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Incorporating Trip-Chaining to Measuring Canadians' Access to Cash

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Abstract

Household mobility data can improve our measurement of access to cash. The existing literature typically assumes that households visit their nearest ABMs or financial institution branches from their homes, without combining cash withdrawals with other activities (i.e., on their way to shopping). However, the typical approach neglects two realistic features: The first is that, due to spatial agglomeration, cash access points could be co-located with popular points of interest, such as retail service centers; and, second, households could combine multiple trips, via trip-chaining, to reduce travel costs. Our paper employs smartphone data to construct an improved cash access metric by accounting for both spatial agglomeration and households' travel patterns. We find that incorporating trip-chaining into the travel metric could show that travel costs are from 15% to 25% less than not incorporating trip-chaining and that the biggest decrease is driven by rural residents.

Topics: Bank notes; Financial services; Regional economic development
JEL codes: D12, O18, R22, R41

Résumé

Les données sur la mobilité des ménages peuvent améliorer notre mesure de l'accès à l'argent comptant. Dans la littérature existante, on suppose généralement que les ménages se rendent au guichet automatique ou à la succursale d'institution financière qui est le plus près de leur domicile, sans combiner les retraits d'argent comptant avec d'autres activités (p. ex., en allant faire des courses). Cependant, l'approche habituelle néglige deux réalités : premièrement, en raison de l'agglomération spatiale, les points d'accès à l'argent comptant pourraient être situés à proximité de lieux d'intérêt populaires, comme les centres où sont regroupés des services de détail; et deuxièmement, les ménages pourraient combiner plusieurs déplacements dans un même trajet afin de réduire les coûts de déplacement. Notre étude utilise des données de téléphones intelligents pour construire une mesure améliorée de l'accès à l'argent comptant en tenant compte à la fois de l'agglomération spatiale et des habitudes de déplacement des ménages. Nous constatons que les coûts de déplacement pourraient être de 15 à 25 % moins élevés si l'on intègre l'enchaînement des déplacements dans les mesures d'accès à l'argent comptant, et que la plus grande différence serait observée chez les résidents des régions rurales.

Sujets : Billets de banque; Évolution économique régionale; Services financiers
Codes JEL : D12, O18, R22, R4

1. Introduction

As per the Bank of Canada Act, one of the key mandates of the central bank is to make adequate arrangements for the supply of bank notes required for circulation (Engert and Huynh 2022). Hence, the Bank of Canada has been constantly monitoring how Canadians perceive their access to cash (Chen, O'Habib and Xiao, 2024) and how far they need to travel for this purpose (Chen, Xiao, O'Habib and Wild, 2025).

For the latter distance metric, the typical approach assumes that households travel to ABMs and or branches of their financial institutions (FI) (banks or credit unions) from their home locations, without combining their cash withdrawals with other activities (Stix 2020; Chen, Strathearn and Voia 2021; Evans and Tischer 2022; Zamora-Perez 2022; Chen, O'Habib and Xiao 2023). However, this typical approach neglects two realistic features: First, due to spatial agglomeration, cash access points could be co-located with popular points of interest (POIs) to reduce household search costs and benefit from the shared demand generated by economies of agglomeration, such as retail or service centers; and second, households could combine trips via trip-chaining to reduce travel costs. For example, since there are usually ABMs in shopping malls (Chen and Felt, 2022), people could make cash withdrawals when they are already at the mall. In addition, the Bank's 2023 Methods-of-Payment Survey Report (Henry et al. 2024) notes that 68% of all respondents who withdrew cash, over the previous week, combined their cash withdrawal trips with other trips for different purposes, versus 32% who made single-purpose cash withdrawal trips only. Of the respondents who did a trip chain, 38% reported combining their cash withdrawal trips with shopping, 19% with going to a restaurant, 15% with getting gas, 14% with entertainment, and 11% with commuting.

As a result, the actual distance a household needs to travel to withdraw cash could be shorter than a withdrawal trip that originates from their home. This suggests that placing the origin points at households' home locations could result in overestimating some households' travel costs for accessing cash as households could take advantage of less-costly trips by accessing cash close to stores they shop at or restaurants they frequent (Chen, Strathearn and Voia 2021, 2024; Miyauchi, Nakajima and Redding 2021; Relihan 2022).

To overcome the above overestimation issue, our main innovation is to employ household mobility data, obtained from mobile devices, to construct an improved cash access metric that accounts for both spatial agglomeration and households' travel patterns.[2] In other words, we propose an improved cash access metric by incorporating households' trip-chaining. Our new metric can be interpreted as a weighted travel cost, where the weight represents the probability of the household starting a new trip at a new origin point; that is, one that could differ from their home. The transportation literature refers to this as an outflow probability. We

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[2] Chen, Strathearn and Voia (2021, 2024) consider the effects of trip-chaining on the frequency of cash withdrawals, based on survey data, while this paper uses smartphone tracking data and the census to measure the travel cost of withdrawing cash.

find that incorporating trip-chaining into a travel metric could show that the travel cost is actually around 15 to 25% less than when measured by the non-trip-chaining travel metric (Chen et al., 2025), with the biggest difference being driven by rural residents.

