Canadian Journal of Regional Science
Revue canadienne des sciences régionales

Landslide Hazards, Public Intervention and Property Values – The Case of Saguenay, Quebec, Canada

François Des Rosiers and Bienvenu Tossou

Volume 47, Number 2, 2024

Canada's Economic Geography

URI: https://id.erudit.org/iderudit/1115222ar
DOI: https://doi.org/10.7202/1115222ar

See table of contents

Publisher(s)

Canadian Regional Science Association / Association canadienne des sciences régionales

ISSN

0705-4580 (print)
1925-2218 (digital)

Explore this journal

Cite this article

Des Rosiers, F. & Tossou, B. (2024). Landslide Hazards, Public Intervention and Property Values – The Case of Saguenay, Quebec, Canada. *Canadian Journal of Regional Science / Revue canadienne des sciences régionales*, *47*(2), 39–49. https://doi.org/10.7202/1115222ar

Article abstract

Since the beginning of the 21st century, over 100 major landslides have been reported worldwide, which resulted in both human casualties and massive damages to property. While the academic and technical literature on landslide hazard risk assessment is quite abundant, relatively few studies address the issue of the impact of landslide exposure on property values. In this research, we look at the impact that public intervention aimed at compensating homeowners affected by landslide hazard constraint zones had on residential values in La Baie, an *arrondissement* of the City of Saguenay (formerly Chicoutimi), in the province of Quebec, Canada. The area was most affected by the Saguenay flood that hit the region on July 19 and 20, 1996 and which was followed by a series of landslides. A difference-in-differences (DiD) spatial hedonic price model is estimated using a representative sample of 813 single-family sales transacted in La Baie between 2009 and 2016. Findings suggest that, *caeteris paribus*, and nearly two decades after the 1996 events, the compensation scheme implemented at the local level in December 2012 did not manage to completely offset the disadvantages of building constraints on high-risk sites induced by the new regulations and translated into a statistically significant price discount of 3.4% for affected properties as opposed to unaffected ones. They also suggest that a panoramic view on the Saguenay fjord adds some 8.6% to a property's value.

CANADIAN JOURNAL
OF **REGIONAL SCIENCE**

REVUE **CANADIENNE** DES
SCIENCES RÉGIONALES

CRSA ACSR
CANADIAN REGIONAL SCIENCE ASSOCIATION
ASSOCIATION CANADIENNE DE SCIENCE RÉGIONALE

LANDSLIDE HAZARDS, PUBLIC INTERVENTION AND PROPERTY VALUES – THE CASE OF SAGUENAY, QUEBEC, CANADA

François Des Rosiers, Bienvenu Tossou

François Des Rosiers
Laval University, Pavillon Palasis-Prince, Québec, QC, G1K 7P4
1 418 656-2131, poste 5012
Francois.Desrosiers@fsa.ulaval.ca

Bienvenu Tossou
The Altus Group, Data Solutions, Valuation & Advisory,
1265 Charest Boulevard West, Suite 1200, Québec, QC, G1N 2C9

Reçu : 2023-06-09
Accepté : 2024-09-02

Abstract: Since the beginning of the 21st century, over 100 major landslides have been reported worldwide, which resulted in both human casualties and massive damages to property. While the academic and technical literature on landslide hazard risk assessment is quite abundant, relatively few studies address the issue of the impact of landslide exposure on property values. In this research, we look at the impact that public intervention aimed at compensating homeowners affected by landslide hazard constraint zones had on residential values in La Baie, an *arrondissement* of the City of Saguenay (formerly Chicoutimi), in the province of Quebec, Canada. The area was most affected by the Saguenay flood that hit the region on July 19 and 20, 1996 and which was followed by a series of landslides. A difference-in-differences (DiD) spatial hedonic price model is estimated using a representative sample of 813 single-family sales transacted in La Baie between 2009 and 2016. Findings suggest that, *caeteris paribus*, and nearly two decades after the 1996 events, the compensation scheme implemented at the local level in December 2012 did not manage to completely offset the disadvantages of building constraints on high-risk sites induced by the new regulations and translated into a statistically significant price discount of 3.4% for affected properties as opposed to unaffected ones. They also suggest that a panoramic view on the Saguenay fjord adds some 8.6% to a property's value.

Résumé: Depuis le début du 21e siècle, on rapporte plus de 100 glissements de terrains d'importance dans le monde, dont certains ont causé des centaines, voire des milliers de pertes de vies humaines ainsi que des dommages matériels considérables. S'il existe une abondante littérature académique et technique sur l'évaluation des risques de glissements de terrain, on retrouve par contre peu d'études portant sur l'impact du risque d'exposition aux glissements de terrain sur la valeur des propriétés. Dans cette recherche, nous nous penchons sur l'impact qu'a exercé le programme municipal de compensation pour les propriétaires affectés par l'instauration de zones de contrainte relatives aux risques de glissements de terrain sur les valeurs résidentielles à La Baie, un arrondissement de la Ville de Saguenay (antérieurement Chicoutimi), située au Québec, Canada. Ce territoire a été particulièrement affecté par le déluge du Saguenay qui a frappé la région les 19 et 20 juillet 1996 et s'est soldée par une série de glissements de terrains. La démarche consiste à appliquer la méthode des doubles différences (DiD) intégrée à un modèle spatial de prix hédoniques à un échantillon de 813 propriétés unifamiliales ayant fait l'objet d'une transaction à La Baie entre 2009 et 2016. Les résultats suggèrent que, toutes choses égales par ailleurs, et près de deux décennies après les événements de 1996, le programme municipal de compensation des propriétaires les plus affectés mis en place par la municipalité en décembre 2012 n'a pas permis de totalement pallier les inconvénients découlant des contraintes de construction sur les sites à haut risque et s'est traduit par une diminution significative des prix de 3,4 % pour les propriétés affectées relativement aux propriétés non affectées. Les résultats suggèrent également qu'une vue panoramique sur le fjord du Saguenay se traduit par une prime de marché de l'ordre de 8,6 %.

Keywords: Hedonics, landslide hazard, property prices, zoning regulations.

JEL Classification Code: C21, R32, R38

INTRODUCTION

Numerous landslides occur each year around the world. Often resulting from earthquake, volcano eruptions or flooding events, they may cause major human casualties as well as economic and environmental disruptions that lead to both private and public costs. From 2001 to 2018, some 107 major landslides have been reported worldwide[1], with some causing hundreds, or even thousands, of human casualties[2] as well as massive damages to property. While the academic and technical literature on landslide hazard assessment and on the ensuing risk for populations and the environment is quite abundant, relatively few studies address the issue of the impact of landslide exposure on property values. This research looks at the impact that public intervention directed at compensating homeowners located in severe landslide hazard areas and affected by new land use constraints had on residential values in La Baie, an *arrondissement* of the now amalgamated City of Saguenay (formerly Chicoutimi)[3], Quebec, Canada. La Baie, which overlooks the Saguenay River – the only navigable fjord in North America – was one of the neighborhoods most affected by the Saguenay flood, the biggest overland flood in 20th-century Canadian history that hit the region on July 19 and 20, 1996. The torrential rainfalls of July 1996 resulted in more than 1,000 landslides that caused severe property damage as well as human casualties. The total estimated cost of the disaster, which claimed two lives in La Baie alone, and destroyed several hundred homes as well as many bridges, exceeded one billion Canadian dollars[4]. As damage resulting from landslides, earthquakes and other earth movements is not covered under home insurance policies and that no coverage is currently available in Canada for such a risk, public initiatives focused on prevention are all the more important for homeowners.

Following that natural disaster, local and provincial authorities worked together to improve resident security. Thus, as soon as 1997, the Quebec Ministry of Public Security (MSPQ) had designed preliminary constraint zones for most of the municipal territory and issued landslide hazard maps that were regularly updated and gradually made public from 2004 onwards, with local authorities making sure that the information on landslide exposure was widely accessible to residents. On the other hand, local authorities issued more stringent land-use regulations for zones potentially exposed to landslides and labelled according to their type and degree of hazard[5]. Such regulations resulted in constraints on extensions to buildings, installation of cut and fill areas and a construction ban on vacant land located in priority constraint zones. Where the new regulations translated into land losses for homeowners, the latter received a compensation under a December 2012 municipal bylaw. Other local measures were implemented which include a slope monitoring system, financial aid for conducting a geotechnical opinion as well as a slope stabilization program.

