830)	(0.0480)	(0.0031)
Constant	-13.8736	-3.0219	2.7926	-10.3777	-10.7041	1.2630	1.0253**
	(14.1268)	(33.4120)	(67.0267)	(37.4278)	(8.7316)	(7.0887)	(0.4523)
Country of origin fixed-effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Bank business model fixed-effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed-effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number observations	657	200	374	465	643	676	676

*Source: BCL. Note that (***, ** and *) indicate significance at the 1 %, 5 % and 10 % levels, respectively. Bias-Corrected Bootstrapped Standard errors are in parenthesis. Source: Author's own estimations based on BCL data.*

Other Systematically Important Institutions (O-SII) Capital Buffers

This section focuses on the effects of O-SII buffers on bank lending, soundness and efficiency. The results are shown in Table 2 with confounding variables. The first column of Table 2 shows that when total lending growth is used as a dependent variable, the interaction term enters negatively and statistically significantly different from zero at the 5 percent level. In terms of the interpretation, this suggests that the O-SII capital requirements reduce total lending by 20 percentage points for banks subject to the buffer versus non-subject. However, the empirical results do not suggest any effect from the O-SII buffers on mortgage, non-financial corporation and bank lending. More importantly, the coefficient of the interaction term enters positively and significantly different from zero at the 10 percent level for bank soundness as captured by the z-score and efficiency. This suggests that the introduction of the O-SII capital requirements increased the soundness and efficiency of identified O-SII banks compared to non-OSIIs. In other words, O-SII capital requirements made banks more resilient to external shocks and more efficient. The mechanism through which O-SII capital requirements might affect bank efficiency is through credit intermediation, specifically they force banks to efficiently use and transform their inputs, namely deposits and labor in terms of outputs such as loans. Furthermore, in Column (1) of Table 2, which uses total loan growth as a dependent variable, one can notice the existence of an inverted U-shaped relationship between total lending growth and bank size, suggesting that larger banks in terms of assets offer more credit compared to smaller banks. Additionally, bank concentration increases lending since the coefficient associated with the lag of the Herfindahl-Hirschmann index enters positively and statistically different from zero at the 5 percent level.

Table 2:

O-SII Buffers: Effects of macroprudential policies on bank lending, risk-taking and efficiency with confounding variables

	TOTAL LOANS	MORTGAGE	NON FIN. CORP.	HOUSE-HOLDS	BANKS	Z-SCORE	EFFICIENCY
Treat×Post	-0.2038**	0.5361	-0.3089	-0.2786	0.2097	0.5976*	0.0110*
	(0.0952)	(0.5163)	(0.2798)	(0.3932)	(0.1360)	(0.3510)	(0.0061)
lag size	-0.6983**	2.1694*	-2.8099*	-0.5378	-0.2318	0.2580	-0.0168
	(0.3523)	(1.2654)	(1.5227)	(0.7684)	(0.2102)	(0.6435)	(0.0419)
lag size^2	0.0212**	-0.0651*	0.0815*	0.0185	0.0063	-0.0034	0.0005
	(0.0106)	(0.0372)	(0.0444)	(0.0232)	(0.0065)	(0.0198)	(0.0013)
lag capital ratio	-0.0270	-0.3587	0.7160	-1.4037***	-0.1716	-0.2609	-0.0068
	(0.2748)	(0.3025)	(1.3543)	(0.5426)	(0.1204)	(0.2857)	(0.0139)
lag equity ratio	0.5130	-1.5954	-1.1199	2.0520	0.6964***	0.1884	0.0937**
	(0.5460)	(1.7909)	(1.7406)	(1.4610)	(0.2683)	(0.9796)	(0.0460)
lag HHI assets	0.5216**	0.0532	1.6221*	0.3937	0.0532	-0.0771	-0.0261
	(0.2494)	(5.5586)	(0.9364)	(0.5024)	(0.2315)	(0.3177)	(0.0161)
lag diversification	0.2718	-0.7922	-7.5772	3.8154	0.2676	1.0366	-0.0856
	(1.5214)	(6.8821)	(10.9797)	(3.6803)	(0.9793)	(3.0761)	(0.0956)
lag funding	0.3346	-1.4078	-0.5127	0.4438	0.1381	-0.4866	0.0168
	(0.2823)	(1.5241)	(1.1267)	(0.5388)	(0.1445)	(0.7624)	(0.0316)
lag GDP	0.1458	-0.1228	0.2707	0.0165	-0.0068	0.0099	0.0042
	(0.1486)	(0.3339)	(0.7510)	(0.7165)	(0.1026)	(0.0621)	(0.0057)
lag CPI	0.1889	-0.1749	0.1876	0.1164	0.1301	-0.0301	-0.0010
	(0.1387)	(0.2843)	(0.6265)	(0.6515)	(0.0910)	(0.0479)	(0.0031)
Constant	-13.9359	0.8347	4.0538	-8.2738	-10.9686	1.1773	0.9824**
	(14.0281)	(29.0746)	(69.4595)	(67.4938)	(9.6068)	(7.4779)	(0.4488)
Country of origin fixed-effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Bank business model fixed-effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed-effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number observations	657	200	374	465	643	676	676