Besides providing a better metric for monitoring households' access to cash, using a measurement that is realistic and accurate in assessing the travel cost of accessing cash is also policy relevant for two other reasons. First, for policymakers considering providing cash access points, our improved metric sheds light on the importance of accounting for households' travel patterns when making these location choices at the local or neighborhood level. That is, given households' propensity to combine their withdrawals and use of cash with other everyday activities, policymakers should think beyond the usual locations close to people's homes and, instead, consider potential cash access points in retail centers, transportation hubs or high foot-traffic areas, allowing some households to minimize their travel costs (Chen, Strathearn and Voia 2024). Second, having an accurate measurement of the cost of travelling to access cash helps pin down an important element of households' overall cost of using cash. This is because the cost of acquiring cash depends on how much time is spent to obtain cash and the value of households' time. From previous literature, Kosse et al. (2017), Fung et al. (2017), and Krüger and Seitz (2025) all find that the shoe-leather cost of cash withdrawals makes up a large part of households' cash management costs.

1.1. Literature

Related to the literature, our paper sits at the intersection between spatial agglomeration, household search-and-shopping behaviors and the application of smartphone-based household mobility data. First, our paper is related to the urban economics literature investigating the agglomeration of goods and services. Locations that provide goods and services, such as restaurants and stores, represent endogenous amenities that attract people to live in cities. Due to agglomeration economies (Arzaghi and Henderson 2008; Benmelech et al. 2019), these locations are often highly concentrated geographically (Ahlfeldt et al. 2022; Liu et al. 2018) and include access to cash and financial services (Chen and Felt, 2022). Moreover, clustering is also driven by the increasing time pressure households face as they try to optimize the efficiency of their shopping patterns. Hence, retailers or service providers have improved shopping convenience by offering greater variety in product categories and making it easier for households to combine visits to multiple stores (Messinger and Narasimhan 1997; Timmermans 2004).

Second, our paper is related to the literature on household search-and-shopping behaviors (i.e., trip-chaining). Dellaert et al. (1998) study the impact of combining multiple shopping purposes on households' shopping patterns, through conjoint design. Baker et al. (2021) build a model of inventory and shopping complementarities, where households rationally bundle purchases of different types of goods into single shopping trips. In addition, because of positive consumption externalities (Shoag and Veuger 2018), one channel through which to reduce marginal costs is to visit nearby locations via trip-chaining (Koster et al. 2019; Miyauchi et al. 2022; Relihan

2022). Regarding households' cash withdrawals, Alvarez and Lippi (2009) generalize the Baumol-Tobin model by introducing financial innovation to capture free withdrawal opportunities driven by the increasing diffusion of FI branches and ABM terminals.

Finally, our work is related to the rapidly growing literature that uses smartphone data to investigate spatial mobility patterns, such as trip-chaining, and their spillover effects (Couture et al. 2022; Kreindler and Miyauchi 2023; Atkin et al. 2022; and Hausman et al. 2023). Focusing specifically on the financial services industry, Sakong and Zentefis (2024) use Safegraph data for the U.S. to estimate access to FI branches from different neighborhoods. And while their most recent study investigates accessibility by assuming single-purpose trips from home locations to branches, our paper innovates by including trip-chaining in the distance metric.

The remainder of our paper is as follows: In Section 2, we discuss the data and introduce our trip-chaining cash access metric. In Section 3, we present the trip-chaining results by comparing them to the non-trip-chaining metrics reported in Chen et al. (2023). Finally, Section 4 concludes the paper and proposes future research.

2. Data and Methodology

2.1. Data

To compute travel-based metrics with trip-chaining, we utilize three primary data sources. First, we identify Canadians' home locations using the Pseudo-Household Demographic Distribution from Statistics Canada, which serves as one set of potential origin points for households' cash withdrawal trips. For destination points, we employ Mastercard ABM location data and self-compiled branch location data to determine the locations of cash access points. Additionally, we use Advan Research data (previously known as Safegraph Patterns data) to identify potential points of interest (POIs) Canadians might combine with their cash access trips and use these as alternative origin points.

The Pseudo-Household (PHH) Demographic Distribution is a geospatially representative distribution of the population along roads and other boundaries. This distribution provides a more accurate home location than using the centroid of an area. To compute the travel distance, we use the dissemination area (DA) as the geographic unit, and we consider that a household can travel both within and outside various DAs. Statistics Canada defines dissemination areas as small, stable geographic units that typically consist of neighborhoods with populations ranging from 400 to 700 people. We use the 2016 PHH distribution, which was the latest available. For locations of FI branches and ABMs, we use the cleaned 2022Q4 locations from Chen et al. (2023).

