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CENTRE FOR THE STUDY OF LIVING STANDARDS

Canada-U.S. ICT Investment in 2009: The ICT Investment per Worker Gap Widens

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Executive Summary

This report is based on the update to 2009 of the Centre for the Study of Living Standards (CSLS) Information and Communication Technology (ICT) database for Canada and the United States. It provides a brief overview of developments in ICT investment in the business sector for both Canada and the United States, focusing on developments in the ICT investment gap in 2009. The report's key findings are the following:

- Measured in domestic currency, nominal ICT investment spending in the Canadian business sector advanced 0.6 per cent in 2009, outpacing that of the United States, which dropped by 3.9 per cent in the same period.

- Even taking into account the fact that business sector employment in Canada decreased significantly less than in the United States in 2009 (-2.5 per cent versus -5.5 per cent), nominal ICT investment per worker growth in Canada still outperformed that of the United States (3.1 per cent versus 1.7 per cent).

- Nominal investment trends among the three ICT components differed considerably in the two countries, especially regarding communications equipment investment, which rose 2.7 per cent in Canada, but fell 10.3 per cent in the United States. Nominal computer investment fell in both Canada and the United States in 2009 (-6.8 per cent and -9.8 per cent respectively) and nominal software investment rose in both countries (4.0 per cent and 0.3 per cent).

- The higher nominal ICT investment per worker growth experienced in Canada relative to that of the United States would imply, *ceteris paribus*, a reduction of the Canada-United States ICT investment per worker gap. However, a sharp 6.5 per cent decline in the purchasing power parity (PPP) for machinery and equipment (M&E) between the two countries in 2009 caused the gap to widen, with the ratio of nominal ICT investment per worker in Canada relative to that of the United States actually falling from 62.8 per cent in 2008 to 59.5 per cent in 2009.

- The prices of ICT investment goods had opposing trends in both countries in 2009. While in the United States the prices of ICT investment goods declined by 4.6 per cent, in Canada they increased by 4.1 per cent. This price increase in Canada reflects in part the significant depreciation of the Canadian dollar, which dropped 6.5 per

cent in 2009 (from 0.937 USD in 2008 to 0.876 USD, according to average noon exchange rates), effectively ending a long trend of declining ICT prices.

- Rising ICT investment prices caused a sharp drop of 3.5 per cent in real ICT investment in Canada. At the same time, falling ICT investment prices in the United States led to a slight increase of 0.7 per cent in real ICT investment. This represents a reversal of the pattern observed for nominal ICT investment in the two countries.

Canada-U.S. ICT Investment in 2009: The ICT Investment per Worker Gap Widens[1]

I. Introduction

This report is based on the update to 2009 of the Centre for the Study of Living Standards (CSLS) Information and Communication Technology (ICT) database for Canada and the United States. The ICT database provides chained and current dollar estimates of ICT investment and ICT capital stock in Canada and the United States for 20 North American Industry Classification System (NAICS) sectors and for the business sector.[2] The data encompasses the 1981-2009 period for Canada and the 1987-2009 period for the United States. Furthermore, it is presented for the three ICT components (computers, communication equipment and software), as well as total ICT. This report provides an overview of developments in ICT investment in the business sector for both Canada and the United States, focusing on developments in 2009.[3]

