Measuring the Price of Internet Access in Canada

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Abstract

This paper describes the methodology used to calculate the Internet access services component of the Canadian CPI. The Internet access services aggregate measures the price change of monthly subscriptions to services that allow for Internet access from a residence. A pure matched-sample cannot properly account for the rapid technological change and marketing practices that characterize the Internet access industry in Canada. Therefore, a novel symmetric hedonic method is used to adjust the prices of both entering and exiting Internet access services plans. Due to a limited number of observations, provider specific effects cannot be reliably estimated with a linear regression. To account for this, the predicted values of missing plans are adjusted using the residuals of the most similar observed plans. Plan weights for both the regression and the index calculation are updated every period based on the median observed download speed.

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1- Introduction

The Canadian Consumer Price Index (CPI) measures the aggregate price changes of a broad range of consumer goods and services. For various reasons, the price changes of some of these products are harder to measure than others. In general, it is more difficult to construct price indexes for services[1] than price indexes for goods. The quality of similar services can vary over time or along hidden dimensions unlike many goods which are quite homogenous due to their standardized production.[2] High-technology products are another type of product for which it is difficult to construct price indexes. These products tend to experience a rapid churn of models as the associated technology changes**.** This in turn can quickly lead to sample depletion if one attempts to adhere to the fixed basket concept that is applied elsewhere in the CPI. In the face of such conditions, the Consumer Price Manual (ILO et al., 2004) recommends the use of chaining and hedonic methods.

Residential Internet access is a high-technology service. As such, its calculation requires methods that are not typically applied to other components of the CPI. This paper describes the methodology that Statistics Canada has adopted to measure the price change of residential Internet access services. It aims to provide sufficient context so that the rationale behind the methodology can be understood. The paper is structured as follows. Section 2 provides some important background information on the scope, history and place of Internet access services in the CPI. In addition, it discusses salient features of the Canadian market for Internet access services. Section 3 outlines data collection procedures. Section 4 covers the weighting of plans by download speeds. The imputation of missing prices is discussed in Section 5 while Section 6 presents the aggregation structure. Section 7 concludes the paper.

2 - Background

2.1 - Scope and Structure

The Internet access services aggregate is a component of the Communications aggregate. When the CPI basket weights were updated to the 2015 reference year in February 2017, the Internet access services aggregate accounted for 28% of the weight of the Communications aggregate. Telephone services is another important component of the Communications aggregate, comprising 67% of the Communications aggregate's weight. The other two components of the Communication aggregate, Telephone equipment and Postal and other communications services, accounted for the remaining 5% of the weight. Table 1 shows that the weight of the Internet access services aggregate has more than tripled since it was first introduced with the 2001 basket. Since its introduction, the Internet access services aggregate has undergone two substantial revisions to its methodology; the first one took place with the release of the March 2008 CPI (Statistics Canada, n.d.). The second substantial revision occurred with the release of the November 2015 CPI (Statistics Canada, 2015b) and introduced most of the methods described in this paper. In addition to the Canada level index, Statistics Canada publishes the Internet access services indexes for all 10 provinces and the capital cities of the Northwest Territories and Yukon.

[1] "A service in the Consumer Price Index (CPI) is characterized by valuable work performed by an individual or organization on behalf of a consumer, for example, car tune-ups, haircuts and city public transportation. Transactions classified as a service may include the cost of goods by their nature. Examples include food in restaurant food services and materials in clothing repair services" *Source: Footnote 18 from Table 326-0020 -CANSIM (database). (accessed: February 12, 2017)*

[2] See OECD/Eurostat (2014) for a thorough treatment of service price indexes in the producer context

Table 1: Canada-Level Weights as Percent of Total Basket at Link Month Prices

Reference Year	Internet access services	Telephone services	Communications
2001	0.30	2.21	2.64
2005	0.51	2.30	2.95
2009	0.68	2.20	3.07
2011	0.81	2.39	3.36
2013	0.96	2.55	3.67
2015	0.96	2.27	3.39

Source: CANSM Table 326-0031; Retrieved: January 26th, 2018

Conceptually, the Internet access services index covers all Internet access services to a residence. Thus, Internet access services to a residence that are furnished by wireless satellite or cellular signal are theoretically in scope. However, as mentioned in Section 3 - Data Collection, the prices of wireless plans to the home are not collected. With only 4% of Canadian residential subscriptions in 2016 (Canadian Radio-television and Telecommunications Commission [CRTC] 2017a), they do not represent an important part of the market. In addition, wireless plans are significantly more expensive than wired plans. This is an indication that wireless plans are different products that should not be directly compared to wired access plans.