The household mobility data from Advan Research aggregates tracking data from a panel of around half a million mobile devices in Canada. This dataset provides a comprehensive overview of household movement patterns by capturing the number of weekly visitors to various POIs from different dissemination areas.[3] The Advan Research data used in this study span 11 consecutive weeks, from October 10 to December 22, 2022, marking the fourth quarter of the year and representing a continuous timeframe between, but not including, Thanksgiving and Christmas. This period is devoid of major holidays that could disrupt regular travel patterns.

2.2. Methodology

Our method starts by using household mobility data to compute outflow probabilities across entire DAs, then we compute the trip-chaining metric as the weighted travel distance (time), where the weights are the outflow probabilities.

Specifically, for a given household i in DA j, the trip-chaining (TC) distance to the nearest ABM (FI branch) $\mathrm{d}_{\mathrm{ij}}^{\mathrm{TC}}$ is computed as

$$\mathrm{d}_{\mathrm{ij}}^{\mathrm{TC}} \equiv \sum_{\mathrm{j}'=1,\cdots,\mathrm{j},\cdots,\mathrm{J}} \left[\mathrm{P}(\mathrm{j}'|\mathrm{j}) \times \min\left(\mathrm{d}_{\mathrm{j}'(\mathrm{popular})}, \mathrm{d}_{\mathrm{i(home)}}\right)\right] + \left[1 - \sum_{\mathrm{j}'=1,\cdots,\mathrm{j},\cdots,\mathrm{J}} \mathrm{P}(\mathrm{j}'|\mathrm{j})\right] \times \mathrm{d}_{\mathrm{i(home)}} \quad (1)$$

where $\mathrm{P}(\mathrm{j}'|\mathrm{j})$ is the outflow probability from DA j to DA j′, $\mathrm{d}_{\mathrm{j}'(\mathrm{popular})}$ is the travel distance to the nearest ABM (FI branch) from the most popular POI in DA j′, and $\mathrm{d}_{\mathrm{i(home)}}$ is the travel distance to the nearest ABM (FI branch) from household i's home. The TC's detailed construction is provided in Section 2.3.

Equation (1) consists of two terms. The first term is the trip-chaining component, $\sum_{\mathrm{j}'=1,\cdots,\mathrm{j},\cdots,\mathrm{J}} \left[\mathrm{P}(\mathrm{j}'|\mathrm{j}) \times \min\left(\mathrm{d}_{\mathrm{j}'(\mathrm{popular})}, \mathrm{d}_{\mathrm{i(home)}}\right)\right]$, which captures the household going to the nearest cash access points from the most popular POI being visited in DA $\mathrm{j}' = 1, \cdots, \mathrm{j}, \cdots, \mathrm{J}$. These popular POIs in DA $\mathrm{j}' = 1, \cdots, \mathrm{j}, \cdots, \mathrm{J}$ are potential new origin points from which to travel to access cash, and the probability $\mathrm{P}(\mathrm{j}'|\mathrm{j})$ assigns the likelihood of the trip starting from these new origin points for a household living in DA j. In addition, the term $\min\left(\mathrm{d}_{\mathrm{j}'(\mathrm{popular})}, \mathrm{d}_{\mathrm{i(home)}}\right)$ reflects that the household minimizes its travel cost by comparing the travel cost of accessing cash from the popular POIs they visit to the cost of travelling from home to access cash. The second component is the typical non-trip-chaining component, $\left[1 - \sum_{\mathrm{j}'=1,\cdots,\mathrm{j},\cdots,\mathrm{J}} \mathrm{P}(\mathrm{j}'|\mathrm{j})\right] \times \mathrm{d}_{\mathrm{i(home)}}$, which captures the household going to the cash access point nearest their home. Here $\left[1 - \sum_{\mathrm{j}'=1,\cdots,\mathrm{j},\cdots,\mathrm{J}} \mathrm{P}(\mathrm{j}'|\mathrm{j})\right]$ is the probability of staying home, which is the residual from subtracting the probabilities of visiting POIs in any DA. Chen et al. (2023) compute the non-trip-chaining metric as

$$\mathrm{d}_{\mathrm{ij}}^{\mathrm{non-TC}} \equiv \mathrm{d}_{\mathrm{i(home)}}, \quad (2)$$

[3] See Appendix A for an example of the Advan Research data. Also note that Advan Research data are POI-based, instead of device-based. Therefore, we cannot directly observe the sequence of stops for each tracked device. In addition, the POIs included in the Advan Research dataset exclude office buildings. This exclusion means that workplaces are not represented in the data, such that our results cannot account for cash access trips that are combined with commuting trips. This effect of missing office buildings should be limited, however, since only 7% of all respondents who reported withdrawing cash during the week did so during their commute to work, according to our latest MOP survey (Henry et al. 2024).

where $\mathrm{P}(\mathrm{j}'|\mathrm{j})$ is equal to zero so that $\left(1-\sum_{\mathrm{j}'=1,\cdots,\mathrm{j},\cdots,\mathrm{J}}\mathrm{P}(\mathrm{j}'|\mathrm{j})\right)=1$. That is, $\mathrm{d}_{\mathrm{ij}}^{\mathrm{non-TC}}$ is a special case of Equation (1) that assigns a 100% probability of the household's cash withdrawal trip originating from their home. In the end, the trip-chaining metric in terms of travel time can be similarly defined by replacing the distance measurements of $\mathrm{d}_{\mathrm{j}'(\mathrm{popular})}$ *and* $\mathrm{d}_{\mathrm{i}(\mathrm{home})}$ in Equation (1) with their corresponding time measurements.