*Source: BCL. Note that (***, ** and *) indicate significance at the 1 %, 5 % and 10 % levels, respectively. Bias-Corrected Bootstrapped Standard errors are in parenthesis. Source: Author's own estimations based on BCL data.*

Robustness Checks

Bank branches and deposit insurance. In Luxembourg there are three types of banks divided as follows: (i) banks working under the Luxembourgish law for both domestic and foreign-bank subsidiaries; (ii) bank branches in Luxembourg but incorporated in other European Union (EU) countries, and (iii) bank branches in Luxembourg but incorporated in countries outside the EU. With this banking structure, it is important to adjust the findings for bank branches. Another reason for doing so is that Aiyar *et al.* (2014b) found that banks operating as branches or subsidiaries may behave differently when macroprudential policy is implemented. In fact, according to the European Systemic Risk Board (ESRB),[150] Luxembourg is one of the euro area countries where the market share of non-EU branches exceeds 1 percent. Moreover, it can be argued that if macroprudential policies are only applied to domestic banks, then foreign banks may increase their lending in host countries, and thus negate the reduction in credit from domestic banks. Furthermore, we also use the dummy variable deposit insurance as a confounding variable. This introduction is motivated by the findings of Diamond and Dybvig (1983) who argued that deposit insurance might prevent bank runs, and Cooper and Ross (2002) who found that deposit insurance alone is not sufficient to prevent bank runs; however, complementing it with capital requirements would help to efficiently prevent bank runs. Therefore, in Table 3, we adjust the findings for bank branching and deposit insurance. Again, the interaction term remains negative and significant at the 1 percent level when total loan growth rate is used as dependent variable. The magnitude of the DID coefficient, namely the interaction term, increased sharply for total lending growth. This suggests that the introduction of the O-SII buffers reduced total lending by 28 percentage points for O-SII banks compared to non-O-SIIs.

The role of mortgage banks. Because five banks account for around 90 percent of mortgage lending activity,[151] we adjust the main findings using a dummy variable that takes the value of 1 if a bank is part of these institutions and 0 otherwise. We then re-estimate the model and still find that the interaction term remains negative and statistically significantly different from zero at the 5 percent level, supporting the interpretation that the O-SII buffers decreased total lending for the banks concerned. In addition, we also show that the O-SII buffers increased bank soundness and efficiency.

150 Macroprudential policy implications of foreign branches relevant for financial stability (ESRB, December 2019).
151 See La Revue de Stabilité Financière (2019, 2020) (BCL).

Table 3:

O-SII Buffers: Effects of macroprudential policies on bank lending, risk-taking and efficiency with confounding variables bank branching and deposit insurance