II. ICT Investment in Canada and the United States

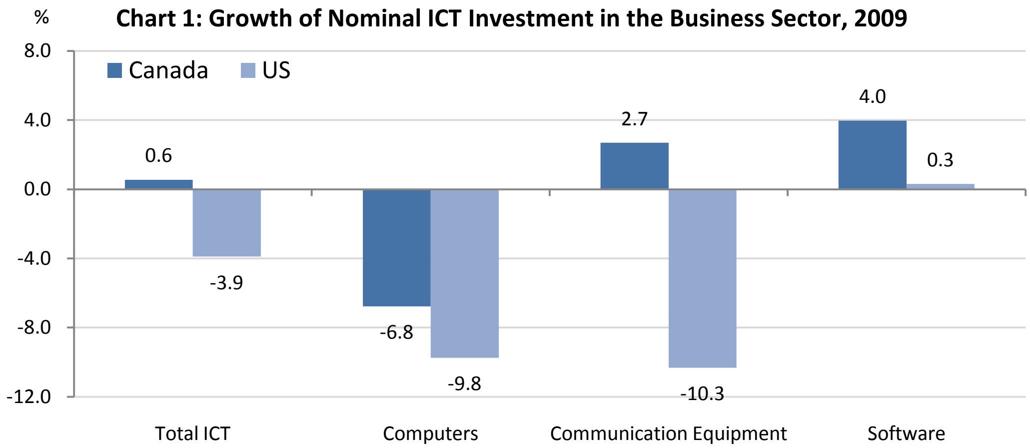
A. Nominal ICT Investment Growth

Nominal ICT investment growth in the business sector in Canada in 2009 was 0.6 per cent, surpassing the 3.9 drop experienced in the United States (Chart 1 and Table 1). These growth rates represent a significant deceleration in ICT investment growth for both Canada and the United States, down from 4.2 per cent and 1.8 per cent, respectively, in 2008. However, ICT investment growth in 2009 was still substantially higher than total investment (fixed, non-residential) growth in the business sector for the two countries, which fell 9.9 in the case of Canada and 18.4 in the case of the United States.

Nominal growth in Canada in 2009 exceeded that of the United States for all three ICT components. Nominal computer investment declined in both countries, but dropped significantly more in the United States (-6.8 per cent versus -9.8 per cent). In contrast, nominal software investment advanced in both countries, but more so in Canada (4.0 per

[1] This report was prepared for the Information Technology Association of Canada. The authors would like to thank Lynda Leonard, Senior Vice-President of ITAC, for her support. The authors would also like to thank David Wasshausen from the U.S. Bureau of Economic Analysis and Erwin Diewert from the University of British Columbia. For comments, please contact the authors at andrew.sharpe@csls.ca or ricardo.avillez@csls.ca.
[2] In the case of Canada, the data also includes estimates for total economy and the non-business sector.
[3] This paper builds on and extends earlier CSLS work on ICT investment trends. For more information on the topic, see CSLS (2008), Sharpe (2005, 2006 and 2010) and Sharpe and Arsenault (2008a and 2008b).

cent versus 0.3 per cent). Nominal communications equipment investment rose in Canada by 2.7 per cent, but fell in the United States by 10.3 per cent.



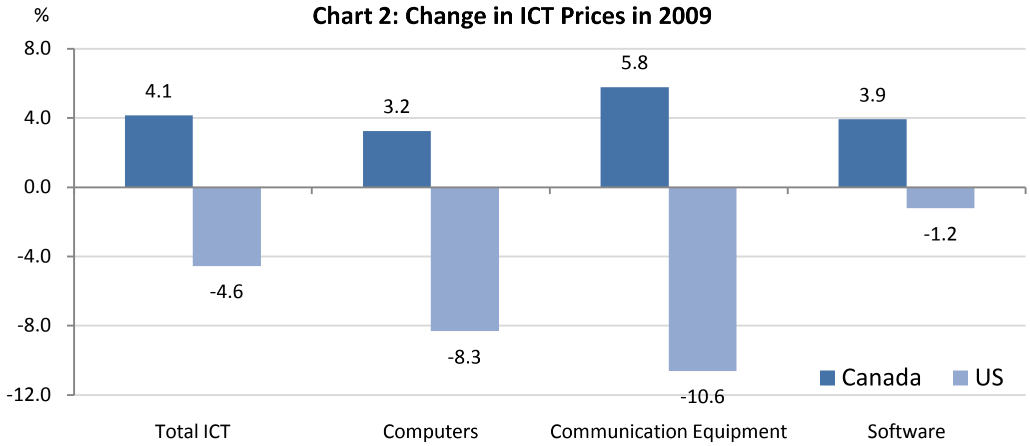
Source: CSLS ICT Database, Tables 1 to 4 and 18 to 21.

Nominal ICT investment in Canada had an average growth rate of 2.3 per cent per year during the 2000-2009 period, well above the 0.3 per cent per year experienced by the United States. This is a reflection of Canada's better performance with respect to all three ICT components during the period in question: computer and communication equipment investment fell less in Canada than in the United States (-0.3 per cent versus -2.9 per cent and -0.2 per cent versus -4.5 per cent, respectively), while software investment experienced a more rapid growth in Canada than in the United States (5.7 per cent versus 3.9 per cent).