In light of all these events, the question then arises as to whether, and to what extent, known exposure to landslide risk has affected the La Baie housing market, which includes some 8,100 housing units, 95% of which (roughly 7,700) are principal residences. Limitations to the full use and enjoyment of the premises or being denied a mortgage loan are factors that could affect homebuyers' perceptions and decisions, hence market values. On the other hand, the local compensation scheme directed at affected homeowners might have alleviated such disadvantages. Thus, the objective of this paper is to test whether the municipal compensation scheme set up in December 2012 has impacted, either positively or negatively, the price of properties located in a high-risk area, once structural, neighborhood, environmental and temporal characteristics are controlled for. In other words, this research can be seen as an *a posteriori* investigation about whether the local real estate market still internalizes in house prices the trauma of a major natural disaster that occurred more than a decade earlier and despite public initiatives designed at alleviating its financial consequences.

The rest of the paper is structured as follows: Section 2 provides a summary review of the literature on recent research pertaining to floods and landslides over the past two decades. The database is described in Section 3 while Section 4 presents the analytical approach used. Research findings and discussion are the object of Section 5. A conclusion (Section 6) ends the paper.

LITERATURE REVIEW

Most of the academic literature on natural disasters deals with floods, wind and tornadoes, earthquakes, and landslides. While the price impacts of landslides are the focus of this study, the latter have a tight relationship with flooding (Promper et al 2015; HEIS 2015; Pereira et al 2016; Salvati *et al* 2018), which makes it relevant here to consider both phenomena.

Price impacts of floods

The literature on the impact of floods on residential property values is quite abundant and can be traced back to Zimmerman (1979) in the late 1970s. This review is not exhaustive and focuses post-2000 studies only. Most studies rest on the classic hedonic price method (HPM), or some adaptation of it (*e.g.* spatial model, difference-in-differences (DiD) procedure, quantile regression, etc.), and target cases in the United-States, Australia, England and Canada.

Starting with Harrison et al (2001), the authors examine the value of homes located within 100-year flood plains in Alachua County, Florida, based on some 30,000 sales over the 1980-1997 period. Their model identifies whether sales are located within Special Flood Hazard Areas (SFHA) while adjusting for those that took place after the implementation of the National Flood Insurance Reform Act of 1994, which followed the devastating flooding events of the 1993 summer. Findings suggest that comparable homes located within a flood zone would sell, on average, for less than homes located outside flood zones, with price discounts being less than the present value of future flood insurance premiums. They also show that post-1994 discounts are more than twice as important as pre-1994 ones, which is attributed to more stringent participation requirements under the new national insurance program.

Bin and Polasky (2014) investigate the effects of flood hazards on residential property values in Pitt County, North Carolina, following Hurricane Floyd in September 1999. Here, the HPM is applied to 8,000 single-family sales over the 1992-2002 period. Their findings indicate that while houses located within a floodplain sell, on average, at a 3.8% discount compared with those located outside the floodplain, the discount reaches some 8.3% for post-Floyd sales, which suggests that recent flooding events tend to increase homeowners' perception of associated risk.

1 World Landslide Timeline, 2018, http://www.mapreport.com/subtopics/d/-.html

2 On June 16, 2013, the landslide that occured in Kedarnath, Uttarakhand, in North India, as a result of floods, killed 5,700 people. In Quebec, the death toll resulting from the major landslide that struck the little municipality of Saint-Jean-Vianney on May 4th, 1971, amounted to 31, with nearly half of the 70 houses of the village being engulfed in a stream of mud.

3 Located roughly 200 kilometers north of Quebec City, the City of Saguenay was amalgamated in 2001 and includes three *arrondissements*, Chicoutimi, Jonquière and La Baie, which were previously autonomous municipalities. It extends over 1,280 km^2, of which 132 km^2 is urban territory. With nearly 147,000 inhabitants, Saguenay ranks eight among cities in the Province.

4 More recently, in June 2022, two minor landslides occurred in Saguenay, a first one in La Baie (June 13) followed by a second one in Chicoutimi (June 24), forcing the evacuation of more than 200 residents.

5 According to the MSPQ classification system, constraint zones are labelled NA1, RA1, NA2, NS1, NS2, and NH, with the first term referring to the type of landslide, *i.e.* retrogressive (R) vs. non-retrogressive (N), the second one to the prevailing soil composition, *i.e.* clay (A), sand (S) or heterogeneous (H), and the third one to the degree of hazard (1 for higher, 2 for lower).

Atreya and Ferreira (2015) estimate the changes in implicit flood risk premium following the 1994 Great Flood in the city of Albany, Southwest Georgia, USA, based on 2,685 single-family houses sold between 1985 and 2007 in the Flint River area. The authors compare the price discount for properties in the actually inundated area to that for properties in the 100-year floodplain – based on Federal Emergency Management Agency (FEMA) maps but outside the inundated area. Their findings suggest that the price discount for properties in the inundated area is substantially larger (42%) than for comparable floodplain, non-inundated properties (34%), but that such a discount only applies after the flooding. They also suggest that in the absence of additional flooding, the price differential between floodplain and non-floodplain properties tends to decrease and vanish over time.

Atreya and Czajkowski (2016) assess the impacts of flood risks and water-related amenities in Galveston County, Texas. They interact distance to the nearest coastline with flood risk while using a more granular flood risk measure compared to the existing literature. Results indicate that the hedonic price effect is dependent upon the distance to the nearest coastline while being subject to the flood risk type. In line with Hansen & Benson (2013), the authors find that coastal properties located in the highest flood risk area still command a price premium for up to nearly a quarter mile from the nearest coastline due to view.

Zhang (2016) investigates whether being located within a 100-year floodplain has an impact on the sale price of single-family houses in the Fargo-Moorhead SMSA, North-Dakota/Minnesota, USA. The author applies a spatial quantile regression approach to some 28,000 sales over the 2000-2013 period, thereby allowing for flood hazard effect estimates by price range while controlling for spatial autocorrelation. Her model namely includes interactive terms meant to capture a potential decay effect of the flood risk after a major flood in 2009. Findings confirm that being located within a floodplain reduces property values – here, by some 5.9% overall – but that the detrimental impact is more pronounced for low-priced properties than for medium and higher-priced ones. Moreover, while both the discount magnitudes and their discrepancies among market segments substantially increase following a major flood, the hazard effect tends to rapidly fade away over time, with post-2010 discounts emerging as statistically non-significant.

Akbar et al (2015) analyze flood impacts through a case study of Rockhampton, a regional city within the Central Queensland region, Australia. The city was severely affected by flooding in January 2011 and isolated from the state's capital, Brisbane, for more than a week. The authors perform a longitudinal analysis of quarterly median property sales prices pertaining to total house sales, new house sales, and land-only sales from 2000 through 2014. They find that whereas the 2011 flood has affected the number of total house sales downwards, it has not significantly affected new house sales nor land-only sales as the negative flood impact had been relatively offset by the positive impact of the local mining boom Rockhampton was undergoing at the time.

Bélanger and Boudreau-Brien (2018) examine the impact of flood risk on the value of some 608,000 residential properties throughout England, spread across 5,581 neighborhoods and sold between January 1995 and January 2016. More precisely, the authors consider (i) major flood episodes that should increase risk awareness, (ii) the introduction of detailed flood maps that are expected to exert a long-lasting effect on flood risk appreciation and (iii) the 2005 renewal of a statement of principles between insurance companies and the government favoring more risk-based flood insurance premiums. The study also investigates whether the flood risk discount still applies in low flood awareness periods and whether it is affected by the housing market cycle. The model accounts for proximity to the seacoast and to a lake, for recently inundated areas as well as for the elevation of the property relative to the nearest waterbody. Model results suggest that, while water proximity and a waterfront location do, by and large, affect prices positively, properties located within a floodplain sell, on average, at a 1.5% discount, with floodplain properties that are also waterfront properties experiencing the largest discount. The authors also show that the effect of flood risk is predominantly associated with the post-2005 period, that is, once detailed flood maps were made available (2004) and following the above-mentioned statement of principles on risk-based insurance policies (2005). Overall, the flood risk discount is found to lessen in hot markets, as sellers' bargaining power is stronger, whereas it is strengthened in the months following a major flood event.

