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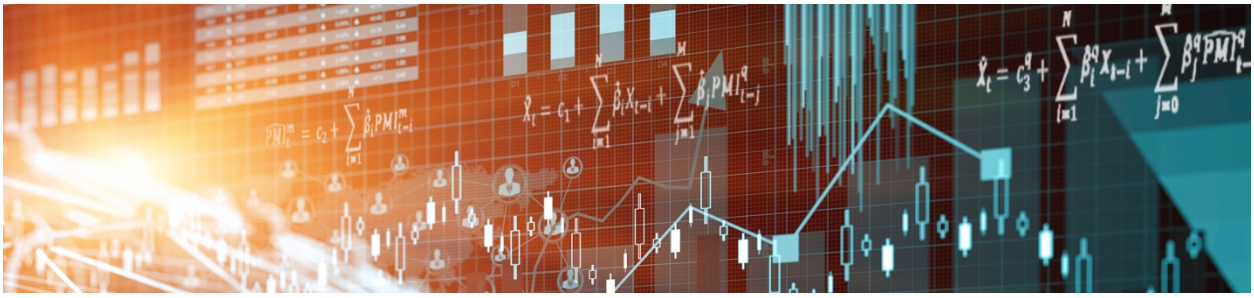
Staff Discussion Paper / Document d'analyse du personnel 2019-10

2018 Bitcoin Omnibus Survey: Awareness and Usage



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November 2019

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ISSN 1914-0568

Acknowledgements

We thank Shelley Edwards of Ipsos for her continued collaboration in improving the Bitcoin Omnibus Survey. We are grateful to Heng Chen, Kevin Foster, Ben Fung, Scott Hendry, Helmut Stix and various participants of conferences and seminars for providing comments. We would like to acknowledge Colette Stoeber for providing editorial assistance. The views expressed in this paper are those of the authors and do not necessarily represent the official views of the Bank of Canada. All remaining errors are solely the responsibility of the authors. All prices are reported in Canadian dollars (CAD) unless otherwise noted.

Abstract

The Bank of Canada commissioned the Bitcoin Omnibus Survey in 2016 to monitor trends in the adoption and use of Bitcoin and other cryptoassets (Henry, Huynh and Nicholls 2018, 2019). This report presents findings from the latest iteration of the survey, which was conducted in 2018. We find that between 2016 and 2018 the share of Canadians who were aware of Bitcoin increased from 62 percent to 89 percent and those who owned Bitcoin increased from 3 percent to 5 percent. However, the share of past owners also increased, suggesting an influx of Bitcoin owners who subsequently divested after the steep rise of prices in 2017. The main reason for owning Bitcoin remains speculation, though this share decreased slightly since 2017. On the other hand, the share of Canadians who reported using Bitcoin for transactions a few times a month or more increased. Finally, we discuss how Bitcoin adopters differ from overall Canadians with respect to their financial literacy, preferences over payment methods, and cash holdings.

Bank topics: Bank notes; Digital currencies and fintech; Econometrics and statistical methods
JEL codes: E4, C12, O51

1 Introduction

The Bank of Canada continues to use the Bitcoin Omnibus Survey (BTCOS) to monitor trends in Canadians' awareness, ownership and use of Bitcoin and other cryptoassets. The most recent iteration was conducted in late 2018, following an 85 percent decline in the price of Bitcoin throughout the year (**Chart 1**). In 2017, almost half of Bitcoin adopters reported investing as their primary reason for owning it, meaning that the dramatic decline in price could have implications for whether Canadians continue to own Bitcoin and, if so, how they use it.

The Bank of Canada's main interest in monitoring Bitcoin adoption is to understand how its usage by Canadians could affect the financial system. Consequently, the BTCOS will aid the Bank of Canada in understanding Bitcoin's potential impact on its core functions. First, our findings on Canadians' cash holdings and plans to go cashless may have implications for the production and distribution of Canadian currency. Regarding the Bank of Canada's role in maintaining financial stability, its 2019 *Financial System Review* (FSR) upgraded cryptoassets to one of the six key financial vulnerabilities it closely monitors. The FSR states that while cryptoassets do not currently pose a financial stability concern, the Bank of Canada will continue to monitor this rapidly evolving technology.[1] The BTCOS contributes to these efforts by characterizing the adoption of cryptoassets by Canadians, which may inform the Bank of Canada about the likelihood of risks materializing.

In 2018, Canadians continued to increase their awareness, as 89 percent reported having heard of Bitcoin. Similarly, Bitcoin ownership increased, although it remained concentrated within a few sub-demographics, such as populations that are aged 18 to 34, university educated and male. We estimate that 5 percent of Canadians owned Bitcoin in 2018, which represents an increase from 2017 (4 percent) and 2016 (3 percent). The primary reason for owning Bit-coin remained speculation in 2018, though reasons such as an interest in the technology and privacy concerns became more common compared with the previous year. While ownership has grown, we also observed an increase in the number of Canadians who reported having stopped owning Bitcoin; and those who remained owning Bitcoin tended to hold smaller amounts than in previous years.

This paper is structured as follows: **Section 2** describes the survey design and methodology of the 2018 BTCOS; **Section 3** discusses Canadians' financial literacy and their awareness and knowledge of Bitcoin; **Section 4** provides a profile of Bitcoin users in 2018; and finally, **Section 5** summarizes the overarching takeaways of the 2018 BTCOS and presents a road map going forward.

[1] Similarly, the Bank of International Settlements released a statement in March 2019 acknowledging that cryptoassets may pose future financial stability risks faced by banks.

2 The 2018 Bitcoin Omnibus Survey

This section summarizes improvements made to the survey design and weighting methodology of the 2018 BTCOS. This iteration evolved considerably from those conducted in 2016 and 2017. First, we updated how respondents report their Bitcoin holdings and how Bitcoin knowledge is assessed. We also added new questions measuring financial literacy, preferences for payment attributes when making online transactions, and plans to stop using cash. Finally, we updated the survey weighting procedure used in previous iterations.

2.1 Updated survey design

In the 2018 survey we asked respondents to report their Bitcoin holdings as a continuous variable, rounded to the nearest Canadian dollar. In contrast, previous iterations asked respondents to report their holdings in categorical ranges, which were denominated in Bitcoin. This change allows us to gain more information about the distribution of Canadians' Bitcoin holdings. When comparing our estimates across time, we group the 2018 Bitcoin holdings data into the same categories used in previous years.

We simplified the knowledge module in 2018 by reducing the number of questions asked to three. The questions, which could be answered with true, false, or don't know, tested knowledge about the total supply of Bitcoin, whether Bitcoin is backed by a government, and its public ledger (**Table 1**). Other questions asked in previous years were removed, as they had relatively fewer attempts and correct answers in the 2017 BTCOS.

Inspired by results from the Bank of Canada's 2017 Methods-of-Payment (MOP) survey (Henry, Huynh and Welte 2018), we added a module on financial literacy. Broadly speaking, financial literacy is a foundational understanding of economic and financial concepts central to economic decision making, such as investing and saving for retirement. The 2018 survey measured financial literacy using the "Big Three" questions of Lusardi and Mitchell (2011). These multiple choice questions, summarized in **Table 2**, test respondents' understanding of compound interest, inflation and the diversification of risk.

Also new to the 2018 BTCOS was a question asking respondents to rank their preferences over four features of online transactions and a question on whether respondents plan to stop using cash. The inclusion of these questions was motivated by the increasing degree of digitalization in commerce and the corresponding decline in cash use at the point of sale. These questions aim to answer whether respondents plan to go fully digital in the future, and if so, which features they value in an electronic payment method.

We report a full schematic of the 2018 survey instrument in **Appendix A.1**. Findings from the previous iterations of the Bitcoin Omnibus Survey are reported in Henry, Huynh and Nicholls (2018, 2019). Final sample sizes were 1,997 in 2016; 2,623 in 2017; and 1,987 in

2018. Similarly, we captured 58, 117 and 99 Bitcoin owners in each year, respectively. Note that all estimates for overall Canadians, such as the results found in **Table 3** and **Table 8**, include the subset of Canadians who adopted Bitcoin.

2.2 Survey methodology

We improved the survey weighting procedure in 2018 to broadly follow the methods used in Chen, Felt and Henry (2018). Using a procedure known as raking, initially outlined in Deville, Särndal and Sautory (1993), we adjusted for differences between the demographic composition of our samples and the Canadian population. Specifically, the procedure yields survey weights so that each sample of the BTCOS matches the 2016 Canadian Census, with respect to the following demographics: age, gender, region, education, marital status, employment and income. Some respondents chose not to report their employment and income status, so we utilized multiple imputation techniques to handle these missing values.

The previous version of the BTCOS weighting methodology only accounted for age, gender and region. As a result, our previous estimates may have been biased, since Bitcoin ownership is correlated with other demographic variables. For example, ownership of Bitcoin grew disproportionately among university-educated respondents between 2016 and 2018. Since BTCOS respondents tend to be more educated than the overall population, we may expect estimates of total Bitcoin ownership to be too large based solely on our sample. Consequently, we have updated our methodology and revised our estimates for all iterations of the BTCOS using the newly developed weighting methodology, which we refer to as MICAL (multiple imputation in calibration).

It is important to note that BTCOS respondents are sampled from an opt-in panel. Consequently, BTCOS participants must first choose to join the panel in order to be sampled. This means that the probability of someone in the population being sampled is unknown, which implies the BTCOS is a non-probability sample. With this in mind, we follow the guidelines laid out by the AAPOR Task Force on non-probability sampling (Baker et al. 2013). In particular, the guidelines emphasize that caution be used when reporting margins of error, as they cannot be computed reliably using data from non-probability surveys. As such, **Appendix A.2** provides an in-depth discussion of the assumptions and methods used to produce our estimates.

After the initial data collection stage, we conducted a systematic data-cleaning exercise by flagging potentially dubious respondents. First, we used the following survey questions to flag dubious responses: respondents' estimates of current Bitcoin prices, their expectations of Bitcoin's price one month ahead, their estimated likelihood that Bitcoin will survive in 15 years, their estimate of the percentage of Canadians that will adopt Bitcoin in 15 years and their share of spending using cryptoassets. For example, the first two responses

indicated how informed respondents were about the Bitcoin market. Considering that the price of Bitcoin fell substantially in November 2018, we argue that Bitcoin owners would likely have been aware of the current price level when sampled in December. After flagging the potentially dubious respondents, we performed a manual check for overall data quality. Some indicators of poor quality included streamlining (entering the same number or seemingly random numbers every time), many missing or unrealistic values, and claimed ownership of all cryptoassets listed in the survey. After the manual check, 17 dubious Bitcoin owners were dropped from the final sample.