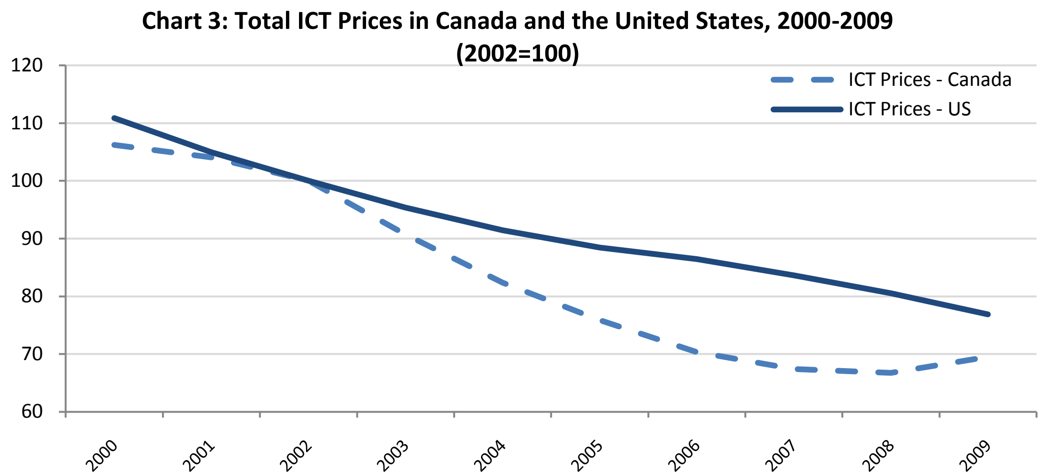
B. ICT Prices

Prices for ICT investment goods increased by 4.1 per cent in Canada in 2009, marking the end of a long trend of declining prices,[4] while prices in the United States declined by 4.6 per cent (Charts 2 and 3, Table 1). The prices for all three ICT components increased in Canada, with communication equipment prices rising the most (5.8 per cent), followed by software (3.9 per cent) and computers (3.2 per cent). Conversely, the prices for all ICT components in the United States fell, with communication equipment prices falling the most (-10.6 per cent), followed by computers (-8.3 per cent) and software (-1.2 per cent).

[4] For a detailed discussion about the price increase experienced by ICT investment goods in Canada in 2009, see Sharpe, St. Dennis and Avillez (2010).



Source: CSLS ICT Database, Tables 17 and 34.



Source: CSLS ICT Database, Tables 17 and 34.

The different price trends between countries can be at least partially explained by the weakening of the Canadian dollar in 2009, which depreciated 6.5 per cent, from 0.937 USD in 2008 to 0.876 USD in 2009 (average noon exchange rates). Since ICT investment goods are traded internationally, the depreciation of the Canadian dollar translates into increased prices of ICT goods because of the exchange rate pass-through. A weaker currency means that Canadian firms can purchase less ICT investment goods at the same level of planned nominal spending, relative to their American counterparts. Price increases attributable to currency depreciations are more significant for computers and communications equipment than for software, as both these components have a larger import share.

Table 1: Growth in ICT Investment in the Business Sector in Canada and the United States, 2000-2009

	Canada				United States			
	Total	Computers	Communication	Software	Total	Computers	Communication	Software
Nominal ICT investment growth, domestic currencies (annual or average annual, %)								
2008	4.2	-5.4	14.8	6.2	1.8	1.9	-8.5	5.9
2009	0.6	-6.8	2.7	4.0	-3.9	-9.8	-10.3	0.3
2000-2009	2.3	-0.3	-0.2	5.7	0.3	-2.9	-4.5	3.9
Nominal ICT investment per worker growth, domestic currencies (annual or average annual, %)								
2008	3.2	-6.4	13.7	5.2	3.3	3.4	-7.1	7.4
2009	3.1	-4.4	5.3	6.6	1.7	-4.5	-5.1	6.2
2000-2009	1.1	-1.5	-1.4	4.5	0.8	-2.4	-4.0	4.5
Growth in ICT prices (annual or average annual, %)								
2008	-1.0	-7.1	0.3	2.4	-3.7	-10.4	-9.8	1.1
2009	4.1	3.2	5.8	3.9	-4.6	-8.3	-10.6	-1.2
2000-2009	-4.6	-9.9	-3.2	-1.3	-4.0	-11.4	-5.1	-0.6
Exchange rate appreciation (annual or average annual, %)								
2008	0.7							
2009	-6.5							
2000-2009	3.0							
Business sector employment (annual or average annual, %)								
2008	1.0				-1.5			
2009	-2.5				-5.5			
2000-2009	1.2				-0.5			
Real ICT investment growth, domestic currencies (annual or average annual, %)								
2008	5.3	1.8	14.4	3.8	5.7	13.8	1.4	4.8
2009	-3.5	-9.7	-2.9	0.0	0.7	-1.6	0.3	1.5
2000-2009	7.2	10.7	3.1	7.1	4.4	9.5	0.6	4.5
Real ICT investment per worker growth, domestic currencies (annual or average annual, %)								
2008	4.3	0.8	13.3	2.7	7.3	15.5	3.0	6.3
2009	-1.0	-7.4	-0.4	2.6	6.6	4.2	6.2	7.5
2000-2009	6.0	9.4	1.9	5.8	5.0	10.1	1.2	5.0