In another study, Bélanger et al (2018) investigate the level of flood-related price discounts for residential properties located mainly along the Saint Lawrence River, in the province of Quebec, Canada. Their transaction-based model rests on roughly 47,000 houses sold between January 2006 and August 2018. In addition to detailed housing structural attributes, a series of accessibility, environmental and socio-economic characteristics are used as control variables in the models, together with municipality and year fixed effects. As for flood-related variables, several specifications are tested that account for flood risk, distance to flood plain, the interaction between distance to water and altitude and whether high risk properties have a finished basement. Findings from the base model suggest that properties located inside or very close (250 m. or less) to a floodplain suffer a 4.1% price discount. Additional model specifications also yield interesting results: high-risk properties with a finished basement sell at a 6.6% discount whereas properties located below water level and within 100 m of water experience a price drop of 4.9%. Finally, the discount is no more significant for houses located beyond the 250 m threshold.

Finally, Beltrán et al (2018) conduct a meta-analysis of 37 published articles on flood risk capitalization performed between 1987 and 2013 in the United-States, Australia, New-Zealand and the Netherlands with 364-point estimates which brings out the great variability of findings, depending on when and where these studies were conducted, as well as the publication bias which affects the flooding literature. For instance, the high prices obtained for properties located in the floodplain of coastal regions may be due to the strong correlation between flood risk and omitted coastal amenities. Results from the meta-regression suggest that controlling for the time elapsed since the most recent flood is of paramount importance. The price discount for inland properties located in a 100-year floodplain is estimated at 4.6%.

To summarize, the literature on flood risk, although only indirectly related to landslide hazards, yields interesting findings that may help explain the impact the latter exerts on house prices. First, almost all articles selected in our literature review on floods report market discounts for properties located in floodplains which vary from 3,8% to 42% and depend on an array of factors such as whether properties have actually been inundated or not, altitude as well as the presence of a finished basement. Distance to the water – *e.g.* waterfront properties – and the flood risk level also heavily affect price discounts, with low-price properties displaying much higher market discounts than mid or high-price ones. Second, discounts are substantially higher for properties sold following a major flood event than for those sold prior to it, which suggests a higher risk perception by the market in the former case. Third, the time elapsed since the most recent event is of paramount importance for the estimation of price discounts since the risk perception tends to fade away quite rapidly. Fourth, a local economic boom or a hot real estate market will lessen flood risk discounts and may even offset them. Fifth, public intervention meant at setting up more stringent flood insurance coverage and risk-based premiums or at publicizing detailed flood risk areas tends to increase risk perception, hence also price discounts. Finally, coastline properties located in high-risk areas while benefitting from a nice view may still command a price premium.

Price impacts of landslides

In contrast to the literature on flooding events, most academic research on landslides deals with assessing occurrence risk and focuses on geomorphological patterns which favor such events or address urban planning, land-use, agricultural practices or socio-economic issues that cause, or result from, landslide episodes. For instance, Demers et al (2014) provide a detailed inventory of large landslides in sensitive clay soil zones in the province of Quebec: between 1840 and 2012, 108 such cases are recorded, mainly concentrated along the shores of the Saint Lawrence River and in the Saguenay-Lac-Saint-Jean region. Quite surprisingly though, there are few studies of the impact such events have on property prices. Hence the relevance and contribution of this paper which fills an important gap in the literature on landslides.

Beyond the province of Quebec, there are a number of studies that offer insights on the price impacts of landslides. Jaiswal et al (2011) introduce a quantitative procedure for estimating landslide risk to life and property and apply it to a mountainous area in the Nilgiri hills of southern India based on an inventory of 1,084 landslides that took place between 1987 and 2009. Direct specific risk is estimated individually for tea/coffee and horticulture plantations, transport infrastructures, buildings and people, both in initiation and run-out areas. Findings indicate that, with regard to damage to properties, the total average expected loss for the study area over 5- and 50-year return periods stands at US$ 341,000 and US$ 851,000, respectively, and may reach US$ 1.7 million in the latter case.

Mertens et al (2015) estimate the direct impact of landslides on household income and investigates the presence of specific risk sharing and mitigation strategies towards landslides in the Rwenzori Mountains in Western Uganda. Ordinary least squares regressions and probit estimations with village fixed effects are performed on a cross-sectional household survey used in combination with geographical data. Their findings indicate the agricultural income of affected households is significantly and substantially reduced during the first years after a landslide has occurred.

Gerui et al (2017) investigate the relationship between land urbanization and landslides using panel data for 28 provinces and municipalities in China from 2003 to 2014. Their results suggest that, at the national level, landslides are negatively related to the percentage of built-up area and positively related to road density while the effect of landslide prevention funding is not obvious.

Persichillo et al (2017) and Pisano et al (2017) look at the influence of land-use changes on landslide susceptibility over time in the Apennines region, Italy, where numerous landslide phenomena occurred between the 1950s and 2014. The former apply a multi-temporal land-use change analysis while the latter use the Spatial Multi-Criteria Evaluation method. Both studies conclude that pronounced land abandonment as well as poor agricultural maintenance practices are the main predisposing factor to shallow landslides.

Pereira et al (2016) apply landslide quantitative risk analysis (QRA) to the municipality of Santa Marta de Penaguiao, in northern Portugal, to evaluate the risk at which buildings are exposed, using a vector data model in GIS. The study rests on a very detailed survey of building characteristics, which makes it possible to assess the economic value (EV) of buildings as well as their physical vulnerability (PV). Landslide risk, in terms of potential damage to the structures, is then derived from combining EV and PV with landslide hazard information (landslide susceptibility of site, landslide magnitude, and rainfall-triggering scenarios). Findings suggest that, while small landslides generate a much lower potential loss for buildings than large ones, the total risk associated with the former is 26 times higher than that associated with the latter due to the much higher probability of occurrence of small landslides.

Vranken et al (2013) perform an economic assessment of the direct and indirect damage caused by landslides in a 2,910 km^2 study area located west of Brussels, Belgium, a low-relief region susceptible to landslides. Their research is based on both structured and semi-structured interviews with homeowners, civil servants and the owners and providers of electricity and sewage infrastructures. Findings suggest that urbanized land, which accounts for only 2.3% of the study area, is responsible for most of the economic damage due to landslides, with direct and indirect yearly costs to residential properties amounting to roughly 551,000 € and 2,000,000 €, respectively.

Kauko (2012) proposes a critical literature review together with expert interviews on hazard management mechanisms, housing design and land-use issues in relation to quick clay landslide hazard areas in contemporary Trondheim, Norway. Analytical approaches include the HPM, contingent valuation as well as the AHP (analytical hierarchy process) methodology. The literature based on HPM suggests that consumer preferences for water locations bring an attractiveness premium of approximately 10% for coastal locations but less so for rivers, canals or lakes. Contingent valuation and AHP-based studies also point toward a 10% premium for water related attractiveness, although the effect is negative where landslide costs exceed benefits.

Finally, Kim et al (2017) explore the case of the Woomyeon Nature Park (WNP) in Seoul, Korea, which experienced a catastrophic landslide disaster in 2011. The hazard and amenity effects of the WNP before and after a landslide event are analyzed using a difference-in-difference (DiD) approach with a random coefficient model. Findings indicate that while the amenity effect of the WNP remains even after the landslide disaster, market premiums for nearby apartment complexes have dropped by as much as 11.3% following the event due to the risk of landslide.

While the literature on estimating the price impact of landslide hazards using modelling methods remains more than scarce, the few studies reported above do confirm some of the findings derived from the literature on flood risk. Thus, properties located in attractive settings that offer nature views, such as coastline locations, may experience a severe drop in market premiums following a major landslide event (Kim et al, 2017), with premiums turning into discounts where landslide costs exceed benefits (Kauko, 2012). According to Jaiswal et al (2011), the detrimental impact landslides have on households' agricultural income may last for a few years following the event, which corroborates the assumption that risk perception vanishes quite quickly over time.

THE DATABASE

La Baie extends over 262 km^2, which represents slightly more than 20% of the territory of the City of Saguenay. Its urbanized area though is highly concentrated and overhangs the west end of the Baie des Ha! Ha!, a cove of the Saguenay River that extends 11 km inland. As of 2016, La Baie's population stood at roughly 18,500 while the housing stock – excluding secondary homes and mobile homes – amounted to some 7,700 units[6], the majority of which consist of single-family houses. The database used for this study combines several information sources:

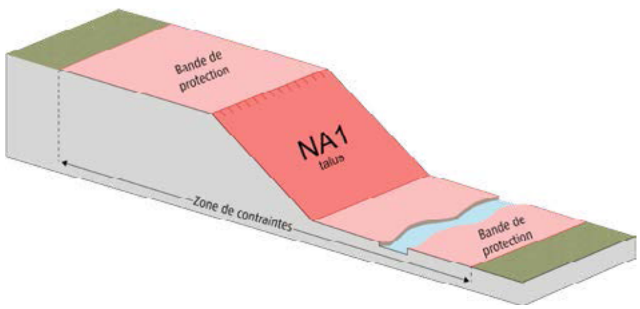
6 Source: City of Saguenay valuation roll.