3 Knowledge, financial literacy and awareness

This section analyzes the state of knowledge about certain aspects of Bitcoin and financial literacy, and explores the differences between Bitcoin owners and the Canadian population. Further, we examine how awareness of Bitcoin has evolved since previous iterations of the BTCOS.

3.1 Bitcoin knowledge and financial literacy in 2018

We report the Bitcoin knowledge module and the "Big Three" financial literacy questions from Lusardi and Mitchell (2011) in **Table 1** and **Table 2**, respectively. For each set of questions, we computed an overall measure by summing the number of correct answers and subtracting incorrect answers, while questions answered "don't know" did not contribute to the measure. Our measure, denoted *score*, can take any integer from -3 to 3, with 3 indicating all questions were answered correctly and -3 indicating all were answered incorrectly. Knowledge and literacy were categorized as low ($score \leq 0$), medium ($score = 1$ or $score = 2$) or high ($score = 3$).

Notably, we found no change in Bitcoin knowledge from 2017 to 2018, in contrast to the sizable increase previously observed between 2016 and 2017. In 2018, almost two-thirds of Canadians had low Bitcoin knowledge and only 6 percent answered all three questions correctly (**Table 3**). As expected, knowledge scores were higher among Bitcoin adopters. In particular, non-adopters were much more likely to answer "don't know" to a knowledge question (almost 50 percent) compared with Bitcoin adopters (less than 15 percent). However, Bitcoin knowledge was not universal even among those who owned the digital currency, with about one-fifth of adopters having low knowledge.

Consistent with the 2017 MOP Survey (Henry, Huynh and Welte 2018), we found that 27 percent of Canadians had low financial literacy and 36 percent had a medium level of financial literacy (**Table 3**). Moreover, 37 percent answered all three questions correctly,

indicating high financial literacy. While the share of Canadians with high financial literacy may seem low, Canada has historically scored better than many other developed countries (Lusardi and Mitchell 2014).

3.2 Canadians' awareness of Bitcoin

Awareness of Bitcoin continued to increase in 2018, with 89 percent of Canadians stating they had heard of Bitcoin, compared with 83 percent in 2017 and 62 percent in 2016. Most demographic patterns observed in previous years persisted in 2018 (**Table 4**). In particular, Canadians who were male, young, university educated or had high household income were more likely to be aware of Bitcoin. However, gaps in awareness decreased as those groups who were less aware of Bitcoin in previous years became more aware in 2018. For example, awareness among males grew marginally from 90 to 93 percent, while awareness among females increased from 77 percent to 85 percent. Other examples of demographic groups catching up include those who have a high school education (76 to 84 percent) and those with household incomes below $30,000 (74 to 87 percent). Finally, as expected we found that higher financial literacy was associated with higher awareness.

4 A profile of Bitcoin adopters in 2018

In this section, we analyze the demographic composition of Bitcoin ownership in Canada. We also discuss cross-validation of our estimates using other surveys on Bitcoin adoption and we utilize regression analysis to drill down further on Bitcoin ownership. Moreover, we delineate the main reasons respondents gave for owning Bitcoin and we study how preferences over features of online transactions differed between Bitcoin adopters and overall Canadians. Further, we analyze the group of past owners and the changes in Bitcoin holdings amongst adopters. Lastly, we study the interplay between cash holdings and Bitcoin adoption, as well as Canadians' plans to go cashless.

4.1 Ownership of Bitcoin in 2018

Bitcoin ownership continued to increase in 2018; we estimate that 5 percent of Canadians owned Bitcoin in 2018, an increase from 4 percent in 2017 and 3 percent in 2016 (**Table 5**). However, Bitcoin ownership did not increase for all demographic groups. For instance, male ownership remained constant at around 6.7 percent, while female ownership increased from 2.1 to 3.7 percent. Similarly, ownership for those aged 18 to 34 remained relatively unchanged in 2018, while ownership tripled among those aged 55 and older from 0.5 to 1.7 percent.

In contrast, the disparity in ownership by education widened. Ownership among the high-school-educated demographic fell from 3.7 to 2.3 percent, while university-educated Canadians increased their ownership from 6.7 to 9.1 percent. Additionally, ownership fell from 4.3 to 2.8 percent among those with household incomes below $30,000 and rose from 4.3 to 7.0 percent among those with incomes above $70,000, creating an ownership gap that did not exist in previous years. Geographically, ownership in the Prairies and British Columbia continued to rise, while Quebec and the Atlantic region experienced a decline in ownership during 2018.

Bitcoin owners were more likely to have low financial literacy (38 percent), compared with the overall population (27 percent) (**Table 3**). In particular, we estimate that 4.1 percent of Canadians with high financial literacy owned Bitcoin, compared with 7.3 percent of those with low literacy. This yields an interesting result, as those with high financial literacy are more likely to have heard of Bitcoin but less likely to adopt it. Technology adoption among those with lower literacy has also been observed by Lusardi, Scheresberg and Avery (2018), who found higher financial literacy was negatively associated with using mobile payments.

The 2018 BTCOS also asked respondents to report if they owned alternative cryptoassets, which are often referred to as altcoins. We estimate that over half of Bitcoin adopters, or 3.2 percent of all Canadians, owned at least one altcoin. A further 1.6 percent reported owning altcoins but not Bitcoin. The most commonly owned altcoins were Bitcoin Cash (3 percent) and Ethereum (2 percent).

To cross-validate our estimates, we compare results with the Ontario Securities Commission (OSC), which surveyed over 2,500 Ontarians in March 2018 regarding their views on cryptoassets (Ontario Securities Commission 2018). This acts as a good source of external validation, as the OSC used a different survey provider and sampling methodology but included several of the same survey questions. The OSC estimates that 5 percent, or approximately 500,000 Ontario residents, owned Bitcoin and an additional 4 percent owned Bitcoin in the past. The BTCOS estimates the same for ownership (5 percent) and slightly lower for past ownership (3 percent). Similarly, the Canadian Consumer Payments Survey, conducted by Technology Strategies International, estimates that 3.9 percent of Canadians owned Bitcoin in 2019 (Technology Strategies International 2019).

Surveys from other countries on the adoption of Bitcoin provide another source of cross-validation. Stix (2019) estimates 1.5 percent of Austrians owned Bitcoin in 2018. The United Kingdom's Financial Conduct Authority conducted a survey in 2018 and concluded Bitcoin ownership was 3 percent (Financial Conduct Authority 2019). Closer to home, in 2018 the Federal Reserve Bank of New York added several questions on cryptoassets to their Survey of Consumer Expectations and found that 85 percent of respondents had heard of cryptoassets, while 5 percent reported they currently or previously owned them (Hundtofte

et al. 2019). Together, these other surveys provide evidence that the magnitude of our ownership estimates are reasonable.

4.2 Regression analysis of awareness and ownership

We complement our analysis of Canadians' awareness and ownership of Bitcoin by employing a logistic regression framework, which allows us to control for all demographics simultaneously. Being aware of Bitcoin and deciding to own Bitcoin are both binary events, making logistic regression a natural choice. In particular, we model choices as a sequential logit, where one first becomes aware of Bitcoin, then chooses whether to own it. In this way we can decompose demographic effects on ownership into these two stages. **Table 6** reports our estimates of the awareness stage (column 1), ownership stage conditional on awareness (column 2) and overall ownership taking into account both stages (column 3). All estimates reported represent the marginal effect of each demographic variable on the outcome variable of interest, holding all other demographic variables constant.

In all three regression models, we include dummy variables for the following demographic variables: age, gender, region, education, martial status, employment and income. We also include dummy variables for responses to each financial literacy question. We have specified the model so that marginal effects are measured relative to the following reference groups: male, aged 18 to 24, from British Columbia, high school educated, married, employed full time, earning income less than $25,000, and who have correctly answered each financial literacy question.

We find that the likelihood of Bitcoin awareness declines with age, being female and living in regions outside British Columbia. Conversely, we estimate Canadians are more likely to be aware of Bitcoin as their education and income increases, as well as if they answer any financial literacy question correctly. These findings are largely consistent with our unconditional, tabular analysis discussed in **Section 3.2**.

The second column displays our estimates of the probability of Canadians owning Bitcoin, conditional on being aware of it. Our results are consistent with our findings in the first column and our discussion in **Section 4.1**. In particular, we estimate that the probability of ownership, conditional on awareness, decreases with age and for Canadians living outside British Columbia. Conversely, we estimate that the likelihood of ownership increases with income and education, as well as with being unemployed. As we previously noted, we find that Bitcoin awareness increases with financial literacy but the likelihood of ownership decreases as financial literacy increases. This finding is also present in the logit framework, as all coefficients on the incorrect component of each financial literacy question became positive in the second column.

Finally, the third column of **Table 6** reports our findings from the full sequential logit

model. These estimates support our previous findings: that ownership decreases with age and location but increases with education and income. In particular, we estimate the likelihood of Canadians owning Bitcoin, conditional on holding all other demographics constant, is 8 percentage points lower if they are aged 55 or older than if they are between 18 and 24 years old. Similarly, we estimate Canadians are 3 percentage points more likely to own Bitcoin if they are university educated as opposed to only graduating from high school, holding all other demographic variables constant. The most interesting finding is the net positive correlation between low financial literacy and Bitcoin ownership. For example, we estimate that failing to understand the diversification of risk is associated with an increase in the likelihood of Bitcoin ownership by 6 percentage points.

4.3 Why do Canadians own Bitcoin?

We study Canadians' usage of Bitcoin to pay for goods and services (**Chart 2a**) or to send peer-to-peer payments (**Chart 2b**). An overarching trend emerged in 2018 for both types of transactions: Bitcoin adopters are trending toward using Bitcoin more frequently for transactions. The observation is consistent with the increasing trend in aggregate Bitcoin transactions throughout 2018, reported in **Chart 1**.

Table 7 summarizes the share of adopters who reported each category as their primary reason for owning Bitcoin. In 2018, speculation decreased from 56 to 40 percent but remained the most selected option. Moreover, privacy-related reasons tripled to 19 percent and payments remained stable around 20 percent. Further, interest in the technology increased from 16 to 22 percent, approaching the level observed in 2016, prior to the large run-up in prices.

Henry, Huynh and Welte (2018) found that Canadians aged 18 or older made 82 percent of transactions with credit and debit cards in 2017. Similarly, Statistics Canada's Digital Economy Survey (DES) found that for 76 percent of their personal spending, Canadians used digital payment methods. Moreover, the DES found that almost 80 percent of Canadians purchased or used free versions of digital products, such as music, e-books, mobile applications and computer software (Statistics Canada 2018).