Source: CSLS ICT Database, Summary Tables

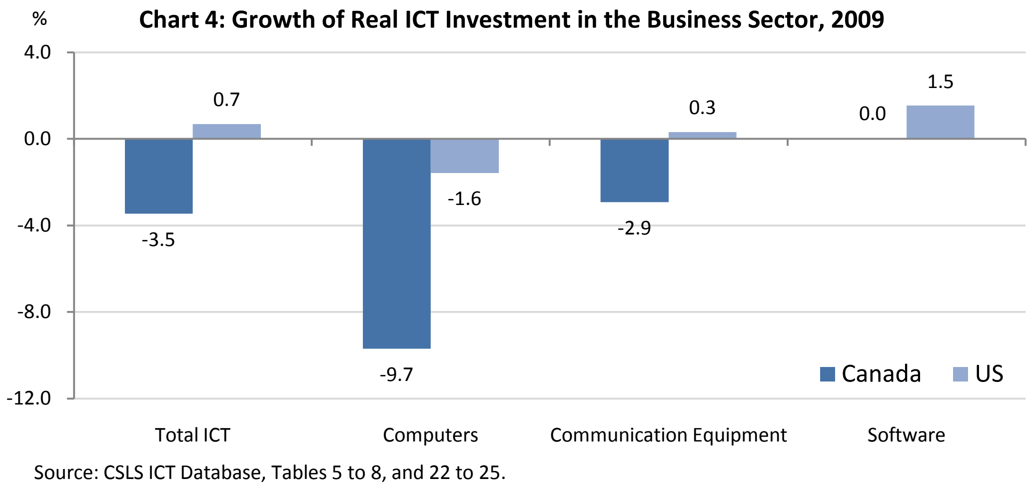
C. Real ICT Investment Growth

Up to (and including) 2008, ICT prices in Canada fell consistently. A major implication of this decline in ICT prices was that real ICT investment growth, which is a more relevant measure from a productivity perspective,[5] had been significantly higher than nominal ICT investment growth. In 2009, the increase in ICT prices in Canada reversed this trend, causing nominal growth to be higher than real growth. In real terms, total ICT investment declined 3.5 per cent in Canada in 2009, reflecting the 0.6 per cent nominal increase and the 4.1 per cent rise in ICT prices (Chart 4 and Table 1). In the United States,

[5] For more information, see Sharpe (2006).

real ICT investment advanced 0.7 per cent in 2009, reflecting the 3.9 per cent nominal investment decline and the 4.6 per cent drop in ICT prices.

In 2009, Canada experienced weak performances in real investment for all three ICT components, with computer investment dropping the most (-9.7 per cent), followed by communication equipment investment (-2.9 per cent), while software investment remained stable at the 2008 level. The situation for the United States is quite different, with real investment in communication equipment and software increasing (0.3 per cent and 1.5 per cent, respectively), and only real investment in computers declining (-1.6 per cent). Note that, although Canada outpaced the United States in terms of nominal ICT investment for all three components, in real terms the situation is the exact opposite, with the United States outpacing Canada in all three components.