- detailed information on a representative sample of 1,078 single-family sales transacted in La Baie between 2009 (Q1) and 2016 (Q4) provided by the City of Saguenay and including all relevant information on sale prices, property location and housing attributes.
- landslide constraint zones digital maps;
- the 2016 valuation roll data with detailed property files;
- the graphic matrix for the study area;
- sales files for the 40 homes whose lot is totally included in NA1-type constraint zones including, where available, the broker's notifications, the seller's declaration, the certificate of location and the full sale contract.

Unsurprisingly, and considering the homogeneity of the housing stock in La Baie, the initial sample proves highly representative of the local market, particularly with respect to constrained lots. Indeed, out of the 1,078 sampled sales, 392 (36.4%) are located on land subject to various degrees of landslide hazard and therefore affected by building constraints over the protection band at either the top or the bottom of the slope, or both. For the whole population of single-family houses in La Baie, the proportion stands at 39%. The remaining sampled properties (686, or 63.6%) are unaffected by land-use constraints. Constraint zones are termed, by order of priority, as NA1, RA1 (summit & base), NH, NS1, NA2 (summit), NS2 (base), NA2 (base) and NS2 (summit). The vast majority (364 cases or 92%) of houses potentially affected by landslides are in *NA1* zones, which are the focus of this study. NA1 zones are predominantly composed of clay and are likely to be affected by landslides of natural or anthropic origins. *Figure 1* provides an illustration of a NA1 constraint zone while *Table 1* reports the distribution of sampled sales by type of constraint zone.

Finally, none of the properties under analysis is located within flood zones, which rules out the possibility of any bias in the assessment of landslide impacts on prices. A cartographic distribution of potential landslide hazard zones subject to building constraints in the La Baie area is provided in *Figure 2*, with slopes being indicated in red while slope tops or bottoms are in pink.

Figure 1. NA1 Constraint Zone With Slope and Protection Bands at Summit and Base*

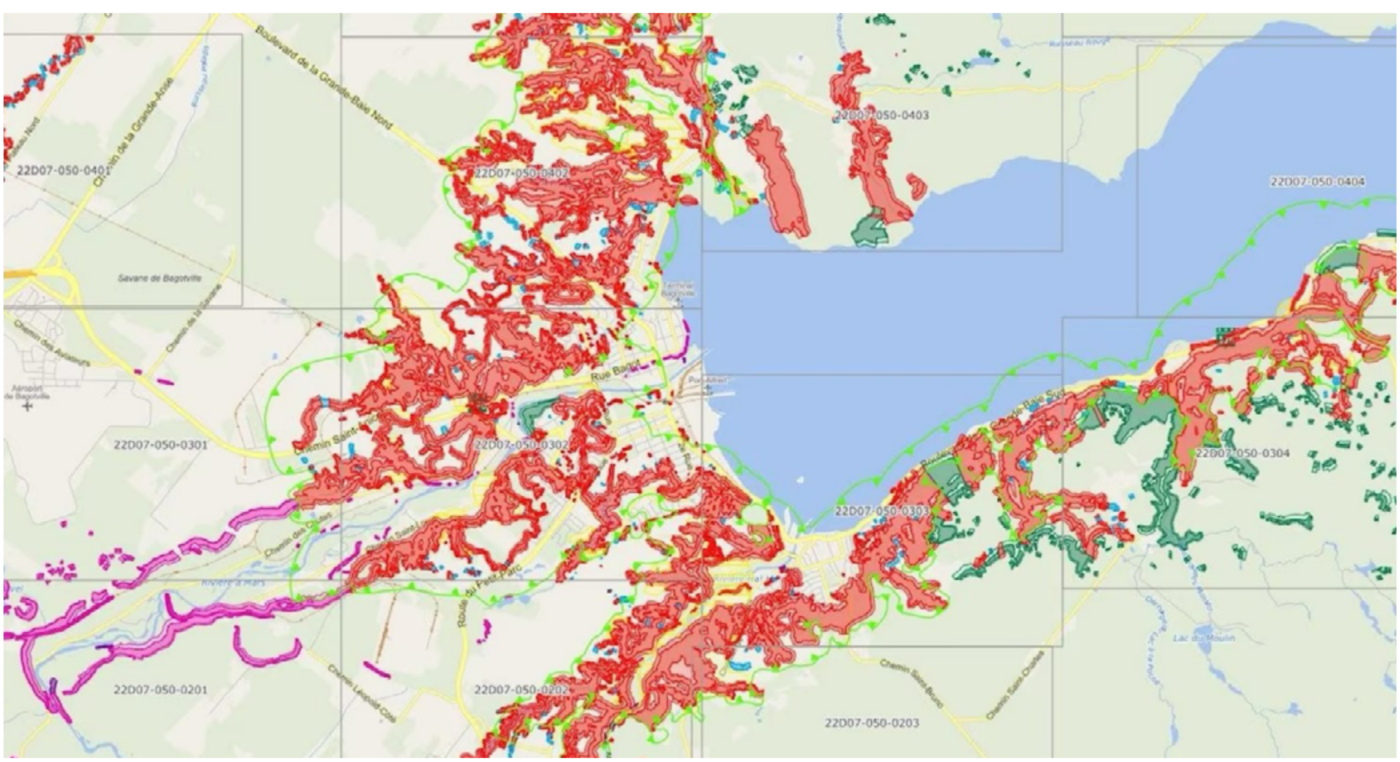


*Source: User Guide of Constraint Maps Relative to Landslides in Unconsolidated Deposits, Government of Quebec, 2016, p. 4.

Table 1. Distribution of Single-family Sales According to Priority Constraint Zones – Original Sample

Type of constraint zone	Number of sales	Percentage
None	686	63.6
NA1	364	33.8
RA1	5	0.5
NH	8	0.7
NA2	15	1.4
Total sample	1 078	100

Figure 2. Cartographic Representation of Potential Landslide Hazard Zones Subject to Building Constraints in La Baie



Source: Map of potential landslide hazard zones (ZPEGT) in La Baie, Données Québec, 2019.

Table 2. Main Descriptive Statistics for Continuous Variables

Continuous Variables	N	Mean	Std. Dev.	Median	Minimum	Maximum
			Overall Sample			
Sale price ($)	813	177 802 $	44 545 $	169 000 $	65 000 $	399 000 $
Total lot area (m²)	813	756	548	608	83	4.687
Total living area (m²)	813	97	27	93	53	288
Number of bathrooms	813	1.7	0.5	2	1	3
Total NA1 protection band lot area (m²)	282	352	365	274	0	2.479
Total NA1 slope lot area (m²)	282	141	216	53	0	1.451
			Unconstrained Properties			
Sale price ($)	531	172 118 $	43 436 $	165 000 $		350 000 $
Total lot area (m²)	531	731	565	581	276	4.687
Total living area (m²)	531	95	28	92	53	263
Number of bathrooms	531	1.7	0.5	2	1	3
Total NA1 protection band lot area (m²)	531	0	0	0	0	0
Total NA1 slope lot area (2²)	531	0	0	0	0	0
			NA1 Constrained Properties			
Sale price ($)	282	188 504 $	44 712 $	177 000 $	95 000 $	399 000 $
Total lot area (m²)	282	803	512	650	83	3.516
Total living area (m²)	282	100	27	95	56	288
Number of bathrooms	282	1.8	0.5	2	1	3
Total NA1 protection band lot area (m²)	282	352	365	274	0	2.479
Total NA1 slope lot area (m²)	282	141	216	53	0	1.451

Once filtered for missing values, atypical sales, extreme outliers as well as residuals with too high Cook's distances, the final sample used for modelling purposes is down to 813 *bona fide* transactions and includes only properties that are either located in NA1 constraint zones or are unaffected by land-use constraints.