Given the upward trend of digitalization in commerce, we added a question in the 2018 BTCOS asking respondents to rank their preferences over four features of online transactions: privacy, security, ease of use and acceptance. **Table 8** reports the share of Bitcoin owners and overall Canadians who ranked each feature from most to least important. Two clear trends emerge: typical Canadians value the security of online transactions much more than Bitcoin adopters, and Bitcoin adopters tend to have more varied preferences than typical Canadians. While Bitcoin adopters tend to prefer privacy almost twice as much as typical Canadians, a similar finding is present for the acceptance and ease-of-use features.

Further research is required to reconcile these results, as cryptoassets tend to be viewed as a form of privacy-enhancing technology. Moreover, cryptoassets have much lower acceptance rates by merchants and are significantly less easy to use than traditional payment methods, such as cash or contactless credit cards. As a result, one would expect Bitcoin adopters to rank privacy higher than all other features and place less emphasis on ease of use and acceptance. This finding is related to the privacy paradox, found by Athey, Catalini and Tucker (2017), which states that despite people saying they care about privacy, they are willing to relinquish private data for a relatively small incentive. The 2018 BTCOS results are related because Bitcoin adopters did not report valuing privacy significantly more than other features of online transactions, despite Bitcoin's pseudo-anonymous design.

4.4 Trends in past ownership of Bitcoin

We classify past owners as the group of Canadians who once adopted Bitcoin but have decided to stop owning it as of the time they are surveyed. As **Chart 3** shows, around 2 percent of Canadians were past owners in 2016, and this share decreased to 1 percent in 2017 as Bitcoin's price rose. However, in 2018, after a dramatic drop in the price of Bitcoin, the share of past owners grew once again to 3 percent. Taken on face value, the fact that current *and* past ownership grew in 2018 suggests an influx of new Bitcoin owners who then quickly sold their Bitcoin in between the 2017 and 2018 surveys, and suggests that a total of 8 percent of Canadians have ever owned Bitcoin.

In 2018, almost 50 percent of past users reported one of three main reasons for not owning Bitcoin. Consistent with results from **Section 3.1**, the most common reason provided was that they do not understand enough about the technology. Other reasons included that they do not trust privately issued currencies, and that they do not believe the Bitcoin system will survive in the future.

Since the 2017 BTCOS was conducted, Canada has experienced two major incidents with cryptoasset exchanges: Edmonton-based Maple Change lost $6 million of users' funds in October 2018, and QuadrigaCX lost access to customers' funds in January 2019, resulting in losses over $260 million (Ernst and Young 2019). Furthermore, the Canadian Securities Association and the Investment Industry Regulatory Organization of Canada recently proposed a regulatory framework for cryptoasset exchanges and platforms. In light of these events, we will consider asking respondents if these events had an impact on their Bitcoin adoption in the next iteration of the survey.

4.5 Bitcoin holdings

We estimate the median amount of Bitcoin holdings in 2018 to be $600. The holdings question was asked differently in previous years, so for comparisons over time we group 2018 numbers into ranges, shown in **Chart 4**. We found a decrease in the share of Canadians who reported holding 1 to 10 Bitcoin and 10 or more Bitcoin, offset by a sizable increase in the share of Canadians who reported owning less than 1 Bitcoin. Together, these observations suggest that Canadian's median holdings, denominated in Bitcoin, decreased in 2018.

4.6 Cash holdings and plans to go cashless

Based on the results of the 2017 and 2018 BTCOS, as well as Henry, Huynh and Welte (2018), three different Canadian survey instruments yield the same conclusion: Bitcoin adopters hold more cash than typical Canadians (**Table 9**). The 2018 BTCOS estimates Canadians' median cash on hand to be $40, while the subset of Bitcoin adopters have median cash holdings of $200. Interestingly, the share of the population that reported currently holding no cash was stable at around 8 percent across all survey instruments and for both Bitcoin adopters and typical Canadians.

Motivated by Engert, Fung and Hendry (2018), who discuss the potential implications of a cashless society in Canada, the 2018 BTCOS included a question on whether respondents have stopped using cash or plan to stop in the future (**Table 9**). We found that Bitcoin owners were more likely to report having stopped using cash (18 percent) and having plans to go cashless within the next five years (17 percent). In comparison, the overall Canadian average was 7 percent and 5 percent, respectively.

Given this finding, an interesting puzzle emerges: Bitcoin adopters hold more cash than typical Canadians but are more likely to go cashless. This puzzle may be driven by a key distinction between interpretations of going cashless. That is, some Canadians may interpret being cashless as ceasing to use cash for transactions. Others may have a stronger interpretation: that, along with ceasing to use cash for transactions, being cashless implies one no longer holds cash for precautionary savings or as a store of value. The Bank of Canada plans to conduct further research on the transactional and non-transactional roles of cash in Canada.

5 Discussion

Findings from the BTCOS suggest that between 2016 and 2018 the share of Canadians who were aware of Bitcoin increased from 62 percent to 89 percent and of those who owned Bitcoin increased from 3 percent to 5 percent. However, consistent with dramatic drops in

Bitcoin prices in 2018, we also observed an increase in the number of past owners of Bitcoin, and those who continued to own Bitcoin did so in slightly smaller quantities. As in 2017, the main reason for owning Bitcoin remained as speculation, though this reason was less common in 2018. In contrast, Bitcoin owners reported using it more often for buying goods and services or making person-to-person transfers in 2018.

While overall ownership increased, this was not uniform across demographics. For example, while there was little change in ownership among men or those aged 18 to 34, ownership increased more among women and those aged 35 or older. Further, those with high education or household income have become much more likely to own Bitcoin than their counterparts with low education or income. Inspired by the work of Lusardi and Mitchell (2011), we included the "Big Three" financial literacy questions on the 2018 BTCOS. We found that, despite the fact that higher-literacy individuals were more likely to have heard of Bitcoin, they were less likely to own it.

New to the survey were questions related to cash and online payment preferences. We found that, while Bitcoin owners held more cash in their pockets at the median, they were more likely to say they had already stopped using cash. This presents something of a puzzle, which may be explained by how respondents interpret the phrase "stop using cash." For example, someone could claim to have stopped using cash at the point of sale, while still holding cash for precautionary purposes. Future surveys by the Bank of Canada will delve deeper into how respondents plan to use their cash for transactional or non-transactional purposes. We also asked respondents which features of online transactions they viewed as most important. Overall, Canadians rated security the most important feature, while privacy, acceptance and ease of use were much less common. The subset of Bitcoin adopters had much more varied preferences, with about an equal share of Canadians rating each attribute the most important.

Going forward, the Bank of Canada will continue to monitor the awareness and ownership of Bitcoin in Canada using the BTCOS. To address this goal, we will continue to improve the design of the BTCOS. Regarding our sampling methodology, for the next iteration of the BTCOS we are considering implementing a choice-based sampling procedure, as discussed in Cosslett (1981). This methodology involves over-sampling Bitcoin adopters, relative to typical Canadians, and then taking into account the increased sampling probability in our weighting methodology. This approach will allow us to obtain more observations of Bitcoin adopters, to produce more granular analysis and to improve statistical precision while maintaining comparability across previous iterations of the BTCOS.

In addition, we may include several new survey questions in the next BTCOS to improve our understanding of Canadians' awareness and ownership. For example, we may ask Bitcoin adopters if they initially obtained their Bitcoin through a cryptoasset exchange, an auto-

matic teller machine, mining, a peer-to-peer transaction or another source. Also, we may ask Canadians about their awareness of the proposed regulatory framework surrounding cryptoassets in Canada and whether the recent experiences involving cryptoasset exchanges have discouraged them from adopting Bitcoin. Such questions may provide evidence of a negative demand shock arising from the recent incidents involving cryptoasset exchanges in Canada. Finally, we may add questions concerning expected lotteries to elicit Canadians' preferences regarding risk. Our hypothesis is that Bitcoin adopters have a low degree of risk aversion relative to typical Canadians, as the price of Bitcoin has historically been very volatile.

Regarding the Bank of Canada's broader mandate, we will continue to monitor the interplay between Canadians' adoption of Bitcoin and their current and planned cash usage. Given its role as the sole issuer of currency in Canada, the Bank of Canada is also interested in understanding Canadians' adoption and usage of privately issued digital currency. One such form, known as stablecoins, is a form of digital money that is designed to maintain a fixed peg with an underlying currency or asset. Correspondingly, we may also study Canadians' views of the emergence this new type of privately issued digital currency and to what extent they would adopt this technology for payments.

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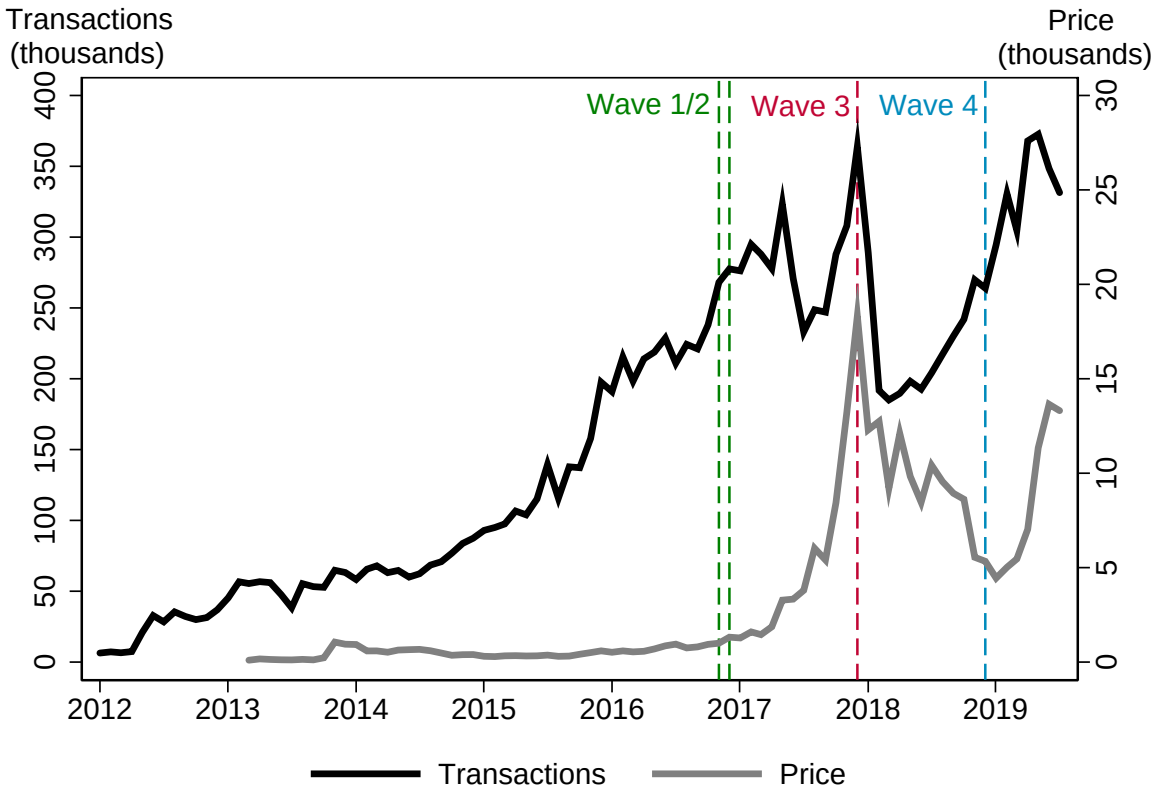
Chart 1: **Price and number of Bitcoin transactions, 2012–19 (monthly average)**