2.2 - Internet Market in Canada

Residential internet access is marketed and sold in a similar manner across Canada. A monthly subscription to a plan from an Internet Service Provider (ISP) allows a consumer to access the Internet in a specific manner. In order to access the Internet, a method of transmitting data to and from the consumer's residence is required. This link between the consumer's home and the next stage of the ISP's network is commonly known as the last mile (CRTC 2017b). It is an important bottleneck and is often the determining factor of residential Internet speeds. The last mile can be wired or wireless, although issues with wireless connections mean that they are normally only employed when wired connections to the internet are not feasible.

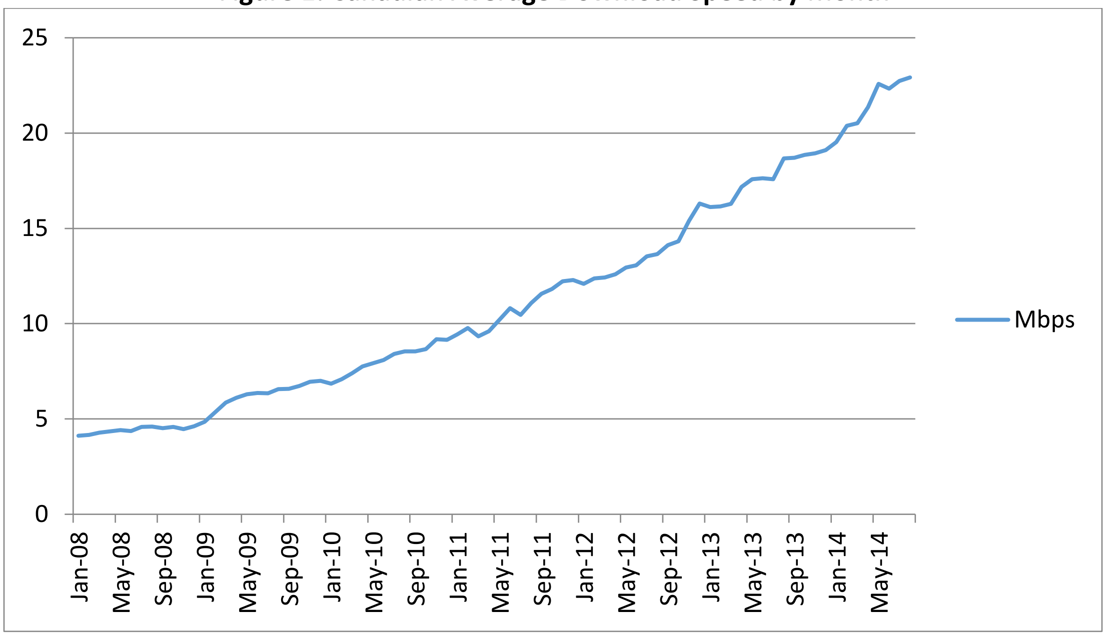
Due to the high cost of laying down wire from the ISP's network to a consumer's residence, cable and telephone companies have repurposed their existing networks to also carry Internet data to the homes of consumers. Optical fibre cables, which can carry large quantities of data, are increasingly being connected to homes but are still uncommon due to their high cost. In 2016, 10% of residential Internet access subscriptions were by fibre optic, a tenfold increase from the 1% share in 2012 (CRTC 2017a). It is usually necessary for customers to have a modem which can turn the signals received over the last mile into a form compatible with their home networks.

2.2.1 – Characteristics of Internet Access Plans

Internet access plans are mainly marketed on three technical specifications: download speed, upload speed and usage cap. Of these three, the primary characteristic of an Internet access plan is its advertised download speed, expressed in Megabits per second (Mbps). It is often incorporated into the plan's name, reflecting the importance that this feature is accorded. This advertised download speed is neither regulated nor typically guaranteed; however, in 2016 SamKnows found "the majority of ISPs delivering speeds above their advertised rate". The number of different download speeds offered by an ISP is limited, ranging from two to ten. As plans are primarily based on download speeds, it means that only a small number of plans are available to consumers.

The download speeds of Internet access plans are constantly increasing. Figure 1 shows the evolution of the average Canadian download speed, as measured by the Ookla Net Index. From January 2008 to August 2014, the average measured download speed more than quintupled, going from 4.17 Mbps to 22.74 Mbps. While Ookla Net Index is no longer available, its successor, the Speedtest Global Index, indicates that in February 2017 the average Canadian download speed was 73.41 Mbps.

Figure 1: Canadian Average Download Speed by Month



Source: Ookla Net Index. Accessed September 2nd 2014. www.netindex.com

Internet access plans are often associated with a monthly usage cap; however, "unlimited" plans without usage caps are also available. The usage cap is the sum of data transferred both to and from the customer's modem over the monthly billing period and expressed in gigabytes. There is a positive correlation (0.603[3]) between the download speed of a plan and its usage cap as users with fast connections will often want to transfer more data. ISPs commonly levy overage fees when the usage cap is exceeded. In many cases consumers can pay for an increased usage cap in order to avoid these overage fees.