	TOTAL LOANS	MORTGAGE	NON FIN. CORP.	HOUSE-HOLDS	BANKS	Z-SCORE	EFFICIENCY
Treat×Post	-0.2811***	0.5929	-0.3344	-0.2791	0.1894	0.5713*	0.0110*
	(0.1031)	(0.4393)	(0.3557)	(0.4203)	(0.1346)	(0.3441)	(0.0063)
Branch	-0.0208	0.6591	-0.6933	0.1158	0.0640	0.0008	0.0137
	(0.1121)	(0.8557)	(0.6056)	(0.4270)	(0.0865)	(0.3831)	(0.0206)
Deposit insurance	0.2837***	0.6209	-0.3939	0.2597	0.1204*	0.3353	0.0094
	(0.0873)	(0.7751)	(0.5443)	(0.1995)	(0.0657)	(0.3540)	(0.0127)
lag size	-0.8333**	2.5150**	-2.4852	-0.4957	-0.2768	0.2053	-0.0166
	(0.3364)	(1.0884)	(1.7105)	(0.8011)	(0.2128)	(0.6425)	(0.0417)
lag size^2	0.0251**	-0.0746**	0.0714	0.0172	0.0077	-0.0020	0.0005
	(0.0101)	(0.0320)	(0.0501)	(0.0240)	(0.0065)	(0.0197)	(0.0013)
lag capital ratio	-0.1083	-0.3732	0.7407	-1.4037**	-0.1951*	-0.2931	-0.0070
	(0.2524)	(0.3067)	(1.1737)	(0.5946)	(0.1179)	(0.2980)	(0.0143)
lag equity ratio	0.4654	-2.1396	-1.9189	1.8723	0.7305**	0.1204	0.0970**
	(0.5237)	(1.6708)	(2.0405)	(1.4362)	(0.2968)	(1.0243)	(0.0482)
lag HHI assets	0.6182**	0.0837	1.6132	0.4870	0.0809	-0.0487	-0.0263
	(0.2588)	(3.5568)	(1.0576)	(0.5671)	(0.2331)	(0.3074)	(0.0171)
lag diversification	0.2682	6.1148	-7.8810	4.2060	0.3027	1.1418	-0.0828
	(1.3789)	(7.1769)	(13.7145)	(3.8867)	(0.9708)	(3.0092)	(0.0930)
lag funding	0.4168	-1.1754	-0.9807	0.4568	0.1784	-0.4502	0.0179
	(0.2671)	(1.2599)	(1.2828)	(0.6316)	(0.1440)	(0.7509)	(0.0328)
lag GDP	0.1520	-0.1564	0.2604	0.0240	-0.0059	0.0145	0.0042
	(0.1418)	(0.2743)	(0.8500)	(0.4310)	(0.1000)	(0.0617)	(0.0056)
lag CPI	0.1908	-0.2101	0.1765	0.1203	0.1294	-0.0256	-0.0010
	(0.1340)	(0.2275)	(0.6855)	(0.3885)	(0.0883)	(0.0491)	(0.0031)
Constant	-13.1179	1.1030	3.0671	-9.0288	-10.5938	1.1185	0.9762**
	(13.5366)	(24.0119)	(74.8921)	(40.7952)	(9.2415)	(7.3353)	(0.4310)
Country of origin fixed-effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Bank business model fixed-effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed-effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number observations	657	200	374	465	643	676	676

*Source: BCL. Note that (***, ** and *) indicate significance at the 1 %, 5 % and 10 % levels, respectively. Bias-Corrected Bootstrapped Standard errors are in parenthesis. Source: Author's own estimations based on BCL data.*

Outward spillovers. Because Luxembourg is a financial center, it is important to investigate the role of outward spillovers in lending. Put simply, several foreign banks operate in the country and it shares borders with the first and second largest economies in the euro area, namely Germany and France. Consequently, it is worth assessing if banks located in Luxembourg would increase cross-border lending with the implementation of macroprudential policies. According to the ESRB report published in December 2019, the differences in the financial structures of home and host countries create additional considerations for authorities working on the adoption and activation of macroprudential measures. The literature on macroprudential policies has found evidence of spillover effects in lending. For instance, Buch and Goldberg (2017) define two possible types of policy spillovers: inward spillovers or leakages, which suggest that domestic macroprudential measures can give rise to policy "leakages" if bank activities migrate to areas/entities not subject to the measures such as foreign banks or non-bank financial institutions. Inward spillovers may render domestic macroprudential policy less effective.