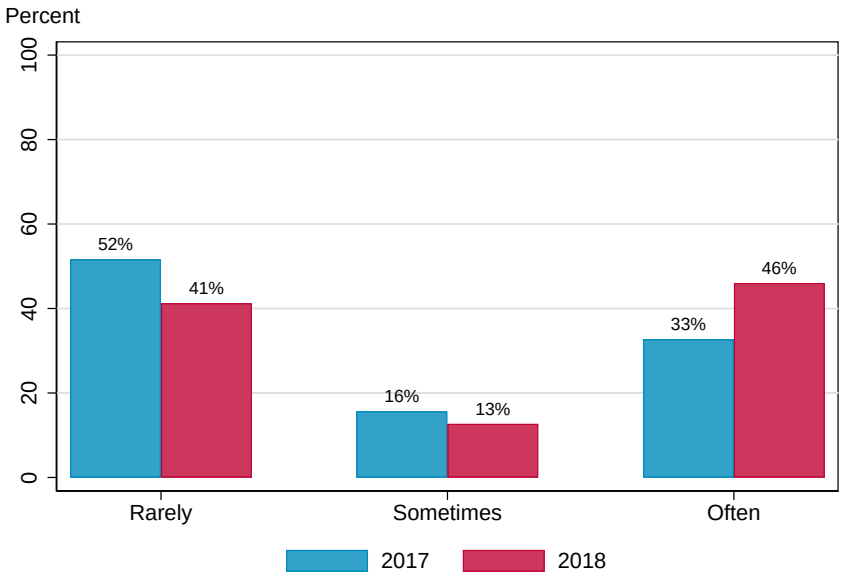


Note: This graph shows the price of Bitcoin in Canadian dollars and the number of daily transactions made with Bitcoin, averaged over each month from January 2012 to January 2019. The data series for price starts at March 12, 2013. The green vertical lines show when the first two waves of the BTCOS were in the field, the red vertical line shows the third wave and the blue line indicates the most recent iteration, the 2018 BTCOS. The last monthly observation is July 2019.

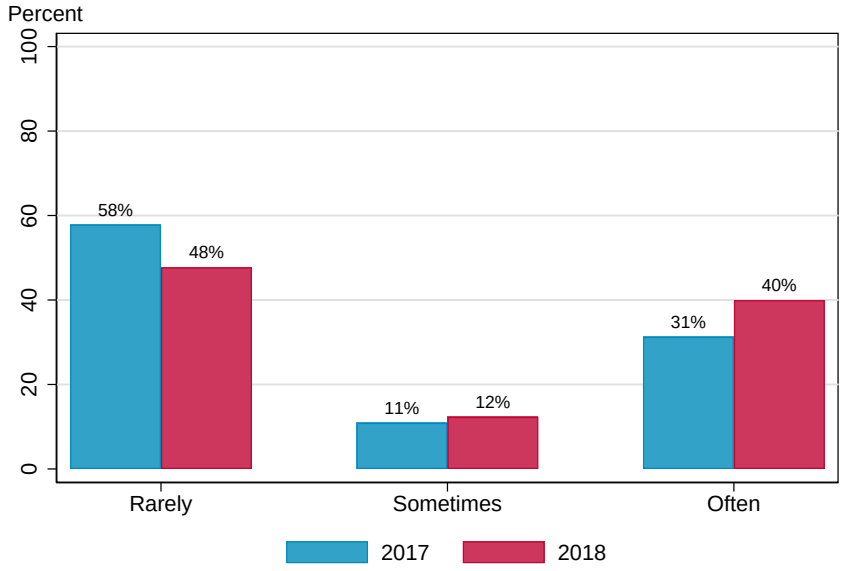
Sources: Daily Transactions (*Charts.Bitcoin.com/BTC*); Bitcoin Prices (BTC/CAD) (*Yahoo! Finance*).

Chart 2: **Use of Bitcoin, 2017–18**

(a) **Buying goods and services**

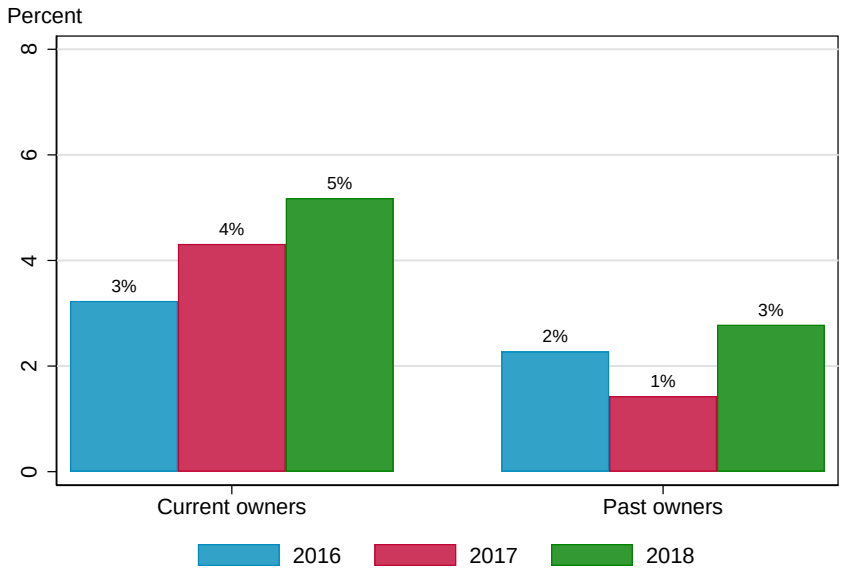


(b) **Making person-to-person transfers**



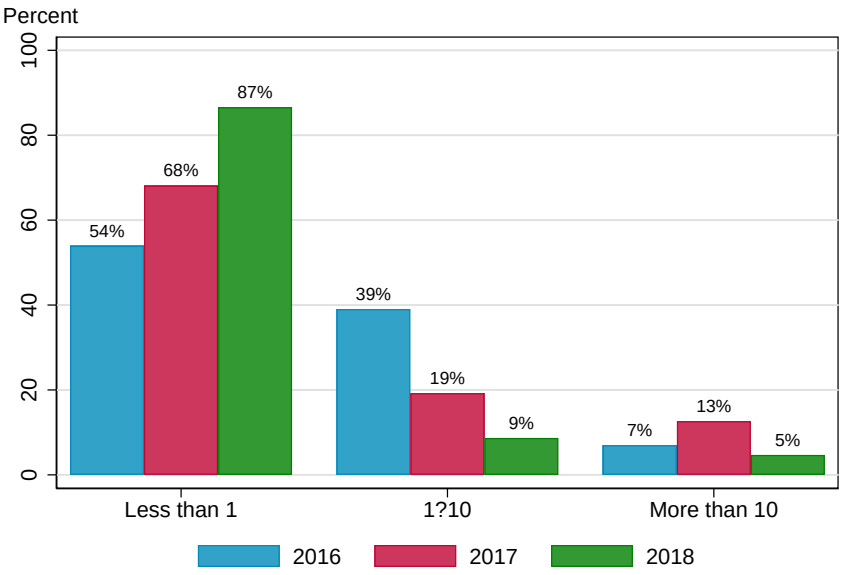
Note: The "Rarely" category consists of Canadians who used Bitcoin at most once a year for transactions. The "Sometimes" category constitutes those who used Bitcoin between a few times a year to once a month, and "Often" constitutes those who used Bitcoin at least a few times a month for transactions. The sample consists of 99 Canadians aged 18 or older who reported they owned Bitcoin in 2018; and similarly, 117 in 2017. All estimates were calculated using MICAL (multiple imputation in calibration) survey weights.

Chart 3: **Current and past ownership of Bitcoin, 2016–18**



Note: The sample includes 99 Canadians aged 18 or older who reported they owned Bitcoin in 2018; similarly, 117 in 2017, and 58 in 2016. Additionally, the sample includes 45 past owners in 2018, as well as 37 in 2017, and 41 in 2016. All estimates were calculated using MICAL (multiple imputation in calibration) survey weights.

Chart 4: **Bitcoin holdings, 2016–18**



Note: In 2018, we asked respondents to report their holdings as a continuous range, denominated in Canadian dollars. For comparability across years, in 2018 we used the prevailing price when the survey was conducted to denominate respondents' holdings in Bitcoin. The sample consists of 99 Canadians aged 18 or older who reported they owned Bitcoin in 2018; similarly, 117 in 2017, and 58 in 2016. All estimates were calculated using MICAL (multiple imputation in calibration) survey weights.

Table 1: **Bitcoin knowledge questions**

Question	Response options
The total supply of Bitcoin is fixed.	**True** False
Bitcoin is backed by a government.	True **False**
All Bitcoin transactions are recorded on a distributed ledger that is publicly accessible.	**True** False

Note: This table shows the three Bitcoin knowledge questions, which were also asked in the 2017 BTCOS. The correct answers are highlighted in bold.

Table 2: **Financial literacy questions**

Concept	Question	Response options
Interest	*Suppose you had $100 in a savings account and the interest rate was 2% per year. After 5 years, how much do you think you would have left in the account if you left the money to grow?*	**More than $102** Exactly $102 Less than $102 Do not know
Inflation	*Imagine the interest rate on your savings account was 1% per year and inflation was 2% per year. After 1 year, how much would you be able to buy with this money in this account?*	More than today Exactly the same **Less than today** Do not know
Risk	*Please tell me whether or not this statement is true or false: Buying a single company's stock usually provides a safer return than a mutual fund of stocks.*	True **False** Do not know

Note: This table reports the "Big Three" financial literacy questions, developed by Lusardi and Mitchell (2011). The "Big Three" questions have been used in many research papers to study financial literacy, including Henry, Huynh and Welte (2018), which yields comparability across survey instruments, countries and time. The correct answers are highlighted in bold.

Table 3: **Financial literacy and Bitcoin knowledge scores**

	Financial literacy		**Bitcoin knowledge**			
	2018		2017		2018	
	Overall	Adopters	Overall	Adopters	Overall	Adopters
Low	27	38	55	24	61	19
Medium	36	33	38	49	33	52
High	37	29	6	27	6	29

Note: This table reports the share of Canadians, in percent, in each category of financial literacy or Bitcoin knowledge. The sample consists of 99 adopters in 2018 and 117 in 2017. All estimates were calculated using MICAL (multiple imputation in calibration) survey weights.