Advertised upload speed, expressed in Mbps, is another defining characteristic of an internet access plan. Again, SamKnows (2016) found that "ISPs also largely met or exceeded their advertised upload speeds". Like usage caps, upload speeds have a positive correlation (0.495[4]) with download speeds, although upload speeds are usually much lower than download speeds. It is sometimes possible to upgrade upload speed, although this is rare. Other services, such as email accounts, modem rentals or anti-virus software are often included with internet access plans. However, they are widely available from other sources and are not considered defining characteristics of an internet access plan.

[3] Calculated from all unique download speed-usage cap pairs, excluding plans with unlimited usage, that were collected for the CPI between November 2013 and February 2018
[4] Calculated from all unique download speed-upload speed pairs that were collected for the CPI between November 2013 and February 2018

2.2.2 - Billing & Bundling

While large companies are subject to regulations that require them to sell wholesale access to networks, Canadian residential internet access prices are unregulated (CRTC n.d.) Billing typically occurs on a monthly basis; the price of a plan is charged one month in advance while overage fees are billed after being incurred. In addition to either purchasing or renting a modem, customers are typically charged an installation and setup fee on new accounts. The rental of the modem can be included in the base price of the plan, especially if the internet access service is bundled with other services. The value of the modem is usually marginal, except when the connection to the ISP is wireless.

As most ISPs offer a variety of residential telecommunications services in addition to Internet access, it is common for ISPs to offer a discount when internet access is bundled with one or more services. The discount can also take the form of extra features, such as an upgrade to unlimited usage. Despite the prevalence of bundling, it is not usually problematic to obtain the price of an unbundled Internet access plan. This means that it is not necessary to account for these bundling effects, which greatly facilitates the calculation of the index. In addition to bundles, it is common for the price of an Internet access plan to be discounted for an initial period, following which the price returns to the "regular" rate.

2.2.3 - Providers

The Canadian Internet access service market is largely controlled by several large companies. As noted by the CRTC (2017a), the top five companies earned 73.1% of Internet access revenues in 2016. Cable companies and former telephone monopolists together accounted for 88.1% of the Internet residential access service revenues in 2016 (CRTC 2017a). Smaller companies are either limited to a small region, resell Internet access that they purchase wholesale, or offer wireless Internet access plans to rural communities. With ten provinces and three territories, the Canadian Internet access market is characterized by geographical fragmentation. Larger ISPs are usually limited to and concentrated in just a few provinces; this means that the market for Internet access in each province is largely controlled by only two or three dominant companies.

3 - Data Collection

Data for the Internet access services index is collected by price evaluators in Statistics Canada's Head Office from the websites of the ISPs. While the Canadian CPI is produced a monthly basis, the collection of Internet prices occurs on a quarterly basis due to operational constraints. Prices are collected in the second month of every calendar quarter. In non-collection months, the previous month's index value is carried forward, as if prices have not changed.

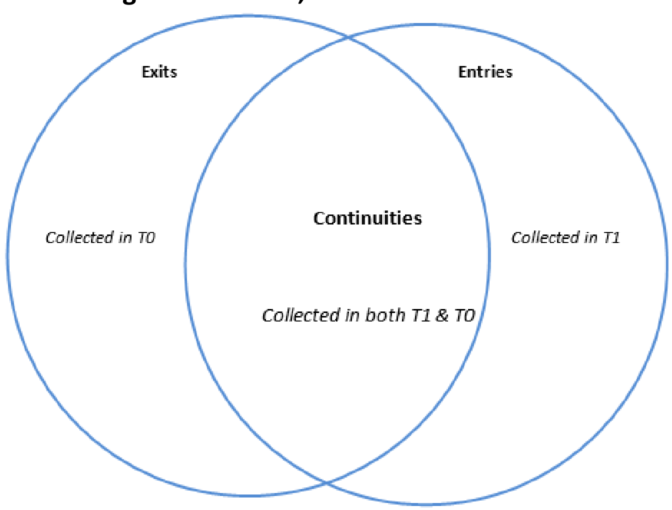
Prices are collected on a provincial basis from all ISPs with at least a 10% market share by revenue. With this cut-off, at least 75% of the market in each province will be covered. Market shares are sourced from the Annual Survey of Telecommunications, conducted jointly by Statistics Canada and the CRTC, and are updated annually. Section 7 discusses how these market shares are used to weight the aggregation of the ISP level price indexes to the provincial index. As several ISPs span several provinces, henceforth the term ISP will refer to the operations of an ISP within a specific province or territory, rather than its operations across Canada.