The second type is called outward spillovers, suggesting that domestic macroprudential measures can induce externalities on other countries through adjustments in the lending behavior of domestic banks to foreign borrowers. For example, following a tightening of macroprudential policies at home, domestic banks may respond by increasing/decreasing their lending abroad via subsidiaries or through direct cross-border lending. On outward spillovers of macroprudential policy actions, findings in the academic literature are mixed regarding the impact on cross-border lending (Aiyar *et al.* (2014b), Ongena *et al.* (2013), Franch *et al.* (2020) and the literature within). Importantly, the potential for cross-border spillovers may be greater in national banking sectors with a strong presence of foreign banks according to the ESRB, which is the case of Luxembourg. In particular, foreign branches can contribute to macroprudential leakages, as they are typically not subject to measures targeting the domestic banking sector and are not under the direct supervision of the domestic authorities.

The results in table 4 account for these potential outward spillovers. We use the growth rates of total, mortgage, non-financial corporation, households and bank loans in the euro area (EA) as dependent variables. The findings do not indicate any outward spillover effects in lending as none of the coefficients is statistically significant, in line with Danisewicz *et al.* (2017).

Table 4:

Outward spillovers (O-SII Buffers): Macroprudential policies and lending

	TOTAL LOANS EA	MORTGAGE EA	NON FIN. CORP. EA	HOUSE-HOLDS EA	BANKS EA	Z-SCORE	EFFICIENCY
Treat×Post	0.2831	0.4425	0.2926	-0.1113	0.2823	0.5713*	0.0110*
	(0.2022)	(0.4587)	(0.2401)	(0.1308)	(0.2146)	(0.3441)	(0.0063)
lag size	-0.4469	-0.3871	-0.6614	0.3922	-0.0767	0.0008	0.0137
	(0.4662)	(1.1391)	(0.9778)	(0.7361)	(0.5351)	(0.3831)	(0.0206)
lag size^2	0.0127	0.0116	0.0162	-0.0095	0.0019	0.3353	0.0094
	(0.0138)	(0.0339)	(0.0286)	(0.0217)	(0.0161)	(0.3540)	(0.0127)
lag capital ratio	-0.2686	0.8048	-0.2652	-1.0453**	0.0407	0.2053	-0.0166
	(0.1680)	(0.9296)	(0.5078)	(0.5026)	(0.2734)	(0.6425)	(0.0417)
lag equity ratio	0.7430	-0.4757	-0.6544	1.2097	0.7657	-0.0020	0.0005
	(0.5078)	(2.2107)	(1.3207)	(1.9007)	(0.7548)	(0.0197)	(0.0013)
lag HHI assets	0.1001	1.1268	0.1025	0.4016	0.3376	-0.2931	-0.0070
	(0.2397)	(2.9859)	(0.3634)	(0.4605)	(0.4652)	(0.2980)	(0.0143)
lag diversification	0.0297	-8.5004	-10.7077	4.7496	1.2645	0.1204	0.0970**
	(1.7882)	(8.3608)	(7.0739)	(3.5787)	(1.8104)	(1.0243)	(0.0482)
lag funding	-0.1942	-0.0923	-0.1916	-0.3654	-0.1435	-0.0487	-0.0263
	(0.3459)	(1.1401)	(0.6883)	(0.8797)	(0.4433)	(0.3074)	(0.0171)
lag GDP	0.0577	-1.2900**	-0.1262	0.1608	-0.0055	1.1418	-0.0828
	(0.1175)	(0.5012)	(0.3949)	(0.2670)	(0.0372)	(3.0092)	(0.0930)
lag CPI	0.1438	-1.1345**	-0.1943	0.2025	0.0946	-0.4502	0.0179
	(0.1171)	(0.4584)	(0.3976)	(0.2436)	(0.0931)	(0.7509)	(0.0328)
Constant	-10.8453	120.6293**	26.6238	-24.4280	-8.8302	1.1185	0.9762**
	(10.3999)	(47.3009)	(41.3624)	(26.2227)	(10.1117)	(7.3353)	(0.4310)
Country of origin fixed-effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Bank business model fixed-effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed-effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of observations	641	190	363	469	602	676	676

*Source: BCL. Note that (***, ** and *) indicate significance at the 1 %, 5 % and 10 % levels, respectively. Bias-Corrected Bootstrapped Standard errors are in parenthesis. Source: Author's own estimations based on BCL data.*