D. Nominal ICT Investment per Worker

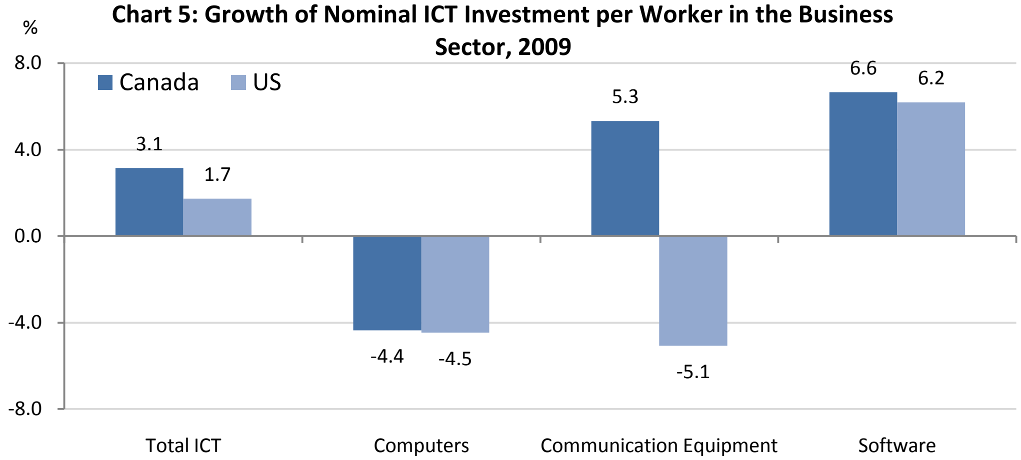
Trends in ICT investment per worker are determined jointly by the rate of growth in ICT investment and employment growth. In 2009, nominal ICT investment in Canada advanced 0.6 per cent while business sector employment decreased 2.5 per cent, producing a 3.1 per cent rise in ICT investment per worker (Chart 5 and Table 1). The decline in business sector employment in the United States was more than twice of Canada's, 5.5 per cent, which, coupled with a nominal ICT investment growth of -3.9 per cent, led to a 1.7 per cent increase in nominal ICT investment per worker. Due to the reduction in employment in both Canada and the United States, the growth rates of nominal ICT investment per worker exceeded total nominal ICT investment for the two countries in 2009.

In terms of ICT components, nominal computer investment per worker growth and nominal software investment per worker growth in Canada in 2009 (-4.4 per cent and 6.6

per cent, respectively) were slightly better than the United States figures (-4.5 per cent and 6.2 per cent). Regarding communication equipment, nominal investment per worker growth in Canada was 5.3 per cent, while in the United States it was -5.1 per cent.

The average annual growth in nominal ICT investment per worker between 2000 and 2009 stood at 1.1 per cent in Canada, with the positive growth rate of software investment (4.5 per cent per year) outweighing the negative growth rates of computer and communication equipment investment (-1.5 per cent per year and -1.4 per cent per year respectively) (Table 1). In the United States, total ICT investment per worker grew at a slightly lower rate of 0.8 per cent per year during the 2000-2009 period. This growth rate is explained largely by a 4.5 per cent average annual growth rate of nominal software investment per worker, which outweighs the negative growth rates experienced by nominal computer investment per worker and nominal communication equipment investment per worker (-2.4 per cent and -4.0 per cent respectively). During the 2000-2009 period, the share of total ICT investment spending going to software increased by 12.8 percentage points in Canada and 17.0 percentage points in the United States (Table 2).

Chart 5: Growth of Nominal ICT Investment per Worker in the Business Sector, 2009



Source: CSLS ICT Database, Tables 9 to 12, and 26 to 29.