Only wired, broadband (non-dialup) plans are priced. For the purposes of this index, a plan is defined by its ISP, download speed, upload speed and usage cap. These characteristics are recorded for each selected plan when it is priced. As was discussed in Section 2, other characteristics such as the inclusion of a wireless modem are ignored. Given that a plan is defined by its ISP, download speed, upload speed and usage cap, these characteristics are also used to identify a plan across time.

Each pricing month, the price evaluator selects and records the price and characteristics of a plan at every available download speed for each ISP. The collected price corresponds to the regular, unbundled, price of the plan. If there are several plans with the same download speed, only one of them is selected, based on the price evaluator's judgment of which one is the most representative plan. As long as a plan remains available it will continue to be priced. A plan is considered a "continuity" when it is observed in both the current and previous period.

When a new download speed is offered, the price evaluator immediately selects and prices a plan corresponding to this new download speed. This means that new plans can "enter" the sample even without a corresponding "exit". In the same way, a plan can exit the sample without a corresponding entry. However, in the case of an exit, the price evaluator will select and price a new plan with the same download speed from the same ISP, if possible. The dynamic nature of entries and exits means that the sample size is not fixed and that it will adjust automatically in response to the introduction of new plans and the discontinuation of older plans. This is necessary due to the high churn rate; at the ISP level, on average 15.1% of plans exited the sample on a quarterly basis between the first quarters of 2016 and 2018. Section 5 describes the hedonic adjustment procedure that accounts for missing prices and allows both entering and exiting plans to enter into the index while Figure 2 graphically represents the difference between entries and exits.

Figure 2: Entries, Exits and Continuities



4 - Weighting by Download Speed

It is standard practice in the Canadian CPI to equally weight prices at the lowest, elementary aggregate (EA), level and to aggregate their price relatives using the Jevons index (Statistics Canada, 2015a). This method works well when combined with the manual definition and selection of a small number of Representative Products (RP). This is because Representative Products are defined in such a way that it is sensible to accord an equal weight to each price within the same EA.

However, this method cannot be applied to the Internet access services index. As described in Section 3, prices corresponding to the full range of available download speeds are collected every period from each ISP. This is done to ensure that new plans enter the sample immediately and to combat sample deterioration. It would not be reasonable to accord the same weight to both a newly introduced, high-speed, plan and a plan with a more representative download speed. It is therefore important to weight plans below the ISP level to help ensure that the index reflects the price changes experienced by consumers. Ideally plans would by weighted by their revenue or expenditure share but at this time Statistics Canada does not have access to expenditure data at the individual plan level. In absence of external quantity or expenditure data at individual plan level, plans are weighted based on their observed download speed. This is done based on the distribution of the available download speeds within an ISP.

The plans of a given ISP, *l*, in a given period, *t,* are assigned a weight vector, q_l^{t*}, such that the weighted sum of their download speeds equals their median download speed. The weight vector q_l^{t*} can be regarded as a vector of quantity shares. This approach assumes that the distribution of available download speeds is reflective of consumer demand. There is a wide body of research that supports the conclusion that the purchasing decisions of consumers can be strongly influenced by "anchors". While some studies have shown that completely arbitrary anchors such as Social Security Numbers can be effective (Ariely, Loewenstein & Prelec 2003), there is evidence that the presentation of similar products with extreme yet plausible prices is a more effective anchoring mechanism (Kishna, Wagner & Yoon 2006)(Sugden, Zheng & Zizzo 2013). In the marketing literature, the presentation of a range of similar products, each at a different price point, is known as price lining (Analoui & Karami, 2003). For the purposes of calculating a price index, it would be inappropriate to estimate the distribution of weights based on the distribution of prices. This is because prices already directly enter into its calculation and we do not want them to also enter indirectly through the estimation of weights.

In addition to the constraint that the weighted sum of download speeds is equal to the median download speed, weights are assigned such that their variance is minimized. This ensures that weights are spread out as evenly as possible, rather than simply assigning all weights to the fastest and slowest plans. Combined with the constraint that the weights sum to one, this minimization of variance is equivalent to minimizing the squared difference between the generated weights and a vector of equal weights, given the constraint that the weighted average download speed equals the median download speed.