Table 4: **Awareness of Bitcoin in Canada, 2016–18**

	2016	2017	2018
Overall	62	83	89
Gender			
Male	71	90	93
Female	54	77	85
Age			
18–34	69	87	91
35–54	58	82	88
55+	62	82	88
Education			
High school	55	76	84
College	59	85	90
University	78	92	95
Income ($)			
<30,000	49	74	87
30,000–69,999	61	82	88
70,000+	69	87	91
Region			
British Columbia	74	93	94
Prairies	66	84	89
Ontario	64	85	92
Quebec	49	75	84
Atlantic	65	80	83
Financial literacy			
Low	.	.	80
Medium	.	.	90
High	.	.	94

Note: This table reports the percentage of Canadians who were aware of Bitcoin in 2016, 2017 and 2018. The sample consists of 99 adopters in 2018, 117 in 2017 and 58 in 2016. All estimates were calculated using MICAL (multiple imputation in calibration) survey weights.

Table 5: **Ownership of Bitcoin in Canada, 2016–18**

	2016	2017	2018
Overall	3.2	4.3	5.2
Gender			
Male	4.4	6.6	6.7
Female	2.2	2.1	3.7
Age			
18–34	9.1	11.1	10.5
35–54	1.6	3.2	4.9
55+	0.5	0.5	1.7
Education			
High school	3.8	3.7	2.3
College	1.5	3.1	5.7
University	4.3	6.7	9.1
Income ($)			
<30,000	3.1	4.3	2.8
30,000–69,999	3.9	5.6	4.8
70,000+	3.7	4.3	7.0
Region			
British Columbia	2.8	5.2	6.3
Prairies	2.1	4.1	6.0
Ontario	2.5	3.9	5.2
Quebec	5.5	5.1	4.6
Atlantic	3.2	3.1	2.8
Financial literacy			
Low	.	.	7.3
Medium	.	.	4.7
High	.	.	4.1

Note: This table reports the percentage of Canadians who owned Bitcoin (answered"Yes" to "Do you currently have or own Bitcoin?") in 2016, 2017 and 2018. The sample consists of 99 adopters in 2018, 117 in 2017 and 58 in 2016. All estimates were calculated using MICAL (multiple imputation in calibration) survey weights.

Table 6: **Regression analysis of Bitcoin ownership**

	Pr(Aware)	**Pr(Own|Aware)**	**Pr(Own)**
Age			
25–34	-2.0	2.3	1.9
35–44	-3.9	-3.8	-3.7
45–54	-5.0 **	-7.3 **	-6.9 **
55–64	-5.0 **	-8.7 ***	-8.2 ***
65+	-4.2	-8.1 **	-7.6 **
Gender			
Female	-5.2 ***	-4.3 ***	-4.2 ***
Region			
Prairies	-2.9	0.1	-0.0
Ontario	-1.1	-0.7	-0.7
Quebec	-8.2 ***	-0.7	-1.1
Atlantic	-5.6 *	-1.2	-1.4
Education			
College	4.2 **	2.5 *	2.3 **
University	7.1 ***	3.4 **	3.3 ***
Martial status			
Single	4.3 ***	-1.7	-1.4
Employment			
Unemployed	-0.9	2.3	2.0
Not in labour force	0.6	-1.7	-1.6
Income ($)			
25,000–44,999	-1.3	1.6	1.4
45,000–64,999	1.2	3.4 **	3.1 **
65,000–84,999	1.1	4.4 **	4.0 **
85,000+	1.5	3.8 **	3.5 **
FL1 – Interest			
Incorrect	-1.5	3.6 *	3.2 *
Don't know	-8.4 ***	1.5	1.0
FL2 – Inflation			
Incorrect	-5.0 ***	1.5	1.1
Don't know	-0.4	-1.5	-1.4
FL3 – Risk			
Incorrect	-4.5	6.7 ***	5.7 **
Don't know	-5.8 ***	-0.0	-0.2

Note: This table displays marginal effects from a sequential logit of Bitcoin awareness and ownership. Column **Pr(Aware)** shows the effect of each variable on the probability of having heard of Bitcoin. Column **Pr(Own|Aware)** shows the effect of each variable on the probability of owning Bitcoin conditional on having heard of it. The final column shows the overall net effect on the probability of ownership given that Pr(Own) = Pr(Own|Aware)*Pr(Aware). FL1, FL2, and FL3 refer to the three financial literacy questions listed in **Table 2**. *** $p < 0.01$ ** $p < 0.05$ * $p < 0.1$. Missing values for employment and income are multiply imputed using the model described in **Section A.2.6**.

Table 7: **Main reason for ownership, 2016–18**

	2016	2017	2018
Payment related	45	23	19
Store of value (investment)	6	56	40
Trust/privacy related	16	5	19
Technology related	33	16	22

Note: This table reports the percentage of Canadians who chose each category as their primary reason for owning Bitcoin in 2016, 2017 and 2018. Each column sums vertically but may sum to less than 100 percent, as we have omitted some options when consolidating the four categories. The sample consists of 99 adopters in 2018, 117 in 2017 and 58 in 2016. All estimates were calculated using MICAL (multiple imputation in calibration) survey weights.

Table 8: **Preferences for online transactions, Canadians vs. adopters**

	Overall Canadians				**Bitcoin adopters**			
	Privacy	Security	Acceptance	Ease	Privacy	Security	Acceptance	Ease
Most	14	61	11	15	26	28	20	26
More	39	19	20	22	26	28	20	26
Less	22	12	29	37	22	26	29	23
Least	25	8	40	26	26	18	31	25

Note: This table shows the percentage of Canadians who ranked each feature of online transactions, from most to least important. The estimates in each column sum vertically to 100 percent. The sample consists of 99 adopters in 2018, 117 in 2017 and 58 in 2016. All estimates were calculated using MICAL (multiple imputation in calibration) survey weights.

Table 9: **Cash management and Bitcoin adoption, 2017–18**

	Median ($)	No cash on hand (%)	Already cashless (%)	Plans to go cashless within 5 years (%)
Overall				
2017 MOP	40	9	.	.
2017 BTCOS	40	8	.	.
2018 BTCOS	40	8	7	5
Adopters				
2017 MOP (4.0%)	65	8	.	.
2017 BTCOS (4.3%)	100	4	.	.
2018 BTCOS (5.2%)	200	8	18	17

Note: We report results from three surveys conducted by the Bank of Canada: the 2017 BTCOS, the 2018 BTCOS and the 2017 Methods-of-Payment (MOP) Survey. The sample consists of 99 adopters in 2018 and 117 in 2017. All BTCOS estimates were calculated using MICAL (multiple imputation in calibration) survey weights and the 2017 MOP estimates used survey weights as well.

A Appendix

A.1 2018 BTCOS survey instrument

1a. Have you heard of Bitcoin?
Yes No
[IF YES TO Q1, ASK Q1b, ELSE SKIP TO Q5]

1b. Please indicate whether the following statements about Bitcoin are true or false. If you are unsure, please select ‘‘Don’t know’’.

[COLUMNS]
True
False
Don’t know

[ROWS: RANDOMIZE]
The total supply of Bitcoin is fixed. [True]
Bitcoin is backed by a government. [False]
All Bitcoin transactions are recorded on a distributed ledger that is publicly accessible. [True]

2. Do you currently have or own any Bitcoin?
Yes No

[IF YES TO Q2, ASK Q3a and Q3b, ELSE SKIP TO Q4a]
3a. Please tell us your main reason for owning Bitcoin.
(Select one)
[RANDOMIZE LIST]
I am interested in new technologies
It is an investment
I use it to buy goods and services on the internet in Canada/elsewhere
I use it to buy goods and services in physical stores in Canada/elsewhere
It allows me to make payments anonymously
I use it to make remittances or other international payments
It uses secure blockchain technology to prevent loss and fraud
I do not trust banks
I do not trust the government or the Canadian dollar

My friends own Bitcoin
It is a cost saving technology
[ANCHOR] Other (specify)

3b. What is the value, in Canadian dollars, of the Bitcoin you currently own? (Please round off to the nearest dollar)
[INSERT NUMERIC BOX]
$ _____ CAD
Unsure/would rather not say

[IF NO TO Q2, ASK Q4a and Q4b, ELSE SKIP TO Q5]
4a. Have you owned or used Bitcoin in the past, but subsequently stopped using it?
Yes No

4b. Please tell us your main reason for not owning any Bitcoin.
[RANDOMIZE LIST]
I do not understand/know enough about the technology
It is not widely accepted as a method of payment
My current payment methods meet all my needs
The value of Bitcoin varies too much
It is not easy to acquire/use
I do not trust a private currency that is not backed by the central government
I am concerned about cyber theft
I am concerned about lack of oversight from regulatory bodies
I use alternative digital currencies instead (e.g. Dogecoin, Litecoin, Ripple,etc)
I do not believe the Bitcoin system will survive in the future
[ANCHOR] Other (specify)

[ASK ALL]
5. Please rank the following features from 1-4 in terms of how important they are for making payments online via the internet ("1" = most important, "2" = 2nd most important, etc.).
[RANDOMIZE] [DROP DOWN BOX BESIDE EACH ITEM. EACH NUMBER CAN ONLY BE USED ONCE]
Privacy/anonymity
Security

Widely accepted
Ease of use

[IF NO TO Q1, SKIP TO Q12 ELSE CONTINUE]
6a. How likely do you think it is that the Bitcoin system will fail
or survive in the next 15 years?
Please use the sliding scale where 0 means that the system
will certainly fail and 100 means the system will certainly survive.
[INSERT SLIDING SCALE WITH WORD ANCHORS]
[DO NOT PUT THE NUMBER 0 OR 100 WITHIN THE WORD ANCHOR BOX]

6b. What percentage of Canadians do you predict will be
using Bitcoin 15 years from now?
Please use the sliding scale where 0 means no Canadians will be
using Bitcoin and 100 means all Canadians will be using Bitcoin.
[INSERT SLIDING SCALE WITH WORD ANCHORS]
[DO NOT PUT THE NUMBER 0 OR 100 WITHIN THE WORD ANCHOR BOX]

7a. What is the current price of Bitcoin?
Please provide your best estimate in Canadian dollars.
Please round to the nearest dollar.
[INSERT NUMERIC BOX]
1 BTC = $ _____ CAD

7b. The current price of one Bitcoin is around $4,649 [INSERT RELEVANT PRICE
EACH MORNING WHILE THE SURVEY IS IN THE FIELD] Canadian,
as of this morning. What do you expect the price of Bitcoin to be in one month?
Please provide your best estimate in Canadian dollars.
Please round to the nearest dollar.
[INSERT NUMERIC BOX]
1 BTC = $_____ CAD