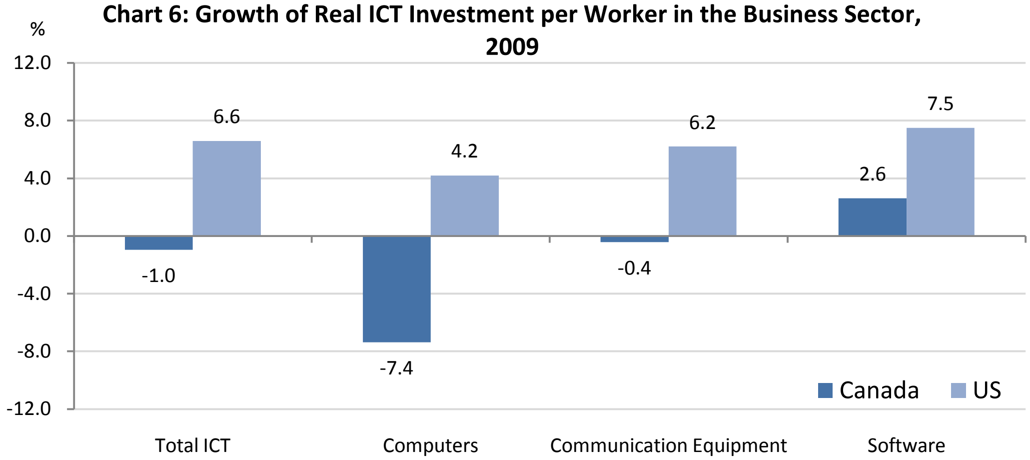
E. Real ICT Investment per Worker

In 2009, real ICT investment in Canada declined by 3.5 per cent while employment dropped by 2.5 per cent, producing a fall of 1.0 per cent in real ICT investment per worker (Chart 6 and Table 1). In the case of the United States, real ICT investment advanced 0.7 per cent and employment declined 5.5 per cent, which led real ICT investment per worker to grow 6.6 per cent. Canada outperformed the United States in terms of nominal ICT investment per worker in 2009 (3.1 per cent versus 1.7 per cent), but not in terms of real ICT investment per worker (-1.0 per cent versus 6.6 per cent). This difference reflects the fact that, while there was a sharp fall of 4.6 per cent in ICT prices in the United States, ICT prices actually increased in Canada by 4.1 per cent in 2009.

In terms of ICT components, real software investment per worker in Canada in 2009 increased 2.6 per cent, but real computer investment per worker and real communication equipment investment per worker declined (7.4 per cent and 0.4 per cent respectively). In the case of the United States, all three components experienced high growth rates for real investment per worker, with software increasing the most (7.5 per cent), followed by communication equipment (6.2 per cent) and computers (4.2 per cent).

Despite Canada's poor performance in terms of real ICT investment per worker in 2009, real ICT investment per worker in Canada increased at a higher average annual rate (6.0 per cent per year) than in the United States (5.0 per cent per year) between 2000 and 2009 (Table 1). As the rate of growth of nominal ICT investment per worker was similar in the two countries (1.1 per cent per year versus 0.8 per cent per year), this growth differential reflects the greater fall in ICT prices in Canada (4.6 per cent per year against 4.0 per cent per year).

Chart 6: Growth of Real ICT Investment per Worker in the Business Sector, 2009



Source: CSLS ICT Database, Tables 13 to 16, and 30 to 33.

Table 2: Current Dollar ICT Investment Shares in the Business Sector in Canada and the United States, 2000-2009

	Canada				United States			
	Total	Computers	Communication	Software	Total	Computers	Communication	Software
ICT investment as a share of GDP (level and percentage point change)								
2000	3.16	1.08	0.90	1.18	5.31	1.32	1.60	2.39
2007	2.61	0.84	0.53	1.24	3.98	0.78	0.92	2.27
2008	2.60	0.76	0.58	1.26	4.02	0.79	0.84	2.39
2009	2.74	0.74	0.62	1.38	3.99	0.74	0.78	2.47
Δ 2008	-0.01	-0.08	0.05	0.02	0.04	0.01	-0.09	0.11
Δ 2009	0.14	-0.02	0.04	0.11	-0.03	-0.05	-0.06	0.09
Δ 2000-2009	-0.42	-0.34	-0.28	0.19	-1.32	-0.58	-0.82	0.08
ICT investment as a share of total non-residential fixed investment (level and percentage point change)								
2000	20.08	6.85	5.71	7.51	32.62	8.10	9.82	14.70
2007	16.09	5.17	3.25	7.67	26.50	5.22	6.14	15.14
2008	16.18	4.72	3.60	7.86	26.45	5.22	5.51	15.72
2009	18.07	4.88	4.11	9.08	31.14	5.77	6.06	19.31
Δ 2008	0.09	-0.45	0.35	0.19	-0.05	0.00	-0.63	0.58
Δ 2009	1.89	0.17	0.51	1.22	4.69	0.55	0.54	3.59
Δ 2000-2009	-2.01	-1.97	-1.60	1.56	-1.48	-2.33	-3.76	4.62
ICT component share of total non-residential fixed ICT investment (level and percentage point change)								
2000	100.0	34.1	28.5	37.4	100.0	24.8	30.1	45.1
2007	100.0	32.1	20.2	47.7	100.0	19.7	23.2	57.1
2008	100.0	29.1	22.3	48.6	100.0	19.7	20.8	59.4
2009	100.0	27.0	22.7	50.2	100.0	18.5	19.5	62.0
Δ 2008	0.0	-3.0	2.1	0.9	0.0	0.0	-2.3	2.3
Δ 2009	0.0	-2.1	0.5	1.6	0.0	-1.2	-1.4	2.6
Δ 2000-2009	0.0	-7.1	-5.7	12.8	0.0	-6.3	-10.7	17.0