The generation of weight vector q_l^{t*}can be formulated as the solution to the following minimization problem. Defining a_l^t as the median download speed of ISP l in period *t,* s_{il} as the download speed of plan *i* from ISP *l* and n *as* the number of available plans:

$$(1) \quad q_l^{t*} = \underset{q_{il}}{argmin} \sum_{i=1}^{n} \left(q_{il} - \frac{1}{n}\right)^2$$

subject to:

$$\sum_{i=1}^{n} q_{il} * s_{il} = a_l^t;$$

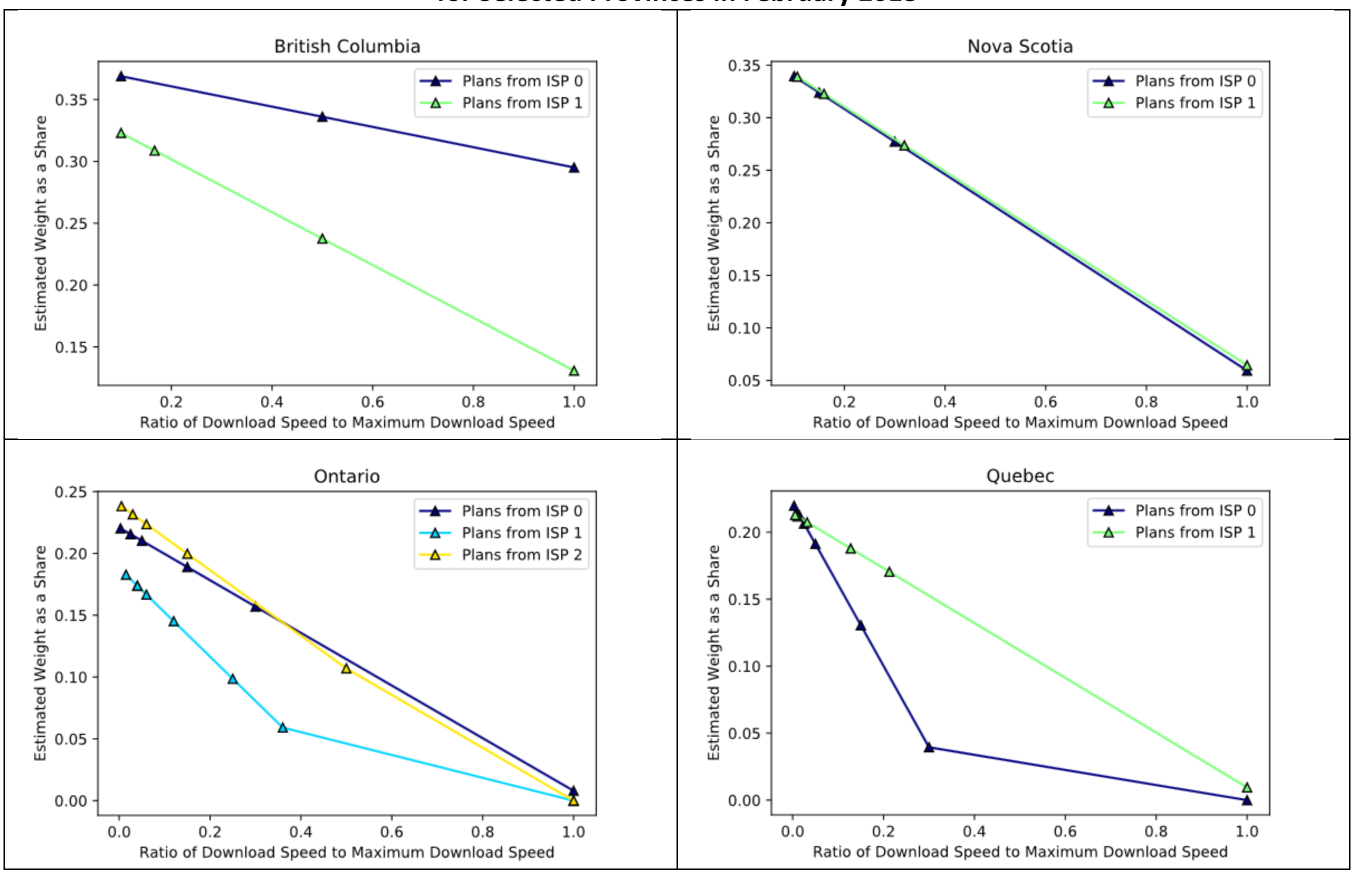
$$\sum_{i=1}^{n} q_{il} = 1;$$

$$\text{and } q_{il} \geq 0$$

Since weight vector q_l^{t*} is treated as a vector of quantity shares, the corresponding vector of expenditure shares, v_l^{t*}, is obtained by multiplying these quantity shares by their respective prices and subsequently dividing by their sum so that:

$$(2) \quad v_{il}^{t*} = \frac{q_{il}^{t*} * p_{il}^{t}}{\sum_{i=1}^{n} q_{il}^{t*} * p_{il}^{t}}$$

Figure 3 - Estimated Distribution of Weights by Normalized Download Speed for Selected Provinces in February 2018