8. Do you hold any of the following other digital currencies?
(Please check all that apply) [RANDOMIZE LIST]
Ethereum
Bitcoin Cash
Ethereum Classic

Litecoin
Dash
Ripple
[ANCHOR] Other (please specify) [PROVIDE TEXT BOX FOR RESPONSE] [DO NOT CODE]
[ANCHOR] No, do not hold any other digital currencies

9. Approximately how often do you use Bitcoin to pay for goods and services? (Please select the most appropriate response)
Once a week or more
A few times a month
Once a month
A few times a year
Once a year
I have used Bitcoin to pay for goods and services once or twice, but not on a regular basis
I have never used Bitcoin to pay for a good/service

10. Approximately how often do you use Bitcoin to send money to other people? (Please select the most appropriate response)
Once a week or more
A few times a month
Once a month
A few times a year
Once a year
I have used Bitcoin to send money to other people once or twice, but not on a regular basis
I have never used Bitcoin to send money to other people

[ASK Q11a IF YES TO Q2 OR IF NO TO Q8, ELSE SKIP TO Q12]
11a. In the past 12 months, what percentage of your total personal spending was made with cryptocurrencies?
[INSERT NUMERIC BOX]%

[ASK Q11B IF Q11a DOES NOT EQUAL ZERO, ELSE SKIP TO Q12]
11b. In the past 12 months, how much cash value did you spend in cryptocurrencies?
$[INSERT NUMERIC BOX]

[ASK ALL]
12. Thinking now about regular Canadian currency, how much cash do you currently have in your purse, wallet, or pockets? (Please include dollars and cents)
$_____.___

13. Suppose you had $100 in a savings account and the interest rate was 2% per year. After 5 years, how much do you think you would have left in the account if you left the money to grow?
More than $102
Exactly the same
Less than $102
Don't know

14. Imagine the interest rate on your savings account was 1% per year and inflation was 2% per year. After 1 year, how much would you be able to buy with this money in this account?
More than today
Exactly the same
Less than today
Don't know

15. Please tell me whether or not this statement is true or false: "Buying a single company's stock usually provides a safer return than a mutual fund of stocks".
True
False
Don't know

16a. How would describe your current credit rating? If you don't have a sense of what your credit rating would be, please select "Not Sure".
Very poor (500 or less)
Poor (500-550)
Fair (551-640)
Good (641-720)
Excellent (721 or more)

Not sure

[IF NOT SURE TO Q16a, SKIP TO Q17 ELSE CONTINUE]
16b. If you know your exact credit score, please write it in:
[PROVIDE NUMERIC INPUT BOX]PRANGE 0-999]
Not sure

17. Do you currently have any plans to stop using cash in the future?
No, I do not have any plans to stop using cash
Yes, I have already stopped using cash
Yes, in the next 12 months
Yes, 2 to 5 years from now
Yes, more than 10 years from now
I'm not sure

[IF YES TO Q2 AND RESPONDENT IS FROM AMPARIO SAMPLE, ASK Q18, ELSE SKIP TO NEXT SECTION]
18. We may have other studies coming up in the near future about Bitcoin usage. Those who participate will receive a monetary incentive as a token of our appreciation. May we contact you with an invitation to future surveys?
Yes
No

[IF YES TO Q18 AND RESPONDENT IS FROM AMPARIO SAMPLE, ASK Q19, ELSE SKIP TO NEXT SECTION]
19. Please type in your name and the email address you would like us to use to contact you.

[INSERT TEXT BOX FOR NAME AND EMAIL ADDRESS]

A.2 Changes to the weighting methodology

We updated the weighting methodology of the 2018 BTCOS from previous years to account for variables omitted from previous iterations. The new methodology follows the spirit of Chen, Felt and Henry (2018), which weights the 2017 Methods-of-Payments (MOP) Survey, our team's core consumer payments survey, using raking. Previously, we post-stratified on age, gender and province (Henry, Huynh and Nicholls 2018). Our new methodology is able to account for the additional demographics of education, marital status, employment, and income thanks to the availability of 2016 census data. Item non-response is present in employment and income, so we incorporate multiple imputation (see, e.g., Rubin 2004, Van Buuren 2018) into our calibration methodology, a procedure we dub MICAL (multiple imputation in calibration). We compare MICAL with other options of methodologies in terms of mean and efficiency, and assess our imputation model using some simple diagnostics.

A.2.1 Background

As the BTCOS is a non-probability survey, we must be careful in accounting for biases arising from differences between our sample and the Canadian population. As seen in **Table 10**, the three iterations of the survey show similar signs of under-representation for certain demographic categories compared with the 2016 population. Namely, the BTCOS tends to under-represent those who are young (18 to 24) or old (65+), male, high-school educated, employed, high income ($85,000 or more), or married or common-law. The most stark of these categories is education, where the high-school sample represents about half of what it should (22 percent in the sample compared with 42 percent in the census) and the university sample is conversely over-represented (41 percent compared with 27 percent). This omission was not as much of an issue in 2016, when Bitcoin ownership was fairly similar across the two groups (see **Table 5**). Over time, however, we have observed an increase in Bitcoin ownership among the university-educated population and a decrease in the high-school-educated population. This newly established correlation between education and ownership necessitates adjusting for education in our calibration procedure.

In previous iterations of the BTCOS, we post-stratified on age, gender and province. For 2018, we updated the methodology using newly available 2016 census data to account for the other demographic variables identified above. Aiming for consistency with the 2017 Methods-of-Payment Survey (MOP), we follow the spirit of Chen, Felt and Henry (2018) in using raking (Deville, Särndal and Sautory 1993) to match our survey to 2016 population totals. In general, for respondent i we calculate weights w_i given by

$$w_i = w_{bi} w_{\text{nra},i} w_{\text{cal},i}, \tag{1}$$

where w_{bi} is the base weight (or design weight in a probability survey), $w_{\text{nra},i}$ is a non-response adjustment (NRA) that scales the sample to the panel it is drawn from, and $w_{\text{cal},i}$ is a "calibration" that scales the panel to the population. We make some simplifications from Chen, Felt and Henry (2018). First, we choose base weight $w_{bi} = 1$ rather than post-stratification. Second, we cannot perform NRA due to a lack of data on non-respondents, so set $w_{\text{nra},i} = 1$. Finally, we avoid interaction terms in our calibration model. Perhaps as a result of these simplifications, we find fewer and less severe outlying weights, and so do not perform weight trimming. We thus proceed with calibration weights $w_i = w_{\text{cal},i}$, which we will compute using the raking ratio method and population counts taken from the 2016 census. Note that this should not be interpreted to mean that non-response is unaccounted for. Calibration is known to adjust for non-response and under-coverage for certain model assumptions (Chang and Kott 2008).

A.2.2 Variable selection

In theory, variables included in calibration should be correlated with the study variable or non-response behaviour. Variables that do not affect either should have no effect on bias while reducing efficiency. Table 7 of Chen, Felt and Henry (2018) illustrates that in the online panel of the 2017 MOP, all of the above variables are significant in predicting non-response. Choosing Bitcoin ownership and awareness as our relevant study variables, we show how they are also correlated with various demographics in a regression context (**Table 11**). Consistent with our observations above, education only becomes a significant predictor of Bitcoin ownership in 2018, and we find a similar trend in income. We thus note the particular importance of including these variables in calibration when comparing Bitcoin ownership over time. Overall, we find that estimates are unstable over time for many demographics, reinforcing the importance of including as much information as possible to improve comparability in future years.

An issue arises that was mostly absent from the 2017 MOP: we see a significant amount of item non-response with respect to income (10 to 12 percent depending on the year) and a small amount of non-response with respect to employment (1 percent). As we have shown income in particular to be an important predictor, we use multiple imputation (see, e.g., Rubin 2004, Van Buuren 2018) to incorporate it into calibration without dropping data. We now provide a description of MICAL.

A.2.3 MICAL: Point estimation

Consider a population Ω of individuals i from which we draw our sample S. Let y be a variable of interest (for example, Bitcoin ownership). Our goal is to estimate the population

mean of y, denoted by $\mu(\Omega)$, using a well-chosen estimator $\hat{\mu}(S)$. Let I_i^S be an indicator for whether i is included in the final sample S. Letting $N = \left|\Omega\right|$ be the population size, assumed known, a simple Horvitz-Thompson (HT) estimator can be used:

$$\hat{\mu}(S) = \frac{1}{N}\sum_{i\in S} w_i y_i, \tag{2}$$

where w_i is the inverse probability of inclusion in S, i.e.,

$$w_i^{-1} = \Pr(I_i^S = 1), \tag{3}$$
$$\equiv p_i. \tag{4}$$

For a probability sample, p_i would be assumed known and non-zero for all i. In our non-probability sample, p_i are unknown, so the best we can do is estimate them under some assumptions.

First of all, we make the same assumption that p_i is non-zero. Further, in order to estimate p_i we reduce the parameter space and assume that the probability of being included in the final sample depends only on characteristics that are observable to us in both S and Ω. Mathematically, we assume $p_i = p_i(x_i)$, where x_i is a vector of characteristics associated with each person i. Deville, Särndal and Sautory (1993) outline some methods for estimating w_i. Consistent with Chen, Felt and Henry (2018), we will employ raking and so require x_i to be discrete. For example, the probability of selection could depend on whether i is aged 18–24.

Now we turn to the issue at hand: what happens if some components of x_i are unobserved for some i? Consider decomposing x_i into observed component x_i^o and unobserved component x_i^u, so that $p_i = p_i(x_i) = p_i(x_i^o, x_i^u)$. Equivalently, we focus on weights $w_i = w_i(x_i) = w_i(x_i^0, x_i^u)$.

If x_i^u were known, we could use a raking procedure to produce weights $\hat{w}_i(x_i^o, x_i^u)$. Our HT-style calibration estimator would thus be

$$\hat{\mu}(S) = \frac{1}{N}\sum_{i\in S} \hat{w}_i(x_i^o, x_i^u) y_i. \tag{5}$$

As x_i^u is unobserved, we instead impute x_{ij}^u from an imputation model J times to produce weights $\widetilde{w_{ij}}(x_i^o, x_{ij}^u)$ for $j = 1, ..., J$. We compute the MICAL estimator $\hat{\mu}_{\text{MICAL}}(S)$ as follows:

$$\hat{\mu}_{\text{MICAL}}(S) \quad = \quad \frac{1}{J}\sum_{j=1}^{J}\frac{1}{N}\sum_{i\in S}\widetilde{w_{ij}}(x_i^o, x_{ij}^u)y_i. \tag{6}$$

Switching the summations around, we find the expression,

$$\hat{\mu}_{\text{MICAL}}(S) \quad = \quad \frac{1}{N}\sum_{i\in S}\frac{1}{J}\sum_{j=1}^{J}\widetilde{w_{ij}}(x_i^o, x_{ij}^u)y_i. \tag{7}$$

Defining $w_i = \frac{1}{J}\sum_{j=1}^{J}\widetilde{w_{ij}}(x_i^o, x_{ij}^u)$, we obtain a familiar-looking expression for our estimator:

$$\hat{\mu}_{\text{MICAL}}(S) \quad = \quad \frac{1}{N}\sum_{i\in S} w_i y_i. \tag{8}$$

In other words, we observe that using the MICAL method does not require imputation for each estimation of $\hat{\mu}$. Instead, we need only run J raking procedures and define final weights as the average of these imputed values. Thus, we preserve the convenience of needing only one set of weights for point estimation. An important exception is when the imputed variables are contained elsewhere in the estimation. For example, if we run a regression of Bitcoin ownership on income, we would require the entire set of imputed weights, as well as the imputed value of income on each iteration.