Source: CSLS ICT Database, Summary Tables

F. ICT Investment Shares in Nominal Business Sector GDP[6]

In 2009, ICT investment represented 2.74 per cent of nominal business sector GDP in Canada, well below the 3.99 per cent share in the United States (Table 2). Between 2000 and 2009, ICT investment as a share of nominal business sector GDP declined by 0.42 percentage points in Canada and 1.32 percentage points in the United States, as nominal ICT investment growth was well below GDP growth in both economies during this period. Computer investment and communication equipment investment experienced falls in their shares of nominal GDP in both countries over the 2000-2009 period, while the share of software investment increased slightly in both countries.

[6] The nominal business sector GDP series published by Statistics Canada goes up to 2007 only. CSLS estimates are used for 2008 and 2009. These estimates assume that nominal business sector GDP grew at the same rate as nominal total economy GDP (expenditure based).

G. ICT Investment Shares in Total Nominal Investment

ICT investment as a share of total business sector investment (fixed, non-residential) was 18.07 per cent in Canada in 2009, compared to 31.14 per cent in the United States (Table 2). Between 2000 and 2009 this share fell 2.01 points in Canada and 1.48 per cent in the United States. Again, computers and communications equipment experienced declines in their shares of nominal investment in both countries over the 2000-2009 period, while the share of software investment increased slightly in both countries.

III. Canada-U.S. ICT Investment Gap

Canada has long had a significant ICT investment gap with the United States and this gap has been identified as a key factor behind Canada's lower level of labour productivity relative to that of the United States. There are three ways to quantify this gap: 1) ICT investment per worker in Canada relative to that of the United States, calculated in a common currency and taking into account the appropriate purchasing power parity (PPP); 2) the ICT investment share of GDP in Canada relative to that of the United States; and 3) the ICT investment share of total investment (fixed, non-residential) relative to that of the United States.

PPP is an exchange rate that equates in a common currency the prices that two countries face for the same basket of goods. Note that only the first of the above measures is adjusted by PPP. This happens because the first measure is the only one that compares absolute numbers, and those numbers are not comparable unless they are in the same currency and take into account the appropriate purchasing power parity. The second and third measures of the ICT investment gap are in terms of shares, not absolute numbers, so no adjustments are necessary. These three measures can be calculated in terms of both current dollars and chained dollars. This report will discuss the Canada-United States ICT investment gap using current dollar measures.

A. Canada-U.S. ICT Investment per Worker Gap

In 2009, nominal ICT investment per worker in the Canadian business sector was 59.5 per cent that of the United States (Charts 7 and 8, Table 3). This represents a substantial decline of 3.3 percentage points from the level observed in 2008, 62.8 per cent, although it is still well above the 2000 level, which was 50.8 per cent.

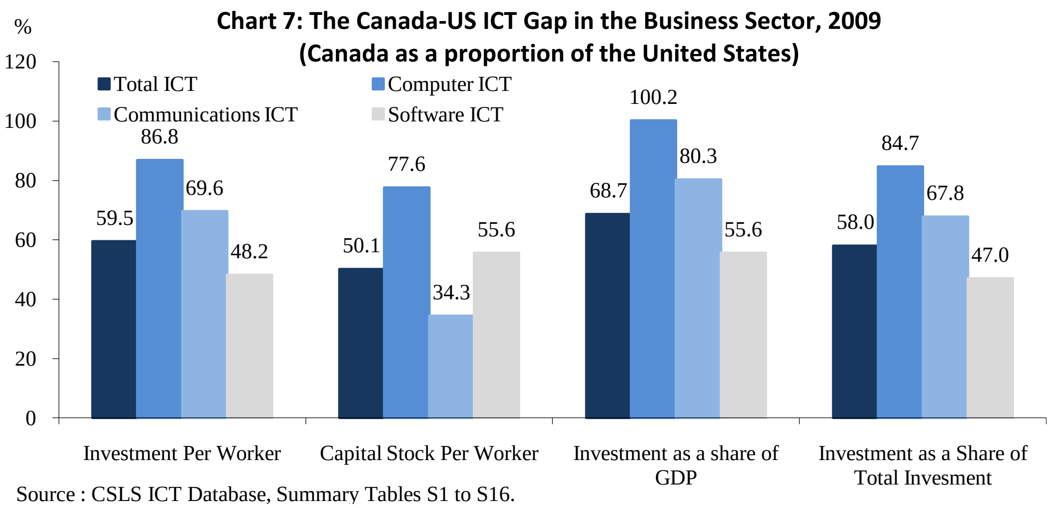
The widening of the ICT investment per worker gap in 2009 might seem surprising at first because nominal ICT investment per worker in Canada outpaced that of the United