2.3. Notations in Equation (1)

We start with the computation of $\mathrm{P}(\mathrm{j}'|\mathrm{j})$ and then provide the computations of $\mathrm{d}_{\mathrm{i}(\mathrm{home})}$ and $\mathrm{d}_{\mathrm{j}'(\mathrm{popular})}$.

2.3.1. Outflow probability $\mathrm{P}(\mathrm{j}'|\mathrm{j})$

The outflow probability $\mathrm{P}(\mathrm{j}'|\mathrm{j})$ of visiting DA j′ from DA j is defined as

$$\mathrm{P}(\mathrm{j}'|\mathrm{j}) \equiv \frac{\sum_{\mathrm{j}'(\mathrm{k})\in\Omega_{\mathrm{j}'}} \mathrm{v}_{\mathrm{j}\rightarrow\mathrm{j}'(\mathrm{k})}}{\mathrm{Device}_{\mathrm{j}}},$$

where $\mathrm{Device}_{\mathrm{j}}$ is the number of devices residing in DA j provided through the smartphone data and $\sum_{\mathrm{j}'(\mathrm{k})\in\Omega_{j'}} \mathrm{v}_{\mathrm{j}\rightarrow\mathrm{j}'(\mathrm{k})}$ is the summation of unique visitors from their homes in DA j to their regular POI, $\mathrm{j}'(\mathrm{k})$ in DA j'. Notice that the outflow probability $\mathrm{P}(\mathrm{j}'|\mathrm{j})$ is identical for all households in the same DA j. This homogeneity is a necessary limitation as we do not have the device-level trip itinerary from the Advan Research data.

Here $\sum_{\mathrm{j}'(\mathrm{k})\in\Omega_{\mathrm{j}'}} \mathrm{v}_{\mathrm{j}\rightarrow\mathrm{j}'(\mathrm{k})}$ is the (out)flow to be derived from the smartphone data and adjusted for three constraints. The first constraint is meant to ensure that the outflows to the POIs in DA j' only include the POIs the households would regularly visit and we exclude the POIs the households irregularly visit. From the 2023 Methods of Payment Survey Report (MOP), households make an average of two cash withdrawals per month to satisfy their demand for cash (Henry et al. 2024). Therefore, we should only consider cash access points that households can reach on a regular basis. Irregularly visited POIs include airports, train stations, and hotels, which people generally only visit when they go on trips away from home. We also exclude places people usually only occasionally visit, such as hospitals, funeral homes, real estate offices, auto dealers, concert venues, stadiums, amusement parks, museums, and historical sites. These irregular POIs account for 10.9% of all visitors in the smartphone data, and we define the remaining regular POIs in DA j' as $\Omega_{\mathrm{j}'}$.

Besides retaining regular POIs within the DAs in the first constraint, the second constraint is to only include the flows to destinations in DA j' if there is regular outflow from DA j. We define regular outflows between two DAs as having non-zero flows for most weeks during the sample period (6 weeks out of 11) or where the distance between two DAs is within 1 km; otherwise, we set $\mathrm{P}(\mathrm{j}'|\mathrm{j})=0$. The former criterion comes from the fact that people usually make cash withdrawals biweekly (Chris, et al. 2024), and the latter criterion is due to the average area size of a DA being small. As a result, the second constraint drops 62.8% of the remaining visitors from the smartphone data.

The third and last constraint is to account for double counting the outflow visitors from the smartphone data, since the same visitor is counted every time they visit a different POI during their trip. This is because when we only have aggregate visitor counts for each POI, and are not tracking data at the individual smartphone level, the POI is the unit of measurement. To obtain the number of unique visits from DA j to DA j′, we use an external data source to calibrate the number of times they visit particular POIs per week by dividing this number by a normalization factor. This factor is based on the 2017 National Household Travel Survey for the U.S. and equals 7.84, meaning that a typical household would visit 7.84 unique POIs during a week. Detailed calculations are provided in Appendix B.[4]

To sum up the impacts of the above three constraints, we convert the raw number of visitors $v^*_{j\to j'(k)}$ going to POI $j'(k)$ in DA j′ from home DA j into the unique number of visitors $v_{j\to j'(k)}$, which measures the regular outflow between the two DAs. To be specific, the relationship between $v_{j\to j'(k)}$ and $v^*_{j\to j'(k)}$ is

$$v_{j\to j'(k)} = \frac{v^*_{j\to j'(k)}}{89.1\% \times 37.2\% \times 7.84} \ \forall\, j, j' \text{where } P(j'|j) > 0$$

2.3.2. Travel distances $d_{i(\text{home})}$ and $d_{j'(\text{popular})}$

From the proprietary 2022 ABM and FI branch data, we have the longitudes and latitudes of all of the ABMs and FI branches in Canada. Then $d_{i(\text{home})}$ can be calculated as the distance originating from the home location of household i in DA j to the nearest ABM or FI branch, where $i(\text{home})$ is the longitude and latitude of household i located in DA j. See details in Chen et al. (2023) for the computation.