The weight generation procedure generally results in a reduced weight being assigned to the faster plans. This is because ISPs usually offer a range of download speeds that increase in an exponential fashion[5]. However, average download is constrained to equal median speed in a linear fashion. This means that any weight that is assigned to a faster plan results in a disproportionate shift of the average download speed, a shift that has to be compensated by increasing the weight of a slower plan. Figure 3 provides a graphical representation of the results of this estimation procedure for selected provinces in February 2018. Estimated weights are plotted against download speeds; download speeds have been normalized by

[5] For example, an ISP might offer plans at the following speeds: 20 Mbps, 40 Mbps, 80 Mbps and 160 Mbps

dividing by the maximum download speed from the same ISP. Plans from the same ISP are joined by lines to help distinguish plans from different ISPs. One can readily observe a negative relationship between download speed and weight. This relationship also tends to be linear, except for two kinks, one in Ontario and one in Quebec. In both cases, the fastest plan has received a minimal weight that is very close to zero. Overall, the results of weight generation procedure are more plausible than the alternative of assigning all plans an equal weight.

5 - Hedonic Adjustment of Entries and Exits

For products that undergo rapid technological change and an associated churn in models, the matched model breaks down and can lead to substantial bias (Silver & Heravi, 2005). This problem applies to Internet access plans since an average of 15.1% of plans exit the sample each quarter. This high churn rate can be explained by both improved technology such as increasing download speeds as well as marketing tactics of the ISPs. Under such conditions, hedonic methods can be applied to account for price change that would be missed under the matched model approach (Triplett, 2004).

The hedonic approach to price indices formulates the prices of products as functions of their characteristics. Generally, regressions are used to estimate these functions, the results of which can be applied in several different ways. In situations with a sufficiently large number of observations, the literature would seem to indicate preference for hedonic imputation indexes (Diewert et al. 2009) (Hill 2011).

However, the small number of ISPs and unique plans pose a challenge to the application of hedonic imputation indexes. Between the first quarters of 2016 and 2018, an average of 5.7 plans were collected from each ISP, while 11.4 plans were collected per province. In addition to this issue, hedonic indexes can be difficult to interpret, a problem that should not be disregarded. It is for this reason that hedonics techniques are applied to adjust the missing prices of exiting and entering plans based on the prices of the most similar plans. Triplett (2004) called this application of hedonic techniques the "hedonic quality adjustment method" while Silver and Heravi (2002) gave it the more colourful name of "patching".

A benefit of this application of hedonics is that it is easier for CPI analysts to interpret and explain due to its similarity to other methods of quality adjustment employed in the CPI. It is interesting to note that Williams (2009) considered three different hedonic indexes in the context of the American CPI; all three indexes employed variants of hedonic adjustment rather than the hedonic imputation indexes preferred by Diewert, Heravi, & Silver (2009) or Hill (2011).

5.1 - Regression Functional Form

A regression is estimated every collection period on the same sample from which the index is calculated. This means that the plans from the two periods are pooled in the same regression. As a result, the estimated coefficients of the characteristics are constrained to be the same between the two periods. Given that all plans were observed in two adjacent quarter, this would seem to be a reasonable restriction.

The dependent variable, logged price, is regressed on the download speed, upload speed and usage cap. Download speed and usage cap enter in logged form. When a plan does not have a usage cap (ie. usage is unlimited), its logged usage cap is set to zero and a dummy variable is set to unity. If usage is limited, this dummy variable is set to zero. Because of the strong correlation between upload speed and download speed, the ratio of upload speed to download speed is used.

Least squares are used to solve for the B vector of parameters in the following formulation:

$$(3)\quad \ln p_i^t = B \cdot X_i^t + \varepsilon_i$$

where p_i^t is the price of plan *i* from period *t*, ε_i is a random error term with an expected value of zero and X_i is plan i's vector of characteristics.

There are a limited number of ISPs providing service to a given residence, and it is assumed that a consumer will not change residences simply to change ISPs. It is therefore readily apparent that there is no Canada-wide market for Internet access services. Ideally separate regressions would be run or dummies included for each ISP. However, in this case there would be too few observations to estimate the relationship between prices and characteristics with much confidence. Instead, all plans from current and previous period are pooled together for one regression.

The regression is weighted in order to ensure that all combinations of characteristics and prices are accorded their proper importance. The results of the optimization model, as specified in equations (1) and (2), are used to assign a regression weight to each plan. The model is constrained so that, for both periods, all providers within a given province are equally weighted and each of the ten provinces receives an equal weight. If a particular plan is not available in a given period, this is equivalent to it having no weight in the regression for that period. Plans from the three territories are excluded from the regression because they are not representative of the overall Canadian market and should not influence the adjustment of plans in the provinces. However, plans from the territories are still subject to same adjustment procedure as the plans from the provinces.