Table 2 reports the main descriptive statistics for the continuous variables in our sample. The average sale price for the whole sample stands at roughly 177,800 Can$. Quite surprisingly though, the mean sale price for properties located within NA1 constraint zones stands at 188,500 Can$, as opposed to 172,100 Can$ for unconstrained properties. Two factors may explain such a discrepancy between the two groups. First, constrained properties exhibit larger lots (803 m²) and living areas (100 m²) than unconstrained ones (731 and 95 m², respectively). Second, while 42 properties in our sample are located on lots that offer a panoramic view of the Saguenay River, 29 of these (i.e. 69%) are located on totally constrained lots. Consequently, a « panoramic view » control variable was designed using Google Earth in combination with on-site visits and included in the model. For both constrained and unconstrained properties, the modal effective age stands within the 20-29 years category. Finally, for affected properties, the median lot area subject to building constraints stands at 274 m² for protection buffers and at 53 m² for slopes.

Descriptive statistics pertaining to dummy variables used in our model are reported in Appendix 1. By and large, based on the characteristics reported in Table 2 and Appendix 1, it can be concluded that both subsamples are quite similar on the whole, although constrained properties are, on average, larger than their unconstrained counterparts and tend to exhibit more upper-end attributes (detached house, presence of a garage and pool, overall quality of building and interior finish, panoramic view) than the latter, which helps explain the 9.5% price differential between the two groups.

The database also contains qualitative information pertaining to sales located on 100 percent constrained land that could prove useful for interpreting study findings. On the one hand, certificates of location made a clear mention of the NA1-type land-use constraints in only 19 out of 40 cases. On the other hand, in 90% of cases, the seller clearly states in its declaration not to be aware of any problem affecting the lot such as landslides, land subsidence, ground motion or soil instability. Thus, while information asymmetry in the local market might induce some bias in household decisions, it should not overshadow the fact that the information on landslide exposure had long been widely accessible to residents and would-be buyers. Furthermore, potential buyers' confidence, hence their willingness to pay for the property, is likely to have been strengthened by the seller's declaration.

ANALYTICAL APPROACH

Addressing the endogeneity issue

This study rests on Rosen's (1974) hedonic framework, whose general formulation is as follows:

$$Y = X\,b + e \qquad (1)$$

where Y is the dependent variable (Log of sale price), X is the matrix of independent variables, b is the vector of housing attributes' parameters – or hedonic prices – and e are the model residuals.

As is often the case with the OLS regression method, endogeneity may be an issue wherever a predictor is correlated with the error term, in which case the predictor is said to be an endogenous variable. This yields a biased estimate of its coefficient while raising the causal interpretation issue. Endogeneity stems from several sources, namely omitted variables, simultaneity and measurement errors. In this case, omitted variables may be a problem since landslide hazards do not occur at random, but on specific parcels of the study area. It is thus possible that some confounding variables be present in the model which are correlated with both the response variable (i.e., the sale price) and some of the independent, or treatment, variables (e.g., structural or locational attributes).

Endogeneity issues in OLS regressions are usually dealt with using instrumental variables (IV) methods involving a Two-Stage Least Squares (2SLS) procedure. The IV approach is conditional to such "external" IVs being strongly, and solely, correlated to treatment variables (Xi) and not to the model residuals (e) while affecting the response variable (Y) indirectly through Xi. The fact is, however, that finding appropriate external IVs is often problematic in applied research. For that reason, Lewbel (2012) proposes a method designed at addressing endogeneity in the absence of any external instrument.

In this paper, we adopt Lewbel's approach to account for the possible presence of endogenous variables in the model. Since this method operates by exploiting model heteroscedasticity to construct instruments using the available regressors (Baum and Lewbel, 2019), we first must make sure that the residuals of the OLS model are not homoskedastic. Appendix 2 shows the histogram of the model residuals and provides the statistics for the Breusch-Pagan (BP) test whose null hypothesis is that residuals are homoskedastic. Considering the BP result (95) and its p-value of 0.02, we can reject the null hypothesis and conclude that the OLS model is affected by heteroskedasticity.

With regard to potentially endogenous variables, the two treatment regressors here are (i) a dummy variable indicating whether a property is located in a NA1 constraint zone; and ii) a dummy variable indicating whether the sale took place before (0) or after (1) the implementation of the municipal compensation scheme in December 2012. Lewbel's approach is a four-step method which consists in designing internal instruments and can be summarized as follows:

Step 1:
Each potentially endogenous variable of interest, denoted P_j, is first regressed on all other exogenous variables X_k, with the ensuing residuals (e′) being retrieved.

Step 2:
Lewbel's internal instruments, denoted Z_k, are designed using the following formula:

$$Z_k = (X_k - \overline{X}_k) * e' \quad (2)$$

where $\overline{X}_k$ is the mean value of X_k.

Step 3:
Endogenous variables P_j are then regressed on both the exogenous variables X_k and the internal instruments Z_k, with the ensuing predicted values of P_j, denoted PE_j, being retrieved.

Step 4:
Finally, the response variable Y is regressed on both the exogenous variables X_k and the PE_j obtained from Step 3.

One can conclude from Equation (2) above that Lewbel's internal instruments, Z_k, are designed using centered exogenous variables, which tends to reduce multicollinearity. Moreover, Lewbel's procedure ensures that the Z_k are independent from the model residuals (e) – a condition for using that procedure – since the response variable Y is regressed on both the exogenous variables X_k and the predicted values PE_j obtained from Step 3.

Weak instruments tend to generate biased IV estimators and to invalidate hypothesis tests. The weak instrument test – which is actually an F-test on the first stage regression – allows to validate the assumption about the strength of the IVs used, the null hypothesis being that the instruments are weak and cannot be relied on. As for the Wu-Hausman test, it tells us whether the IV model is just as consistent as the OLS one, the null hypothesis here being that both are equally consistent. Where this is the case, the OLS model should be preferred as it is more efficient than the former. Finally, the Sargan statistic tests whether the model is overidentified, which is the case when there is more than one instrument per endogenous variable. It ensures that all instruments used are actually exogenous, as well as uncorrelated with the model residuals. Instruments should be considered invalid where the test is statistically significant.

Regression results obtained with Lewbel's method are reported in Appendix 3 together with diagnostic tests. The weak instrument test clearly shows that both instruments included in the model are highly correlated with endogenous regressors, that they are sufficiently strong and, consequently, that the weak instrument hypothesis should be rejected. Moreover, the Wu-Hausman test is not statistically significant, which leads to the conclusion that the IV estimation approach is not preferable to the standard OLS method, which should thus be opted for. Finally, the Sargan test is statistically significant at the 0.10 threshold, but not at the 0.05 threshold, which suggests that both instruments used are exogenous and, therefore, that the OLS model is appropriate. To summarize, following our investigation of the endogeneity issue, we conclude that it is not a problem with regard to this study.

Dealing with spatial autocorrelation

Following the Moran's I test, the null hypothesis of absence of spatial autocorrelation (SA) had to be rejected, thereby leading to opt for a spatial model that corrects for SA through a spatial weights matrix W. Two maximum likelihood estimation procedures were tested – as well as their robust version and combination – using the Lagrange Multiplier (LM) diagnostics for spatial dependence: the Spatial Autoregressive Model (SAR)[7], where W is applied to the dependent variable, and the Spatial Error Model (SEM), where W is applied to the model residuals. The general formulation of these models is as follows:

$$\textbf{SAR}: \; Y = rW_1Y + X\,b + e \quad (3)$$

$$\textbf{SEM}: \; Y = X\,b + u, \text{ with } u = lW_2 + e \quad (4)$$

where W_1 and W_2 are the spatial weights matrices, r and l the autoregressive parameters and e and u the models residuals. Based on the LM test p-value, the SAR model was selected, with the spatial weights matrix being based on the k-nearest neighbor approach and with the optimal k set at 5, in line with previous studies.