To summarize, this procedure consists of two core parts. First, we must use a calibration model to estimate weights for a given set of demographics. Our selection of variables for this raking procedure is discussed in the previous sections. Second, we must estimate an imputation model. This is complicated by the fact that multiple variables could be missing at once; in our case, we find item non-response in both employment and income. Thus, we use multivariate imputation by chained equations, or MICE (see, e.g., White, Royston and Wood 2011), to generate imputations for both employment and income using other demographic characteristics as predictors. Our algorithm for estimating $\mu(\Omega)$ by $\hat{\mu}_{\text{MICAL}}(S)$ is as follows:

1. Using MICE, impute unobserved demographics x_i^u J times: $\widetilde{x_{ij}^u}$, $j = 1, ..., J$.
2. For each $\widetilde{x_{ij}^u}$, use raking to produce weights $\widetilde{w_{ij}}$.
3. Compute final weights $w_i = \frac{1}{J}\sum_{j=1}^{J}\widetilde{w_{ij}}$.

4. $\hat{\mu}_{\text{MICAL}}(S) = \frac{1}{N}\sum_{i\in S} w_i y_i$.

A.2.4 MICAL: Variance estimation

For variance estimation, we again follow the methodology of Chen, Felt and Henry (2018) in using bootstrap replication weights. For each bootstrap sample, we estimate an imputation model, estimate multiply imputed weights, and define final weights based on averages. This bootstrap procedure thus takes into account the fact that both the imputation model and weights are estimated based on the observed data and their demographics. Our algorithm for bootstrapping the MICAL estimator is as follows:

1. Sample n observations with replacement from S to obtain sample S_b, $b = 1, ..., B$, where B is the number of bootstrap replications.
2. For each bootstrap sample S_b, impute unobserved demographics x_i^u J times: $\widetilde{x_{ijb}^u}$, $j = 1, ..., J$.
3. For each $\widetilde{x_{ijb}^u}$, use raking to produce weights $\widetilde{w_{ijb}}$.
4. Compute final weights $w_{ib} = \frac{1}{J}\sum_{j=1}^{J} \widetilde{w_{ijb}}$.
5. $\hat{\mu}_{\text{MICAL}}(S_b) = \frac{1}{N}\sum_{i\in S} w_{ib} y_i$.

Using the point estimate from the previous section and these bootstrap replications, we come to the bootstrap variance estimator:

$$\hat{V}(\hat{\mu}_{\text{MICAL}}(S)) = \frac{1}{B}\sum_{b=1}^{B}(\hat{\mu}_{\text{MICAL}}(S_b) - \hat{\mu}_{\text{MICAL}}(S))^2. \tag{9}$$

A.2.5 Comparison

We now compare estimates of Bitcoin ownership using the following methodologies:

- **PS:** Post-stratification on age, gender and province. This is the methodology used for the first two iterations of the BTCOS. See Henry, Huynh and Nicholls (2018) for more details.
- **Cal3:** Raking on age, gender and province.
- **Cal4:** Raking on Cal3 + education.
- **Cal5:** Raking on Cal4 + marital status.

- **Cal7:** Raking on Cal5 + employment and income, where those with missing values are dropped.
- **MICAL7:** Cal7, but with missing values for employment and income handled by multiple imputation.

Chart 5 provides a summary of how Bitcoin ownership estimates are affected by weighting methodology in each of the three years of the survey. We see that in 2016, PS would have produced very similar results to other methodologies. In 2017 and 2018, however, PS diverges from the others, suggesting an ownership rate of over 6 percent. Cal3, which uses the same variables as PS but with no interaction terms, similarly diverges but to a lesser extent. Cal7, which deletes rows with missing data, produces relatively large estimates of ownership in all years and produces significantly different results from MICAL7, suggesting we should not accept its implicit assumption that income and employment are missing completely at random.

Remaining methodologies (Cal4, Cal5, MICAL7) produce more moderate estimates of ownership in 2018 and are fairly similar across years. Taking MICAL7 as the "least biased," we see that ownership is adjusted upward from the raw sample in 2016, downward slightly in 2017, and upward slightly in 2018. This again reflects the changing demographic trends for Bitcoin ownership and illustrates the need to adjust for as many demographics as possible to reduce the bias in our non-probability sample.

Following the advice of Chen and Shen (2015), we employ 300 bootstrap replications when computing standard errors. For MICAL7, we use 10 imputations per bootstrap, expecting a small upward bias in variance resulting from using a finite number of imputations (see **Section A.2.6**). **Tables 12** and **13** display Bitcoin ownership estimates and standard errors by demographic for each of the above methodologies. We see that our original method, PS, often results in higher standard errors. As it is expected to be more biased, we reject it in favour of the updated methodologies. We see that Cal7 also tends to have higher standard errors, consistent with having to drop observations with missing values. MICAL7 does not seem to inflate standard errors significantly considering it includes more explanatory variables as well as imputation, and it sometimes even results in smaller standard errors. If we accept that it reduces bias by taking into account the additional information on income and employment, this makes it a suitable estimator compared with its competition.

A.2.6 Multiple imputation diagnostics

As discussed above, imputation was implemented using MICE. This is due to the fact that some values are missing in both employment and income and that each should be used to predict the other. Here we use two chained equations: a multinomial logit for employment

and an ordered logit for income. In each case, we included a set of demographic characteristics as predictors: age, gender, province, education, marital status, household size and number of children. The latter two were found to be significant only in the income equation and so are included only as predictors of income. Results from these regressions are available upon request.

To assess the chosen imputation model we adapt the guidelines of Marchenko and Eddings (2011) for use in our context for multinomial and ordinal logit models. First, we run the imputation models for each year using complete cases in the data, and assess their goodness of fit. Second, we examine if there is evidence to reject the assumption of data missing completely at random (MCAR). In addition to their recommendations, we describe our choice of the number of imputations to be used in each bootstrap replication.

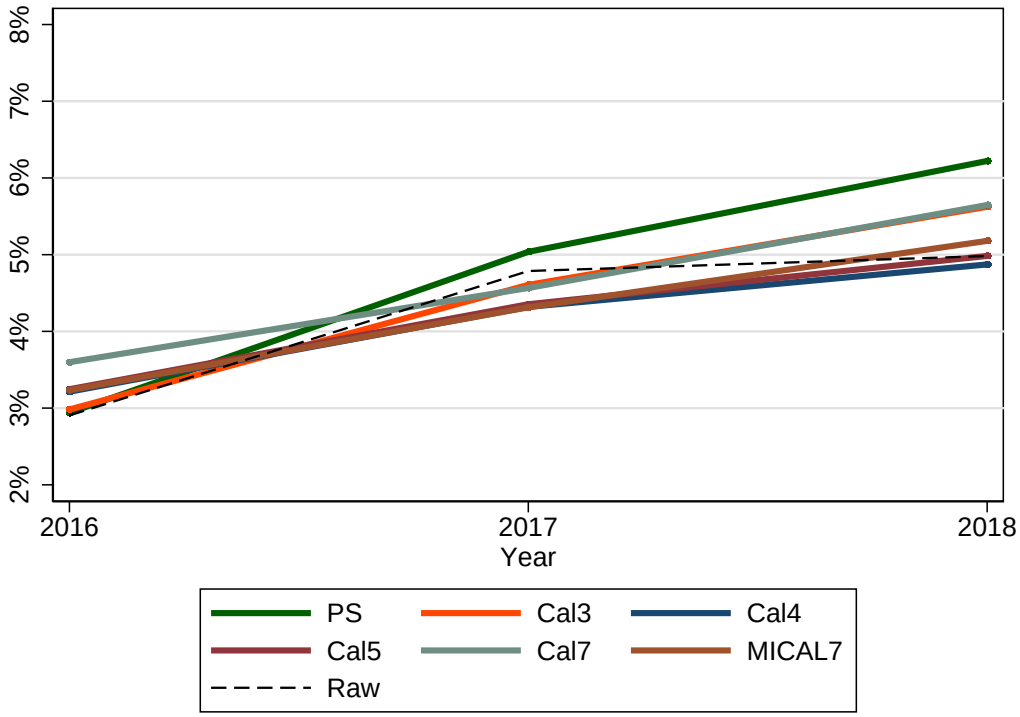
Marchenko and Eddings (2011) recommend assessing the goodness of fit of the imputation model. In our context we must use different means because our outcome variables are discrete. Thus, we employ the Hosmer-Lemeshow goodness-of-fit test, which has been adapted to the multinomial logit (Fagerland, Hosmer and Bofin 2008) and ordinal logit (Fagerland and Hosmer 2013) cases. The results of these tests can be found in **Table 14**. We note that pooling data together results in an imputation model that rejects the test in most cases. However, running the model in individual years results in tests that are usually not significant.

It is impossible to test whether income and employment are missing at random, but we can test if they are MCAR by assessing whether non-response is correlated with any observable demographic characteristics. Running a logit of missing employment and income on demographics (**Table 15**), we do find some indications that we should reject MCAR. For example, women are found to be less likely to report their household income. On the other hand, those with college or university educations are less likely to report their employment status. These results provide a case against the simple route of assuming MCAR.

Finally, we choose a level of imputation to be used in our bootstraps. In principle, we should choose as many imputations as possible when computing a point estimate, as well as in each bootstrap replication. Otherwise, there may be a bias present in our standard errors. For point estimation, we use a large number of imputations (200); but for variance estimation via the bootstrap, we must use a smaller number to make the procedure feasible (consider that for 300 bootstrap replications, imputing 200 times each would require 60,000 total imputations, which are themselves slow in a MICE context). We restrict our analysis to 10 imputations per bootstrap and thus expect a $1/10B$ bias in our variance estimation, where B is the between-imputation variance (see Rubin 2004, summarized in Murray 2018). Using 20 simulations of estimates of Bitcoin ownership based on 10 imputations, we estimate $\sqrt{\hat{B}}$ to be close to 0.0001 and so expect this bias to be fairly small. Note that this is a non-

negative bias on our variance, and so results will, if anything, be slightly conservative.