As for $d_{j'(\text{popular})}$, this can be calculated as the distance originating from the popular POI of DA j′ to the nearest ABM or FI branch, where $j'(\text{popular})$ represents the longitude and latitude of the popular POI in DA j'. We chose to use the most popular POI because, in a given DA, it usually accounts for the majority of visits among all POIs and is more representative than the geographical centroid of that particular DA. Furthermore, in DAs where there are multiple popular POIs, these points of interest tend to be clustered together because DAs are usually small geographical areas.

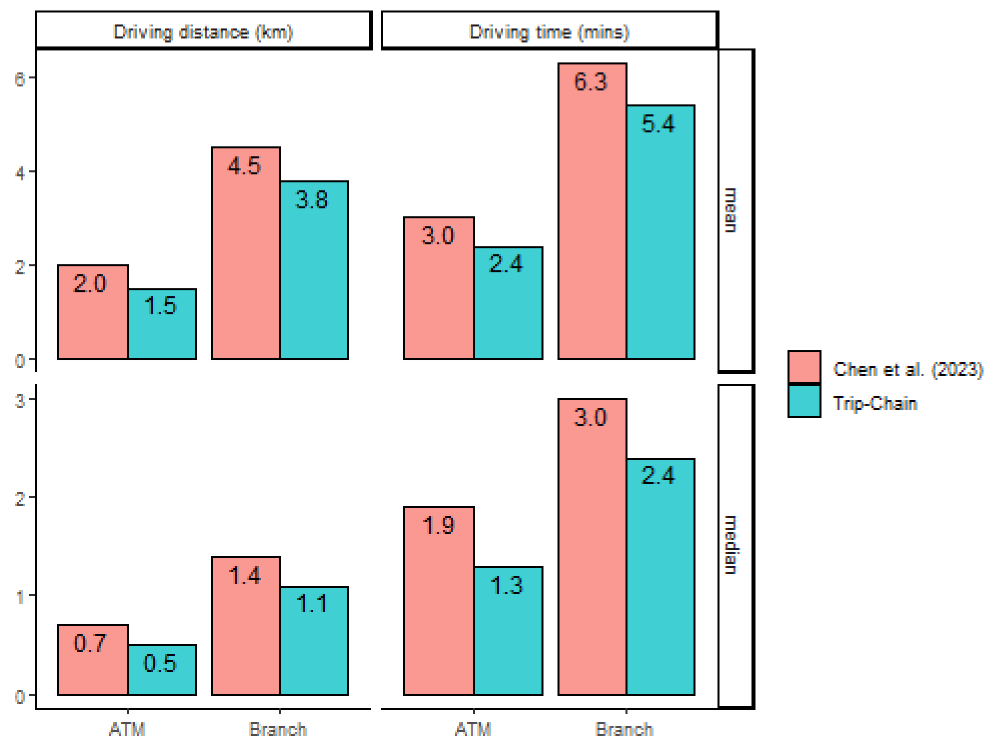
[4] Due to the lack of representative Canadian trip-chaining data, we use the U.S. as an alternative because its economy is similar to Canada's. As a robustness check, we also calibrate the number of visits (stops) per week, using the Japanese mobile phone tracking data detailed in Miyauchi et al. (2022), which gives very similar results as the ones from the U.S. Calculations from both the U.S. and Japanese data can be found in Appendix B.

3. Results

In this section, we present the trip-chaining metric $d_{ij,}^{TC}$ defined in Equation (1) and we compare it against the non-trip-chaining metric $d_{ij,}^{non-TC}$ defined in Equation (2).[5]

The results indicate that cash is even more readily accessible for Canadians than discussed in the previous findings of Chen et al. (2023). As shown in Chart 1, in 2022, the mean and median travel distances to the nearest ABMs were found to be 1.5 km and 0.5 km, respectively, after taking trip-chaining into account. This is a significant decrease compared to the mean and median distances of 2.0 km and 0.5 km found using the previous metrics without trip-chaining. The story is the same for access to FI branches, with the mean and median trip-chaining distances to the nearest FI branch being 3.8 km and 1.1 km, respectively, versus 4.5 km and 1.4 km, respectively, from the previous non-trip-chaining metrics. A similar difference in the findings can also be seen in terms of driving times.

Chart 1: Driving distance and time to the nearest ABM and FI branch, with and without Trip-Chaining



[5] To compute the aggregated statistics from the individual household metric, 1% of households within each census subdivision (CSD) are sampled following simple random sampling without replacement and the resulting weights are applied to construct the Horvitz–Thompson estimator (Chen et al., 2023).