Similarly, several specifications were tested for the SAR model, with dummy and continuous variables being alternately used as land-use constraint indicators. Threshold dummies were also tested to account for properties with above-mean land-use constraints for both slopes and protection bands, but using the logged lot area in both the NA1 protection band and slope as land-use constraint indicators did not improve in any way the model specification while causing excessive collinearity. Neither did the inclusion of an interactive term between a constrained lot and a panoramic view. Property descriptors used as control variables include: lot and building living areas; effective age of property, in years (with effective age [0-10[as the reference); type of building (with attached or semi-detached as the

7 Also referred to as the Spatial Lag Model.

Table 3. DiD Regression Results for the OLS and Spatial Autoregressive Models

DiD Estimation for OLS and SAR Models
Dependent variable: Log(Sale price)

Variable Name	Regression Coefficients (standard errors between brackets)	
	OLS Model	Spatial Autoregressive Model
Property is in NA1 constraint zones (treated)	0.034*** (0.009)	0.032*** (0.008)
DiD estimator (sold after Dec. 2012: treated)	-0.033*** (0.013)	-0.033*** (0.012)
Panoramic view	0.080*** (0.015)	0.078*** (0.014)
Log(Total lot area) – m^2	0.130*** (0.012)	0.130*** (0.011)
Log(Total living area) – m^2	0.210*** (0.015)	0.210*** (0.014)
Detached house	0.120*** (0.011)	0.120*** (0.011)
Effective age category (yrs) [10-20[	-0.110*** (0.011)	-0.100*** (0.010)
Effective age category (yrs) [20-30[	-0.210*** (0.011)	-0.200*** (0.011)
Effective age category (yrs) [30-40[	-0.270*** (0.012)	-0.260*** (0.012)
Effective age category (yrs) [40-50[	-0.410*** (0.019)	-0.400*** (0.019)
Effective age category (yrs) [50+[	-0.400*** (0.039)	-0.390*** (0.038)
Property quality class 5	-0.140*** (0.030)	-0.150*** (0.029)
Property quality class 6	-0.140*** (0.032)	-0.150*** (0.030)
Property quality class 7	-0.220*** (0.054)	-0.220*** (0.052)
Number of bathrooms	0.045*** (0.007)	0.045*** (0.007)
Kitchen Cabinet-wood	0.084*** (0.015)	0.083*** (0.014)
Kitchen Cabinet-melamine	0.050*** (0.012)	0.049*** (0.012)
Kitchen Cabinet-thermoplastic	0.100*** (0.023)	0.100*** (0.022)
Percentage of hardwood floor	0.001*** (0.0001)	0.001*** (0.0001)
Inferior quality Foundation	-0.093*** (0.020)	-0.092*** (0.019)
Inferior quality Kitchen	-0.049*** (0.011)	-0.050*** (0.010)
Inferior quality Roof	-0.034*** (0.008)	-0.034*** (0.008)
Inferior quality of Interior finish	-0.083*** (0.015)	-0.082*** (0.014)
Inferior quality of facing	-0.019** (0.008)	-0.018** (0.007)
Presence of a garage	0.050*** (0.007)	0.050*** (0.007)
Presence of an excavated pool	0.120*** (0.016)	0.120*** (0.016)
Presence of an above-ground pool	0.026*** (0.007)	0.026*** (0.007)
Neighborhood B	0.014 (0.021)	0.015 (0.020)
Neighborhood C	0.013 (0.043)	0.012 (0.041)
Neighborhood E	0.120*** (0.020)	0.120*** (0.019)
Neighborhood F	0.079** (0.031)	0.091*** (0.030)
Neighborhood G	0.078*** (0.023)	0.088*** (0.022)
Neighborhood H	0.120*** (0.019)	0.120*** (0.018)
Neighborhood I	0.130*** (0.019)	0.130*** (0.018)
Neighborhood J	0.120*** (0.018)	0.120*** (0.017)
Neighborhood K	0.160*** (0.019)	0.160*** (0.019)
Neighborhood L	0.150*** (0.056)	0.140*** (0.053)
Neighborhood M	-0.006 (0.034)	-0.002 (0.032)
2009 quarter 2	0.015 (0.029)	0.019 (0.028)
2009 quarter 3	0.027 (0.029)	0.028 (0.027)
2009 quarter 4	0.062* (0.033)	0.065** (0.031)
2010 quarter 1	0.002 (0.037)	0.003 (0.035)
2010 quarter 2	0.067** (0.028)	0.070*** (0.027)
2010 quarter 3	0.130*** (0.031)	0.130*** (0.029)
2010 quarter 4	0.150*** (0.031)	0.150*** (0.030)
2011 quarter 1	0.160*** (0.034)	0.160*** (0.033)
2011 quarter 2	0.160*** (0.027)	0.160*** (0.026)
2011 quarter 3	0.120*** (0.029)	0.120*** (0.027)
2011 quarter 4	0.150*** (0.035)	0.150*** (0.033)
2012 quarter 1	0.200*** (0.034)	0.200*** (0.032)
2012 quarter 2	0.210*** (0.028)	0.210*** (0.027)
2012 quarter 3	0.250*** (0.029)	0.250*** (0.027)
2012 quarter 4	0.270*** (0.035)	0.270*** (0.034)
2013 quarter 1	0.300*** (0.036)	0.300*** (0.035)
2013 quarter 2	0.300*** (0.028)	0.300*** (0.027)
2013 quarter 3	0.300*** (0.031)	0.310*** (0.030)
2013 quarter 4	0.270*** (0.034)	0.280*** (0.032)
2014 quarter 1	0.260*** (0.039)	0.270*** (0.038)
2014 quarter 2	0.340*** (0.029)	0.350*** (0.028)
2014 quarter 3	0.310*** (0.031)	0.310*** (0.029)
2014 quarter 4	0.280*** (0.034)	0.280*** (0.032)
2015 quarter 1	0.320*** (0.035)	0.320*** (0.033)
2015 quarter 2	0.260*** (0.029)	0.260*** (0.027)
2015 quarter 3	0.250*** (0.031)	0.260*** (0.030)
2015 quarter 4	0.260*** (0.036)	0.260*** (0.035)
2016 quarter 1	0.230*** (0.038)	0.240*** (0.036)
2016 quarter 2	0.280*** (0.030)	0.290*** (0.028)
2016 quarter 3	0.240*** (0.032)	0.250*** (0.031)
2016 quarter 4	0.230*** (0.035)	0.240*** (0.033)
Constant	9.900*** (0.110)	9.300*** (0.300)
Nb. Observations :	813	813
R^2 :	0.890	Nagelkerke Pseudo R^2 : 0.89
Adjusted R^2 :	0.880	-
Log Likelihood :	-	905.000
$Sigma^2$:	0.07	0.006
Akaike Inf. Crit. :	-1,664	-1,667
Residual Std. Error :	0.083 (df = 743)	0.079
F Statistic :	89.000*** (df = 69; 743)	-
Wald Test :	-	5.000** (df = 1)
r :	-	0.054** (p-value :0.027)
LR Test :	-	4.900** (df = 1)

Note: Statistical significance thresholds are as follows: *p<0.10; **p< 0.05; ***p<0.01; ****p<0.001

reference); number of bathrooms; type of kitchen cabinet (with other than wood, melamine or thermoplastic as the reference); percentage of hardwood floor; quality level of foundations, roof, kitchen, interior finish and exterior siding (with a superior quality as the reference); presence of a garage and of an excavated or above-ground pool; 12 neighborhood dummies (with NBHD A as the reference); a series of time quarterly dummies (2009Q2/ 2016Q4, with 2009Q1 as the reference); and the presence of a panoramic view from the property.

The final formulation of the spatial hedonic model can be expressed as:

$$\mathrm{Log}(P_i) = \beta_0 + \rho W \mathrm{Log}(P_i) + \sum_{j=1}^{2} \beta_j \, CI_j + \sum_{k=3}^{K} \beta_k X_k + \varepsilon_i, \quad (5)$$

where P_i is the sale price vector, β_0 is the constant term, W is the spatial weights matrix[8] applied to the dependent variable $\mathrm{Log}(P_i)$, ρ is the autoregressive parameter, CI_j are the land-use constraint variables, X_k are the k control variables, β_j and β_k the associated parameters, respectively, and ε_i are the model residuals.

RESULTS AND DISCUSSION

Main regression findings

Regression results for both the DiD-OLS and DiD-SAR models are reported in *Table 3*. In terms of overall performances, either model may be considered equivalent: their respective explanatory power reaches 0.88 (OLS) and 0.89 (SAR) although the Akaike information criterion (AIC) suggests that the spatial DiD model is slightly more parsimonious than the OLS one. In addition, the former exhibits a substantially lower prediction error (SEE) than the latter (0.079 vs 0.083). Finally, while some statistically significant SA still remains in

8 Based on the k-nearest neighbor approach, with k=5.

the spatial model (r: 0.054, significant at the 5% level), its magnitude is rather limited and should not affect the model estimates. In order to streamline the discussion, we thus focus on presenting only coefficient estimates pertaining to the DiD-SAR model. It is also important to remember that with regard to the interpretation of Table 3 regression coefficients, the semi-log functional form of the model requires that estimates be transformed to provide a reliable measure of housing attributes' marginal impact on value[9]. Consequently, percentages reported in the text are transformed ones and thus differ from Table 3.