Chart 5: **Ownership estimates by weighting method, 2016–18**



Note: This figure compares the different calibration methods listed in **Section A.2.5**. We plot estimates of Bitcoin ownership for each methodology and each year of the survey. Our final estimates are based on MICAL7. The sample consists of 1,997 respondents in 2016, 2,623 respondents in 2017 and 1,987 respondents in 2018.

Table 10: **Sample composition, 2016 Census vs. 2016–18 BTCOS**

	2016 Census	**BTCOS**		
	2016	2016	2017	2018
Overall (N)	28,040,330	1,997	2,623	1,987
Age				
18–24	11	9	7	7
25–34	16	18	18	16
35–44	16	17	18	16
45–54	18	21	23	20
55–65	17	20	18	25
65+	21	16	16	16
Gender				
Male	49	47	46	42
Female	51	53	54	58
Region				
British Columbia	14	12	14	14
Prairies	18	19	19	15
Ontario	38	36	34	41
Quebec	23	23	24	24
Atlantic	7	9	9	7
Education				
High school	42	22	23	23
College	30	37	35	36
University	27	41	43	41
Marital status				
Married or common-law	61	57	59	58
Single	39	43	41	42
Employment				
Employed	62	59	60	59
Unemployed	5	4	4	5
Not in labour force	33	37	36	36
Income ($)				
<25,000	9	15	15	14
25,000–44,999	16	18	17	18
45,000–64,999	17	21	19	20
65,000–84,999	16	18	14	16
85,000+	42	27	34	31

Note: This table reports the 2016 Statistics Canada Census (which provides population targets for the weighting methodology) and the sample composition for each iteration of the BTCOS. In 2016, income was defined slightly differently, with a cutoff at $90,000 instead of $85,000, so the highest two categories are really "65,000–89,000" and "90,000+" in 2016.

Table 11: **Logit results: Awareness and ownership, 2016–18**

	Awareness			Ownership		
	2016	2017	2018	2016	2017	2018
Constant	0.770**	2.791***	1.934***	-0.516	0.883	-1.488*
Age						
Continuous	0.002	-0.011**	0.002	-0.058***	-0.065***	-0.055***
25–34	0.069	0.007	0.170	0.712**	0.310	0.439
Gender						
Female	-0.796***	-1.048***	-0.888***	-0.645**	-1.319***	-0.941***
Region						
Prairies	-0.499**	-0.879***	-0.171	0.591	-0.758**	-0.086
Ontario	-0.461**	-0.811***	-0.184	-0.007	-0.331	-0.103
Quebec	-1.344***	-1.536***	-0.903***	0.496	-0.207	-0.282
Atlantic	-0.472*	-1.191***	-0.721*	-0.291	-0.721	-0.353
Education						
College	0.237*	0.499***	0.808***	-0.761*	-0.257	0.785*
University	0.863***	1.150***	1.187***	-0.367	0.196	1.021**
Marital status						
Single	0.153	0.185	0.672***	-0.126	-0.307	-0.385
Employment						
Unemployed	0.619**	0.0548	0.399	0.605	-1.671**	0.467
Not in labour force	-0.0402	0.160	0.155	-0.651	-0.717**	-0.328
Income ($)						
25,000–44,999	0.190	0.313	-0.063	-0.155	0.198	0.664
45,000–64,999	0.441**	0.466**	0.395	-0.024	0.129	1.029*
65,000–84,999	0.326	0.487**	0.266	0.057	-0.309	1.257**
85,000+	0.517***	0.745***	0.422	-0.061	-0.476	1.080**

Note: This table reports the logit results of demographics on ownership and awareness in each year of the BTCOS. Observations with missing values for income or employment are excluded, leaving 1,759 observations in 2016, 2,335 in 2017 and 1,743 in 2018. This analysis motivated us to extend the set of variables we calibrate on to the seven discussed. *** $p < 0.01$ ** $p < 0.05$ * $p < 0.1$.

Table 12: **Ownership estimates by demographic and weighting method, part 1**

	PS	Cal3	Cal4	Cal5	Cal7	MICAL7
Overall	6.2	5.6	4.9	5.0	5.6	5.2
	0.7	0.6	0.5	0.5	0.6	0.6
18–24	10.1	8.1	8.6	8.4	8.2	7.4
	3.2	2.4	2.8	2.7	2.7	2.5
25–34	16.0	13.4	10.7	11.0	13.8	12.5
	2.6	2.0	1.6	1.7	2.1	2.0
35–44	8.5	8.1	6.7	7.0	8.0	7.1
	1.8	1.7	1.5	1.6	2.0	1.7
45–54	3.1	3.0	2.7	2.7	3.2	2.8
	0.9	0.9	0.8	0.8	1.0	0.9
55–64	1.3	1.5	1.3	1.4	2.0	1.7
	0.5	0.6	0.6	0.6	1.0	0.9
65+	1.4	2.0	1.9	1.9	1.4	1.7
	0.6	0.9	0.8	0.9	0.7	0.8
Male	9.3	7.4	6.5	6.6	7.0	6.7
	1.3	1.0	0.9	1.0	1.0	1.0
Female	3.3	4.0	3.3	3.4	4.3	3.7
	0.5	0.6	0.5	0.6	0.7	0.6
British Columbia	7.2	6.6	5.4	5.6	6.1	6.3
	1.7	1.6	1.4	1.4	1.7	1.7
Prairies	6.2	6.3	5.6	5.7	7.0	6.0
	1.7	1.5	1.5	1.5	1.9	1.6
Ontario	6.1	5.8	5.2	5.2	5.8	5.2
	1.0	0.9	0.9	0.9	1.0	0.9
Quebec	6.5	4.6	4.1	4.2	4.9	4.6
	1.6	1.1	1.1	1.1	1.2	1.1
Atlantic	3.9	4.4	3.1	3.1	3.0	2.8
	1.7	2.0	1.4	1.4	1.4	1.3

Note: This table provides estimates of Bitcoin ownership based on the various weighting methodologies considered in **Section A.2.5**. We used 200 imputations to compute point estimates. Standard errors were computed as described in **Section A.2.4**, with 300 bootstrap replications and 10 imputations per replication.

Table 13: **Ownership estimates by demographic and weighting method, part 2**

	PS	Cal3	Cal4	Cal5	Cal7	MICAL7
Overall	6.2	5.6	4.9	5.0	5.6	5.2
	0.7	0.6	0.5	0.5	0.6	0.6
High school	2.8	2.4	2.3	2.3	2.5	2.3
	1.1	0.9	0.8	0.8	1.0	0.9
College	5.9	5.2	5.4	5.4	6.0	5.7
	1.2	0.9	0.9	0.9	1.0	1.0
University	8.4	7.7	8.3	8.7	10.1	9.1
	1.1	1.0	1.0	1.1	1.3	1.2
Married or common-law	6.7	6.0	5.0	5.1	5.7	5.2
	0.9	0.7	0.7	0.7	0.8	0.8
Single	5.6	5.2	4.7	4.9	5.6	5.1
	1.0	0.8	0.8	0.8	0.9	0.9
Employed	9.1	7.9	7.0	7.2	7.5	7.1
	1.1	0.9	0.8	0.9	0.9	0.9
Unemployed	4.7	5.6	5.2	5.4	5.9	5.2
	1.9	2.4	2.7	2.7	2.8	2.5
Not in labour force	2.2	2.3	2.1	2.1	2.2	1.9
	0.7	0.6	0.7	0.7	0.7	0.6
<$25,000	3.2	2.9	3.2	3.3	3.8	3.7
	1.7	1.4	1.6	1.7	2.0	1.9
$25,000–$44,999	5.0	4.2	3.4	3.4	3.2	3.2
	1.8	1.3	1.1	1.1	1.1	1.1
$45,000–$64,999	5.7	5.6	4.7	4.6	4.5	4.6
	1.5	1.3	1.3	1.2	1.3	1.4
$65,000–$84,999	9.1	8.7	7.9	8.0	7.4	7.5
	1.9	1.7	1.5	1.5	1.4	1.5
$85,000+	9.6	8.2	7.4	7.5	6.8	6.8
	1.5	1.2	1.2	1.2	1.1	1.1

Note: This table provides estimates of Bitcoin ownership based on the various weighting methodologies considered in **Section A.2.5**. We used 200 imputations to compute point estimates. Standard errors were computed as described in **Section A.2.4** with 300 bootstrap replications and 10 imputations per replication.

Table 14: **Goodness-of-fit tests for imputation model**

Employment status (multinomial logit)				
Baseline	**2016**	**2017**	**2018**	**Combined**
Employed	0.333	0.106	0.064	0.000
Unemployed	0.521	0.199	0.593	0.150
Not in labour force	0.073	0.199	0.003	0.000
Income (ordered logit)				
	2016	**2017**	**2018**	**Combined**
	0.482	0.173	0.108	0.014

Note: This table reports p-values from goodness-of-fit tests for imputation models of employment and income. These are based on the Hosmer-Lemeshow test for multinomial logit (Fagerland, Hosmer and Bofin 2008) and ordinal logit (Fagerland and Hosmer 2013), respectively. For employment, we report the tests for different baselines, which is not an issue for the ordered logit.

Table 15: **Logit Results: Tests of MCAR assumption**

	Employment	**Income**
Age		
25–34	1.010 *	-0.492 *
35–44	0.624	-0.054
45–54	-0.076	0.044
55–64	-0.588	0.402 *
65+	-1.892 *	0.284
Gender		
Female	-0.090	0.537 ***
Region		
Prairies	-0.161	0.123
Ontario	-0.180	0.133
Quebec	-0.746	-0.174
Atlantic	0.229	-0.023
Education		
College	-1.132 ***	-0.075
University	-0.761 **	0.075
Employment		
Unemployed		0.240
Not in labour force		0.191 *
Missing		2.401 ***
Income ($)		
$25,000–$44,999	-1.460 **	
$45,000–$64,999	-1.358 **	
$65,000–$84,999	-1.212 *	
$85,000+	-1.051 *	
Missing	1.520 ***	
Marital status		
Single	0.736 **	-0.031
Household size		
2		0.342 *
3+		0.591 ***
Number of children		
1		-0.389 *
2+		-0.610 **

Note: This table reports the logit results for item non-response in employment and income variables using 1,987 respondents from the 2018 BTCOS. Significant estimates indicate that missing rates are correlated with certain demographics, and we therefore conclude that the data are not missing completely at random. Note that we include missing income/employment as predictors to show a positive correlation between non-response in the two variables. For the sake of brevity, we have omitted standard errors. *** $p < 0.01$ ** $p < 0.05$ * $p < 0.1$.