Further robustness tests.[152] In this section, we further investigate the robustness of the findings to selection bias issues for O-SII capital buffers using a resampling approach and the propensity score matching. According to Mayer (1995) the DID approach can be reinforced by the use of additional comparison groups. Since we have data on banks that are no longer operating in Luxembourg, we use these banks as a treatment group. In other words, we assume that these banks are affected by O-SII buffers and re-estimate the model. If our findings are not subject to selection bias we should find a statistically insignificant coefficient for the interaction term. However, if this is not the case then the estimates of the differences in outcomes between banks cannot be explained solely by the introduction of O-SII capital buffers. As expected, the coefficient of the interaction term enters insignificantly in all columns, providing more support for the non-selection bias issue. Finally, we perform a second robustness test by randomly constructing the treatment group within banks. Again, the coefficient of the interaction terms remains insignificant in all specifications. The findings of these two exercises support our main results as they account for potential concerns with respect to the identification strategy and selection bias issues.

Propensity score matching (PSM). We also use the propensity score matching in order to deal with the selection bias. This technique matches O-SII banks in relation to capital buffers with non-O-SIIs that may have similar probability to be treated. Concretely, we match banks in the treatment groups with banks in the control groups based on nearest neighbour matching with respect to several bank characteristics such as the logarithm of total assets, capital and equity ratios, concentration proxied by the HHI and income diversification based on the nearest neighbour matching estimator. We use two matches for the estimator since Abadie and Imbens (2011) and Gropp *et al.* (2019) found that this estimator provides a very good trade-off between bias and variance of the nearest neighbour matching estimator. The introduction of several covariates in the matching procedure is motivated by the fact that Heckman *et al.* (1997), Caliendo and Kopeinig (2008) among others showed that the omission of important covariates can increase the bias in the estimates. The results indicate that O-SII capital buffers decreased total loan growth but the coefficient of the interaction term entered insignificantly. However, we find that O-SII buffers boosted bank soundness and efficiency as the coefficient of the interaction term remains positive and statistically significantly different from zero at the 1 percent level.

Lastly, we test the robustness of the main findings by dropping a bank that recently acquired a branch status. However, before becoming a branch in 2017 that bank was identified as an O-SII financial institution in 2015 and 2016. Furthermore, the ESRB states that the systemic importance of foreign branches and subsidiaries is not taken into account when setting the consolidated O-SII buffer of the banking group. In particular, according to the EBA Guidelines on criteria for the assessment of O-SIIs, the consolidated position of the entire group is assessed in relation to the home banking system and without taking into account the systemic importance of the group in host member states. Therefore, it is generally possible that a smaller banking group established in a large economy would be of a little systemic importance, or would not be identified as an O-SII at all, but would have a dominant and highly systemic presence in other smaller economies. To avoid these shortcomings we re-estimate the model without this institution, finding that the sign and significance of the interaction term remain unaltered and the effects become a little bit stronger as the magnitude of the coefficient increased moderately.

CONCLUSION

This research studied the effectiveness of macroprudential policies in Luxembourg. Moreover, it used the timing of the introduction of the capital conservation and O-SII capital buffers and variation across

152 The results of these additional robustness tests can be seen in the long version of the Working Paper.

banks to investigate their effects on bank lending, risk-taking, efficiency and employment using an unbalanced panel of 141 banks over the period 2011-2018. Using the difference-in-differences (DID) methodology, the following findings emerge. The O-SII capital buffers decreased total lending and boosted bank soundness and efficiency. However, we did not find any such effects for the CCoB requirements. These findings remain robust when adjusting for bank branches and the presence of deposit insurance, the use of several resampling tests and the propensity score matching for the selection bias. In addition, we showed that the macroprudential instruments used in this study did not generate outward spillovers for banks operating in the country.

The results obtained in this research have relevant implications for Luxembourg. They suggest that macroprudential policies, in particular the O-SII capital requirements, have an effect on total lending, bank soundness and efficiency. However, this decrease in total lending might generate certain costs for the real economy. Such costs have to be weighed against the measures' ability to mitigate the adverse impact of future crises.

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