The shares of the Canadian population living within a certain threshold of trip-chaining driving distances and times to the nearest cash access points are presented in tables 1 and 2, along with comparisons to the metrics without trip-chaining. Integrating the trip-chaining feature into the access to cash metric increases the shares of Canadians having easy access to cash. Specifically, the share of Canadians having access to an ABM within 1 km increases from 63% without trip-chaining to 75% with trip-chaining. Similarly, the share of Canadians having access to an FI branch within 1 km increases from 33% to 48%. In addition, findings show that 93% of the population has access to an ABM within a 5 km trip-chaining distance and 88% have access to an FI branch within a 5 km trip-chaining distance. In terms of driving time, the share of Canadians having access to an ABM within a five-minute drive increases from 88% without trip-chaining to 91% with trip-chaining, while the share of Canadians having access to a branch within a five-minute drive increases from 75% without trip-chaining to 82% with trip-chaining.

Table 1: Driving distance to the nearest cash source—cumulative distribution

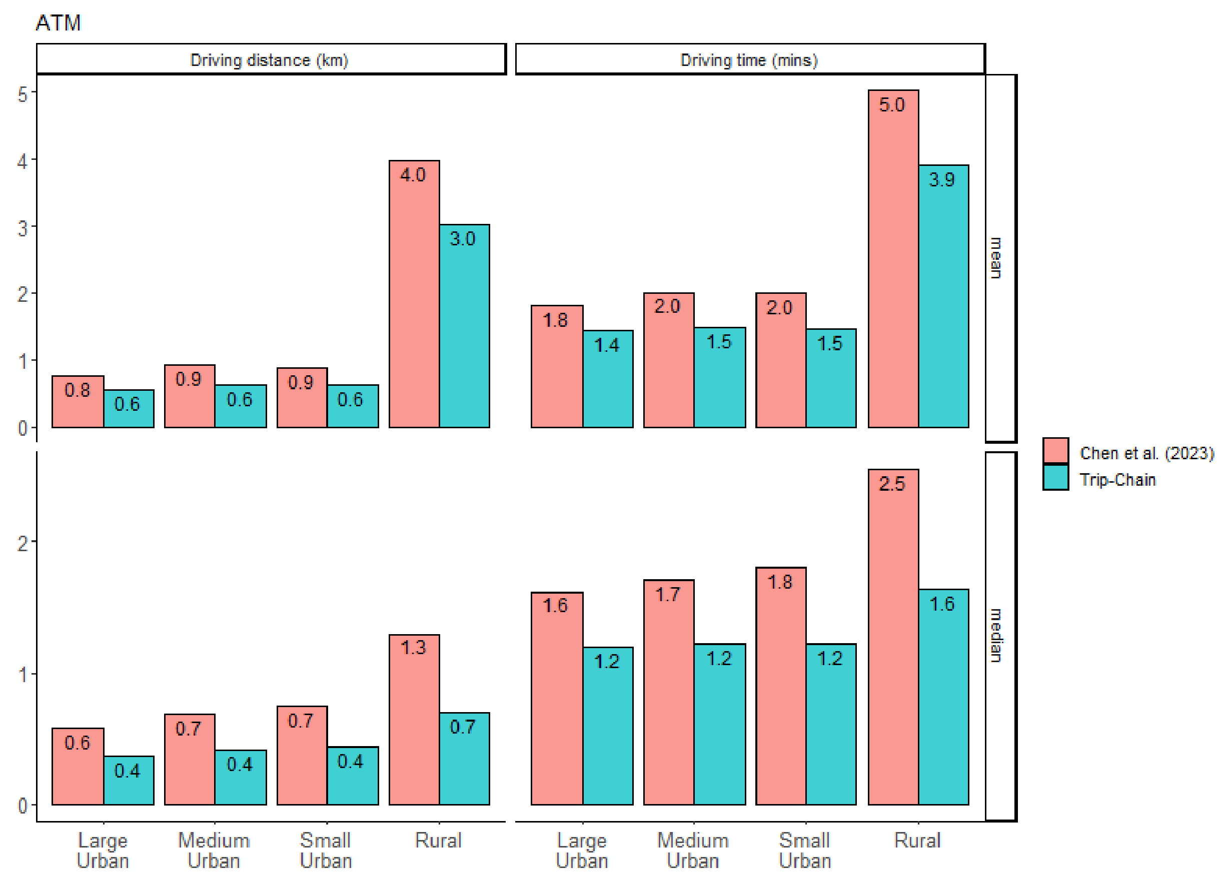
	ABM		FI Branch	
Share of population within	Non-trip-chaining	Trip-chaining	Non-trip-chaining	Trip-chaining
1 km	0.63	0.75	0.33	0.48
1.57 km (transit/ walk threshold)	0.78	0.84	0.54	0.65
5 km	0.91	0.93	0.84	0.88
10 km	0.96	0.97	0.91	0.93
20 km	0.99	0.99	0.97	0.97
> 20 km	1	1	1	1