Regarding the model variables of interest, findings clearly suggest that, once controlled for the panoramic view from the property as well as for all other control variables, properties located in a NA1 constraint zone still command, on average, a premium of roughly 3.4% compared with unconstrained ones. This is not the case though for constrained houses that sold following December 2012, i.e. once the municipal compensation scheme was implemented, and which are assigned a market discount of 3.4%. In other words, while publicizing updated landslide hazard maps and adopting more stringent land-use controls on affected lots seem to reduce homebuyers' risk, thereby pushing-up home prices, addressing landslide hazards through some form of monetary compensation has the opposite effect and cancels out this advantage. Finally, it is worth noting that the presence of a panoramic view on the Saguenay River does translate into a market premium of 8.6% for both constrained and unconstrained properties.

Turning to control variable estimates, they are in line with theoretical expectations regarding both their signs and magnitudes and differ very little between the OLS and spatial versions of the model. Elasticity coefficients for lot and living areas stand at 0.14 and 0.22, respectively. Compared with an attached home, a detached one sells at a 13.5% premium. Effective age estimates are also quite consistent and suggest that a house aged 50 years or more commands a depreciation of roughly 34.1% when compared with a house that is less than 10 years old. Property quality classes range from 1 (best) through 7 (worse), with 5 as the average quality. Here, findings suggest that when compared with upper-quality homes (classes 1 to 4, used as the reference), lower-quality properties sell at a 20.9% discount. An additional bathroom adds 4.8% to the price. Building intrinsic attributes generate regression estimates that are in line with previous research, with above and below-standard attributes generating highly significant premiums and discounts, respectively. The presence of a garage adds 5.4% to the market value of a property while the premium for an excavated swimming pool stands at 13.5%, as opposed to 2.8% for an above-ground one.

Except for three neighborhoods (B, C and M) which do not differ from the reference (NBHD A), houses are assigned a location premium that ranges from a low of 9.7% (NBHD G) to a high of 18.3% (NBHD K)[10]. Finally, quarterly time dummy coefficients report some fluctuations in local house prices over the eight-year study period[11]. The resulting price index suggests that, between the first quarter of 2009 and the last quarter of 2016, home prices in La Baie have grown by 28.7%, or roughly 3.2% on a yearly basis.

Discussion

This research aims at investigating whether the implementation in December 2012 of a municipal compensation scheme targeting homeowners located in severe landslide hazard areas and affected by new land use constraints impacts local property values in La Baie, an *arrondissement* of the City of Saguenay, Quebec, Canada. To adequately interpret our findings, one must bear in mind that, prior to the compensation scheme being implemented, the provincial government, through its Ministry of Public Security, had long designed building constraint zones and issued updated landslide hazard maps that were widely publicized to residents and homebuyers from 2004 onwards. The 3.4% premium assigned to properties located in a NA1 constraint zones – as opposed to houses built on unconstrained lots – suggests that such an initiative, rather than driving house prices downward, seems to have operated as a risk-reduction device and to have comforted, rather than worry, would-be buyers regarding the actual landslide risk incurred. Due to the lack of any specific reference date for new land-use regulations though, it is not possible to assess, through a before/after analysis, whether homebuyers' risk aversion has evolved over time.

In contrast, and quite unexpectedly, the second major research finding shows that post-2012 treated properties sold at a 3.4% discount compared with their pre-2012 counterparts. One could have expected that compensation measures as well as financial aid for site improvement that were granted to the most affected homeowners might have contributed to further alleviate economic agents' risk perception. This is obviously not the case. A possible explanation for such a counterintuitive result lies with the lack of any information on the extent of the compensation measures and financial aid granted by the local authority. Firstly, those initiatives might not have been commensurate with the real cost of the transformations required on the lot. Secondly, beneficiaries of the compensation scheme may have spent only part of the aid they received on securing their property, without adequately reducing landslide hazards. In both cases, this would translate into a relative drop in sale price, as suggested by our study. In the end, two opposite price impacts emerge that cancel each other: a positive impact that stems from a reduction in perceived risk, and a negative one that reflects insufficient investment in property as a stopgap.

The originality of this research lies with the use of a difference-in differences approach in a public policy context, with very few such examples being found in the literature on both flood and landslide events (Harrison et al 2001). While the DiD procedure could not be applied to isolate the publicization of landslide hazard maps by the provincial government due to data constraints, it was applied to test for the price impact of a local compensation scheme implemented in December 2012 and directed at homeowners who were most affected by building constraints following the July 1996 Saguenay flood which resulted in a series of major landslides. Our research corroborates some of the findings found in the literature. Thus, several authors mention the positive impact of a nice view which can lessen the price discount that generally occurs following a major event or even outweigh such a discount. In this case study, the presence of a panoramic view adds 8.6% to the price of both constrained and unconstrained properties.

The time elapsed since the most recent event is yet another factor that is brought out in the literature as having a paramount importance on homebuyers' risk perception, hence on market discounts. While discounts – or premium reductions – are generally highly pronounced in the months following a major event (Kim et al, 2017; Bélanger et al, 2018), they tend to fade away quite rapidly thereafter (Jaiswal et al, 2011). In the case of La Baie, sales span over an eight-year period (2009-2016), i.e., some 13 to 20 years after the Saguenay

9 Considering that the dependent variable is log transformed, the true percentage price premium or discount pertaining to the dummy variables' coefficients are obtained using the following transformation: [Exp (b)-1]*100, while the parameter estimates of the log transformed independent variables are expressed as elasticity coefficients. For both dummy and continuous variables though, the SAR procedure used in this paper requires that the coefficients be also multiplied by (1 – r)-1 to yield their actual marginal impact (Dubé et al 2017, p.4).

10 Neighborhood D was not included in the analysis due to an insufficient number of sales.

11 It is worth mentioning that, in contrast with the situation that prevailed on the US and UK property markets, and except for Toronto and Vancouver in 2009 only, Canadian house prices were not significantly affected by the Great Recession of 2008-2009. This applies to the whole of Quebec's residential markets, including the Saguenay metropolitan region where prices experienced a rather steady growth, at least until the first quarter of 2015.

flood. While the latter caused huge material damage and despite the fact that a similar event had affected the region some 25 years before (see footnote 2), it is still considered as a non-recurrent phenomenon by most local residents. On such grounds, and in contrast with Harrison et al (2001) who found that more stringent flood insurance conditions following the National Flood Insurance Reform Act of 1994 resulted in an enhanced risk perception and in larger price discounts, it is therefore not surprising that our findings suggest the opposite, namely that publicizing updated landslide hazard maps acted as a risk-reduction device, hence exerting an overall positive impact on constrained property values. Finally, our assumption regarding the relative discount assigned to high-risk properties that sold after 2012 makes sense based on Kauko's (2012) findings that price premiums can turn into discounts where landslide costs exceed benefits.

CONCLUSION: STUDY LIMITATIONS, SUMMARY OF FINDINGS AND PROSPECTS FOR FUTURE RESEARCH

Based on a representative sample of 813 single-family homes transacted between January 2009 and December 2016 in La Baie, an *arrondissement* of the City of Saguenay, Quebec, Canada, this study aims at assessing the price impact of a municipal compensation scheme targeting homeowners located in severe landslide hazard areas (NA1 constraint zones) and affected by building limitations. It rests on the hedonic framework and applies a difference-in-differences (DiD) procedure within a standard OLS framework complemented by a spatial autoregressive (SAR) model to account for spatial autocorrelation. Considering that no specific reference date is available for the implementation of new land-use regulations based on the publicization of updated landslide hazard maps[12], a before/after analysis under a DiD framework could not be performed on that issue, which is a limitation of this study. However, a DiD analysis was conducted to assess the efficiency of the local compensation scheme that was implemented in December 2012, which is thus the focus of this research.

The model includes an array of control variables to account for land and building attributes, location factors and the time dimension. It also controls for the presence of a panoramic view from the property. The variables of interest – or treatment variables – consist of (i) a dummy variable indicating whether a property is located in a NA1 constraint zone, and (ii) a dummy variable indicating whether the sale took place before (0) or after (1) the implementation of the municipal compensation scheme in December 2012. Findings clearly suggest that, once controlled for the panoramic view on the Saguenay River which adds 8.6% to the price of both constrained and unconstrained properties, houses located in a NA1 constraint zone still command, on average, a premium of roughly 3.4% compared with those built on unconstrained lots. Such a somewhat counterintuitive result is assumed to mirror the fact that, some 13 to 20 years after the devastating event of July 1996, homebuyers have long overcome the trauma phase and are rather comforted by the availability of quality hazard maps that lower their perception of risk. As for the 3.4% discount assigned to high-risk properties that sold after 2012, it can reasonably be assumed that the compensations paid to the most affected homeowners under the municipal program still didn't match the true cost of the damages incurred by the latter.