5.2 – Adjustment Procedure

Once the regression model has been estimated and the coefficients estimated, the missing prices of entering and exiting plans are calculated. This is done by applying an adjustment factor to the predicted price from the regression. The adjustment is necessary since the hedonic regression is constrained to hold characteristics coefficients constant across the two-time periods. Thus, the missing of price of plan *i* in period *t* from ISP *l* is calculated as:

$$(4)\quad p_{il}^t = e^{\hat{\beta} \cdot X_{il}^t} \times A_{il}^t$$

Here $\hat{\beta}$ is the vector of characteristic coefficients estimated from the regression; note the lack of time subscript, t, on the β vector of coefficients. X_{il}^t is the missing plan's vector of characteristic while A_{il}^t is the adjustment factor calculated from the plans available in period *t* from ISP l that are most similar to the missing plan. Having noted that the adjustment procedure only considers plans from the same ISP, henceforth the ISP subscript l will be dropped for legibility reasons. This is because However, the

The selection of the most similar plans is fully automated. The download speed of plan *i*, s_i, compared to the download speeds of all plans available from ISP *l* in period *t*, the set S_l^t. If plan *i's* download speed is either higher or lower than any other plan, i.e.:

$$(5)\quad \begin{aligned} &s_i > \underset{s \in S_l^t}{\operatorname{argmax}}(s) \\ &\text{or } s_i < \underset{s \in S_l^t}{\operatorname{argmin}}(s) \end{aligned}$$

then the following equation holds:

$$(6)\quad A_i^t = \frac{p_j^t}{e^{\hat{\beta} \cdot X_j}}$$

Here p_j^t is the price of the plan from ISP l available in period t with the closest speed to plan *i*'s. This corresponds to Cases 1 and 2 in Table 2. The above calculation also applies if $s_{jl} = s_{il}$, i.e. when there is a plan from ISP *l* in period *t* with a download speed exactly equal to the download spend of missing plan *i*. This corresponds to Case 3 in Table 2. If none of these conditions are satisfied, then A_i^t is calculated as:

$$(7)\quad A_i^t = \left(\frac{p_k^t}{e^{\hat{\beta}\cdot X_k}}\right)^{0.5} \times \left(\frac{p_j^t}{e^{\hat{\beta}\cdot X_j}}\right)^{0.5}$$

In this case, the adjustment factor is based on the price of two different plans, *j* and *k*, both available from ISP *l* in period *t*. Their download speeds, s_j and s_k, bound the download speed of plan *i*, such that $s_k \geq s_i \geq s_j$. In addition, s_j and $s_k$satisfy the following conditions:

$$(6)\quad \begin{aligned} s_k &= \underset{s \in S_l^t; s > s_i}{\operatorname{argmin}} (s - s_i) \\ s_j &= \underset{s \in S_l^t;\, s_i > s}{\operatorname{argmax}} (s_i - s) \end{aligned}$$

In other words, plan *k* is the plan offered by ISP *l* in period *t* with a download speed that is faster than s_i, but by a minimal amount. Plan *j* is the plan offered by ISP l in period t plan that slower than s_i, but by minimal amount. The different methods of calculating the adjustment factor $A_i^t$are summarized in Table 2, while Tables 3-6 provide examples (entries and exits are shaded).

TABLE 2

Case	Condition	Calculation of A_{il}^t	Where
1	$s_i \geq \underset{s \in S_l^t}{\operatorname{argmax}}(s)$ *The missing plan has a download speed that is higher than or equal to the download speed of any plan offered in period t, the period for which the plan is missing*	$A_i^t = \frac{p_j^t}{e^{\hat{\beta}\cdot X_j}} = p_j^t e^{-\hat{\beta}\cdot X_j}$	$s_j = \underset{s \in S_l^t}{\operatorname{argmax}}(s)$
2	$s_i \leq \underset{s \in S_l^t}{\operatorname{argmin}}(s)$ *The missing plan has a download speed that is lower than or equal to the download speed of any plan offered in period t, the period for which the plan is missing*	$A_i^t = \frac{p_j^t}{e^{\hat{\beta}\cdot X_j}} = p_j^t e^{-\hat{\beta}\cdot X_j}$	$s_j = \underset{s \in S_l^t}{\operatorname{argmin}}(s)$
3	$s_i = s_j$ *The missing plan has a download speed that is exactly equal to the download speed of a plan offered in period t, the period for which the plan is missing*	$A_i^t = \frac{p_j^t}{e^{\hat{\beta}\cdot X_j}} = p_j^t e^{-\hat{\beta}\cdot X_j}$	$s_j \in S_l^t$
4	Else *There are two plans offered in period t with download speeds that bound the download speed of the missing plan*	$A_i^t = \left(\frac{p_k^t}{e^{\hat{\beta}\cdot X_k}}\right)^{0.5} \times \left(\frac{p_j^t}{e^{\hat{\beta}\cdot X_j}}\right)^{0.5}$	$s_k > s_i > s_j$ $s_k = \underset{s \in S_l^t}{\operatorname{argmin}}(s - s_i)$ $s_j = \underset{s \in S_l^t}{\operatorname{argmax}}(s_i - s)$