Table 2: Driving time to the nearest cash source—cumulative distribution

	ABM		FI Branch	
Share of population within	Non-trip-chaining	Trip-chaining	Non-trip-chaining	Trip-chaining
5 min	0.88	0.91	0.75	0.82
10 min	0.95	0.97	0.89	0.92
20 min	0.99	0.99	0.97	0.97
> 20 min	1	1	1	1

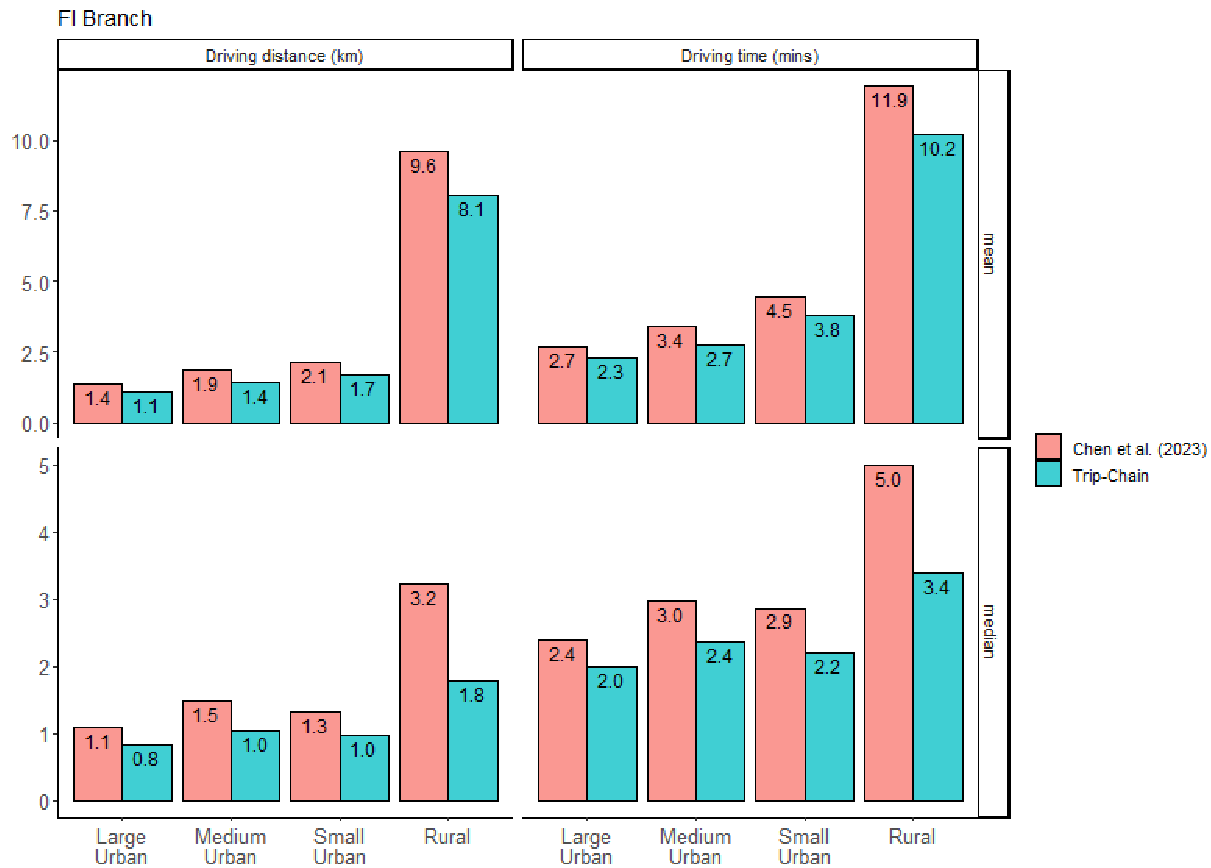
Next, we break down the travel distances and driving times by urban versus rural census subdivisions (CSD), shown in charts 2 and 3.[6] While all areas show an improvement in access to cash after taking trip-chaining into account, rural residents clearly benefit the most from combining multiple visits into a single trip. In Chart 2, while the resident in the large urban area sees their median travel distance to the nearest ABM decrease by 0.2 km, the rural resident sees a 0.6 km decrease in their median travel distance. The story is similar for FI branches, shown on Chart 3, with the resident in the large urban area seeing a reduction of 0.3 km in their median travel distance to the nearest branch, versus an improvement of 1.4 km for the rural resident.

Chart 2: Driving distance and time to the nearest ABM, with and without trip-chaining, by census subdivision type



[6] Census subdivisions (CSDs) are municipalities or equivalent-level administrative divisions across Canada. We classify CSDs in a manner similar to how Statistics Canada defines population centres. CSDs are urban if they have a total population of 1,000 residents or more and a population density of 400 people or more per square kilometre. All other CSCs are classified as rural. Urban CSDs are classified as large, medium-sized, or small if they have populations of 100,000 or more; between 30,000 and 99,999; and 29,999 or fewer, respectively.