In addition to the data limitations already underlined above, results obtained with the La Baie sample are likely to reflect local housing preferences and risk perception with regard to landslide hazard exposure and the efficiency of any compensation measure implemented to compensate for the damage incurred to homeowners. Consequently, any generalization of the risk-monitoring policy impact to other urban contexts remains premature and calls for other case studies to be conducted in more densely inhabited areas of the province.

Finally, this research must be placed in a broader context, that of climate change and of public policy responses to it. According to Gariano and Guzzetti (2016), while the relationship between climate change and landslide occurrence remains highly complex, there is no doubt that greenhouse gas emissions are the key to understanding the frequency and severity of major rainfall events which in turn act as the primary trigger of potentially devastating landslides. The authors predict that an increasing number of people will be exposed to landslide risk in the future and advocate the establishment of communication channels between climate scientists on the one hand and, decision makers and the public on the other hand. This paper fills a gap in the literature by addressing the issue from a public policy perspective, with a focus on the house price impact of landslide hazards as a means to assess the consequences of the phenomenon on the most important determinant of household wealth.

REFERENCES

Akbar, D., J. Rolfe, G. Small & R. Hossain (2015). Assessing Flood Impacts on the Regional Property Markets in Queensland, Australia. *Australasian Journal of Regional Studies* 21(2): 160-177.

Atreya, A. & S. Ferreira (2015). Seeing is Believing? Evidence from Property Prices in Inundated Areas. *Risk Analysis* 35(5): 828-848.

Atreya, A. & J. Czajkowski (2016). Graduated Flood Risks and Property Prices in Galveston County. *Real Estate Economics*, https://doi.org/10.1111/1540-6229.12163.

Baum, C. F. & A. Lewbel. 2019. Advice on using heteroskedasticity-based identification. *The Stata Journal* 19(4): 757-767. https://doi.org/10.1177/1536867X19893614.

Bélanger, P. & M. Bourdeau-Brien (2018). The Impact of Flood Risk on the Price of Residential Properties: the Case of England. *Housing Studies* 33(6): 876-901. DOI:10.1080/02673037.2017.1408781.

Bélanger, P., M. Bourdeau-Brien & M. Dumestre (2018). The Impact of Flood Risk on Residential Property Prices: the Case of Canada. *Journal of Sustainable Real Estate* 10: 135-162.

Beltrán, A., D. Maddison & R. J. R., Elliott (2018). Is Flood Risk Capitalised Into Property Values? *Ecological Economics* 146 : 668-685.

Bin, O. & S. Polasky (2004). Effects of Flood Hazards on Property Values: Evidence Before and After Hurricane Floyd. *Land Economics* 80(4): 490-500.

Demers, D., D. Robitaille, P. Locat & J. Potvin (2014). Inventory of Large Landslides in Sensitive Clay in the Province of Québec, Canada: Preliminary Analysis, pp. 77-89, in L'Heureux, J-S., A. Locat, S. Leroueil, D. Demers & J. Locat, Editors (2014). Landslides in Sentivive Clays - ISBN 978-94-007-7079-9 (eBook), 418 pages.

Dubé, J., D. Legros, M. Thériault & F. Des Rosiers (2017). Measuring and Interpreting Urban Externalities in Real-Estate Data: A Spatio-Temporal Difference-in-Differences (STDID) Estimator. *Buildings* 7(51), 23 pages.

Gariano, S. L. & F. Guzzetti (2016). Landslides in a Changing Climate. *Earth-Science Reviews* 162: 227-252.

Gerui, L., L. Yalin, Y. Huajun, Y., W. Sanmang & G. Ping (2017). The Influence of Land Urbanization on Landslides: An Empirical Estima-

12 While landslide hazard maps were made public from 2004 onwards, the implementation of the publication process was very gradual and does not allow for any specific date to ground a before/after analytical framework.

tion Based on Chinese Provincial Panel Data. *Science of The Total Environment* 595: 681-690.

Hansen, J. L. & E.D. Benson (2013). The Value of a Water View: Variability Over 25 Years In a Coastal Housing Market. *The Coastal Business Journal*, 12(1): 76-99.

Harrison, D. M., G. T. Smersh & A. L. Schwartz, Jr. (2001). Environmental Determinants of Housing Prices: The Impact of Flood Zone Status. *Journal of Real Estate Research* 21(1/2): 3-20.

Hydro-Engineering Institute Sarajevo (HEIS) (2015). *Floods and Landslides Risk Assessment for the Housing Sector in Bosnia and Herzegovina*, EU Flood Recovery Program, 125 pages.

Jaiswal, P., C. J. van Westen & V. Jetten (2011). Quantitative Estimation of Landslide Risk from Rapid Debris Slides on Natural Slopes in the Nilgiri Hills, India. *Natural Hazards Earth System Sciences* 11: 723–1743.

Kauko, Tom (2012). 'We Are Not Afraid of Flooding' …but What About Landslide? The Effects of Assumed and Perceived Hazards on the Value of Residential Locations. *Aestimum*, XLI Incontro di Studio del Ce.S.E.T.: 635-651.

Kim, J., J. Park, D.K. Yoon & G.H. Cho (2017). Amenity or Hazard? The Effects of Landslide Hazard on Property Value in Woomyeon Nature Park Area, Korea. *Landscape and Urban Planning* 157: 523-531.

Lewbel, Arthur (2012). Using Heteroscedasticity to Identify and Estimate Mismeasured and Endogenous Regressor Models. *Journal of Business & Economic Statistics* 30(1): 67-80.

Mertens, K., L. Jacobs, J. Maes, C. Kabaseke, M. Maertens, J. Poesen, M. Kervyn & L. Vranken (2016). The Impact of Landslides on Household Income in Tropical Regions: a Case Study from the Rwenzori Mountains in Uganda. *Science of the Total Environment* 550: 1032-1043.

Pereira, S., RAC. Garcia, JL. Zêzere, SC. Oliveira & M. Silva (2016). Landslide Quantitative Risk Analysis of Buildings at the Municipal Scale Based on a Rainfall Triggering Scenario. *Geomatics, Natural Hazards and Risk*, 25 pages. DOI: 10.1080/19475705.2016.1250116.

Persichillo, M. G., M. Bordoni & C. Meisina (2017). The Role of Land Use Changes in the Distribution of Shallow Landslides. *Science of the Total Environment* 574: 924–937.

Pisano, L., V. Zumpano, Ž. Malek, C.M. Rosskopf & M. Parise (2017). Variations in the Susceptibility to Landslides as a Consequence of Land Cover Changes: A Look to the Past, and Another Towards the Future. *Science of the Total Environment* 601–602: 1147–1159.

Promper, C., C. Gassner & T. Glade (2015). Spatiotemporal Patterns of Landslide Exposure – a Step Within Future Landslide Risk Analysis on a Regional Scale Applied in Waidhofen/Ybbs, Austria. *International Journal of Disaster Risk Reduction* 12:25-33.

Rosen, S. (1974). Hedonic Prices and Implicit Markets: Product Differentiation in Pure Competition. *The Journal of Political Economy* 82(1): 34-55.

Salvati, P., O. Petrucci, M. Rossi, C. Bianchi, A. A. Pasqua & F. Guzzetti (2018). Gender, Age and Circumstances Analysis of Flood and Landslide Fatalities in Italy. *Science of The Total Environment* 610-611: 867-879.

Vranken, L., P. Van Turnhout, M. Van Den Eeckhaut, L. Vandekerckhove & J. Poesen (2013). Economic Valuation of Landslide Damage in Hilly Regions: A Case Study from Flanders, Belgium. *Science of The Total Environment*, 447: 323-336.

Zhang, L. (2016). Flood Hazards Impact on Neighborhood House Prices: A Spatial Quantile Regression Analysis. *Regional Science and Urban Economics* 60: 12-19.

Zimmerman, R. (1979). The Effect of Flood Plain Location on Property Values: Three Towns in Northeastern New Jersey. *JAWRA Journal of the American Water Resources Association* 15(6): 1653–1665.