TABLE 3: CASE #1 - ENTRY

Period	Download Speed	Upload Speed	Cap	Actual Price	$e^{\widehat{\ln p}}$	A^t	Calculation	Adjusted Price	Missing Period	Relative
T	40	4	250	$99.95	$76.11	99.95/76.11 = 1.3132	1.3132 X 86.46	$113.54	T	107.95/113.54 = 0.9508
T+1 Entry	80	8	250	$107.95	$86.46					

TABLE 4: CASE #2 - EXIT

Period	Download Speed	Upload Speed	Cap	Actual Price	$e^{\widehat{\ln p}}$	A^t	Calculation	Adjusted Price	Missing Period	Relative
T Exit	6	1	100	$55.00	$48.84	60.00/59.24 = 1.0128	48.84 X 1.0128	$49.47	T+1	49.47/55.00 = 0.8995
T+1	15	1	150	$60.00	$59.25					

TABLE 5: CASE #3 - ENTRY

Period	Download Speed	Upload Speed	Cap	Actual Price	$e^{\widehat{\ln p}}$	A^t	Calculation	Adjusted Price	Missing Period	Relative
T	5	1	20	$46.95	$39.92	46.95/39.92 = 1.1761	1.1761 X 43.23	$49.67	T	46.95/49.67 = 0.9452
T+1 Entry	5	1	40	$46.95	$43.23					

TABLE 6: CASE #4 - EXIT

Period	Download Speed	Upload Speed	Cap	Actual Price	$e^{\widehat{\ln p}}$	A^t	Calculation	Adjusted Price	Missing Period	Relative
T Exit	35	3	120	$67.99	$67.78	$(69.99/75.65)^{0.5}$ x $(61.99/62.91)^{0.5}$ = 0.9548	67.78 x 0.9548	$64.72	T+1	64.72/67.99 = 0.9519
T+1	60	10	120	$69.99	$75.65					
T+1	30	5	70	$61.99	$62.91					

6 - Aggregation

Provincial and territorial elementary price indexes are calculated in a two-stage fashion. In the first stage, plan level price relatives are aggregated to produce ISP level price movements. The price movements of all plans, whether continuing, entering or exiting, are included in the calculation, after applying the hedonic adjustment procedure described in Section 5. These price movements are weighted with an average of the estimated weight vectors v^t and v^{t-1}, from equation (2) in Section 4. If a plan is not available in certain period due to entering or exiting the sample, it receives a weight of zero in that period. For example, if plan *i* has entered the sample in period *t*, then v_i^{t-1} will equal zero. This aggregation to the

ISP level movement resembles a chained Tornquist-Thiel index. The following equations show the calculation of price change for ISP *l*:

$$(7)\quad I_l^{t-1:t} = \prod_i \left(\frac{p_{il}^t}{p_{il}^{t-1}}\right)^{\frac{v_{il}^{t-1}+v_{il}^t}{2}}$$

Where:

$$\sum_i v_{il}^{t-1} = 1;\ \sum_i v_{il}^t = 1$$

In the second stage, provincial and territorial elementary price indexes are calculated as the weighted geometric mean of the ISP specific price movements. The weight vector, w, contains the per ISP shares of residential internet access revenues from the most recent Annual Survey of Telecommunications. As described in Section 2, these weights are updated on an annual basis. Aggregation of price movements using a geometric mean with fixed weights is generally known as the geometric Young (ILO et al., 2004). The following equations show the calculation of price change for a given province.

$$(8)\quad I^{t-1:t} = \prod_l \left(I_l^{t-1:t}\right)^{w_l}$$

Where:

$$\sum_l w_l = 1$$

7 - Conclusion

This paper has covered the challenges that arise in the calculation of the Internet access services component of the Canadian CPI as well as the methods that have been adopted to deal with these challenges. Hedonic adjustment of entering and exiting plans as well as estimation of plan level weights are key features of the adopted methodology. Statistics Canada is continually engaged in efforts to improve the Consumer Price Index program. Access to timely administrative data directly from telecommunications companies could greatly benefit the Internet access services index. This would obviate the need to estimate plan level weights and would also allow for the calculation hedonic of imputation indexes.

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