Chart 3: Driving distance and time to the nearest financial institution branch, with and without trip-chaining, by census subdivision type



In summary, for Canadians accessing cash, taking trip-chaining into account decreases the estimated travel cost by around 20%, with the decrease being disproportionately driven by rural residents.

4. Conclusion

By utilizing smartphone mobility data, our paper advances the existing access to cash metrics by incorporating the novel trip-chaining feature into the household's cash withdrawal trip. Our proposed trip-chaining access to cash metrics address the overestimation of travel costs in the existing metrics, which typically assume that cash withdrawal trips only originate from home. Our findings reveal that incorporating trip-chaining reduces the travel cost by approximately 20% for Canadian households compared to not incorporating trip-chaining. This reduction is predominantly driven by rural households, indicating the importance of trip-chaining as an efficient way of reducing these households' travel costs and their responses in the face of spatial agglomeration.

Our study has two potential policy implications for access to cash. First, the role of trip-chaining underscores the importance of household mobility when identifying potential "cash deserts." Although households might live far from their nearest cash access points, they can benefit from shorter travel distances or times by combining multiple visits into a single trip. Hence, to alleviate the negative impact of the "cash desert," policymakers might consider placing ABM / FI branches in places where spatial agglomerations occur. Second, our trip-chaining metric is a more accurate measurement of the cost of travel to obtain cash, which is a critical ingredient of computing the overall cost of using cash.

For future research, the potential heterogeneity of trip-chaining across households warrants further exploration. This is because there could be different trip-chaining behaviors between urban and rural households and across different age groups and other socioeconomic statuses. This issue might be dealt with by studying self-reported survey data on both extensive and intensive trip-chaining choices.

Appendix A: Example of observations from the Advan Research data

In Table A1, each row represents the number of weekly visitors to a POI during a given week. For the week of October 27, 2022, visits to a McDonald's restaurant and a Shoppers Drug Mart are recorded. The dataset captures the weekly date, the name of the POI (Location Name), its category, its dissemination area (DA), and the home dissemination areas (DAs); that is, where the visitors come from and their associated numbers.[7] For example, the first row represents that four visitors from DA 24730163 visited the McDonald's restaurant located at DA 24730150 during the week of October 27, 2022. In addition, there are other variables such as the total number of visits and visitors to each POI during that week.

Table A1: Example Advan Research for October 2022

Week date	Location name	Location category	POI DA	Visitor's home DAs and total visitors
October 27	McDonald's	Restaurants	24730150	{24730163:4}
October 27	Shoppers Drug Mart	Drug stores	24870064	{24870050:4, 24870067:4, 24870096:4}

[7] Advan Research determines a visitor's home DA, using a clustering algorithm. It uses a device to cluster GPS signals between 6 pm and 7 am (overnight) and identifies the DA with the most clusters as the potential home location. Advan Research then aggregates the previous six weeks of the device's potential home locations and identifies the most frequent one as the actual home location. This location is updated over time.

Appendix B: Calculation of the normalization factor to avoid double-counting

This appendix details the calculation of the normalization factor used in Section 2.3.1. We use data from the U.S. 2017 National Household Travel Survey, in the following steps:

- From the survey, each person makes 3.37 one-way trips per day, on average. This accounts for trips to POIs and workplaces and returning home.
- Next, there is a weighted average of 1.40 trips home per person per day. This number will need to be subtracted from the total number of trips per day.
- Moreover, 17.4% of all trips are to/from the workplace. Assuming that these trips to the workplace must be followed by trips from the workplace, then 17.4%/2 = 8.7% of all trips are associated with the workplace.
- Given the above three steps, the number of trips to POIs other than workplaces and homes per day is as follows:

  $$\begin{aligned}&\#\text{ of trips to POIs}\\&= \#\text{ of total trips} - \#\text{ of trips to workplace} - \#\text{ of trips to home}\\&= 3.37 - 1.40 - 3.37 * 8.7\%\\&= 1.68\end{aligned}$$

- Then we convert the daily number to the weekly number and we get the number of POI visits (stops) per week outside of homes and workplaces, which is 1.68*7 = 11.76.
- To obtain the number of unique travelling households in a week, we use the ratio between the average number of visits and the number of visitors derived from the Advan Research data, which equals 1.5. As a result, each household visits 11.76/1.5 = 7.84 unique POIs during a week, and this forms the normalization factor used in Section 2.3.1.

Using alternative data from Japan as a robustness check, we use Miyauchi et al.'s (2022) results on the trip-chaining behavior of Tokyo mobile phone users. Miyauchi et al. (2022) found that the users in their sample had, on average, 1.6 stays outside their homes and workplaces per day during the workweek and 1.93 stays per day on weekend days. Therefore, the total number of POI stops per week outside of their homes and workplaces is 1.6*5 + 1.93*2=11.86. Using the same ratio of 1.5 from the Advan Research data, this results in 11.86/1.5=7.90, which represents that each household visits 7.90 unique POIs during a week.

As we can see, the normalization factors computed from the U.S. and Japan are closely aligned, thereby validating the robustness of our results in Section 2.3.1.

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