States (3.1 per cent versus 1.7 per cent). This would imply, *ceteris paribus*, a reduction of the gap. However, a decline in the purchasing power parity (PPP) for machinery and equipment (M&E) in Canada relative to the United States was more than enough to outweigh the nominal ICT investment growth differential, causing the gap to widen.[7]

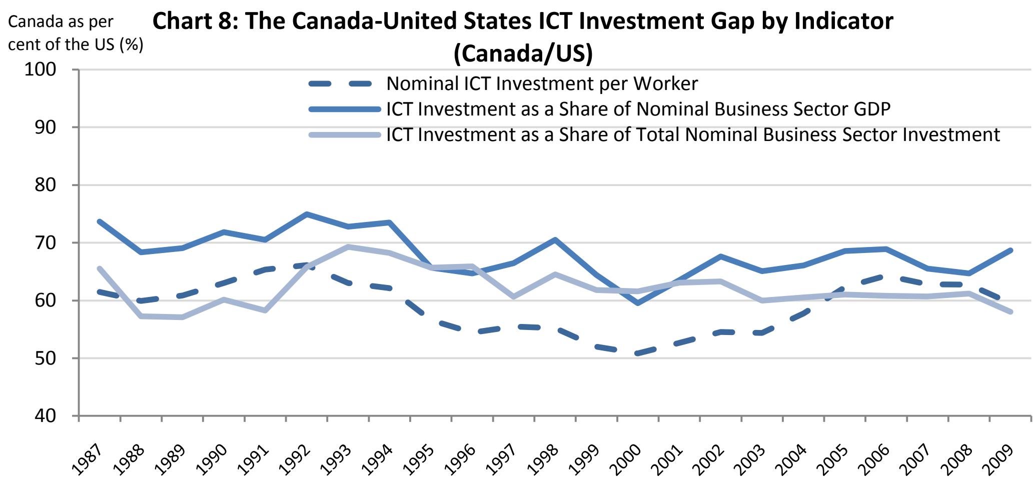
Statistics Canada provides official PPP estimates for M&E for the 1992-2008 period (Table 4).[8] Although there are no official estimates for 2009, CSLS calculated an implicit PPP estimate for M&E, which is based on the United States-Canada difference in M&E price deflator growth. Over the 1992-2008 period, this difference was highly correlated with changes in the official PPP for M&E series (the correlation coefficient is equal to 0.89), and therefore it is reasonable to assume that it is a good proxy of PPP for M&E changes. According to the CSLS estimate, PPP for M&E dropped 6.5 per cent in 2009. This is a consequence of M&E prices rising 6.0 per cent in Canada, but falling 0.5 per cent in the United States. Since the magnitude of the fall in PPP for M&E was significantly higher than the rate by which nominal ICT investment per worker in Canada outpaced that of the United States, the ICT investment per worker gap increased.

The Canada-United States ICT investment per worker gap varies greatly by ICT component (Charts 7 and 9, Table 3). It is by far the greatest in software, with software investment per worker in Canada being only 48.2 per cent that of the United States in 2009. The gap is smallest for computers, with computer investment per worker in Canada being 86.8 per cent that of the United States, up from 69.8 per cent in 2000, but down from 102.4 per cent in 2007. Communications equipment occupies the middle ground, with Canada's per worker level of communications equipment investment in 2009 being 69.6 per cent that of the United States, which represents a major narrowing of the gap from its 48.0 per cent level in 2000.

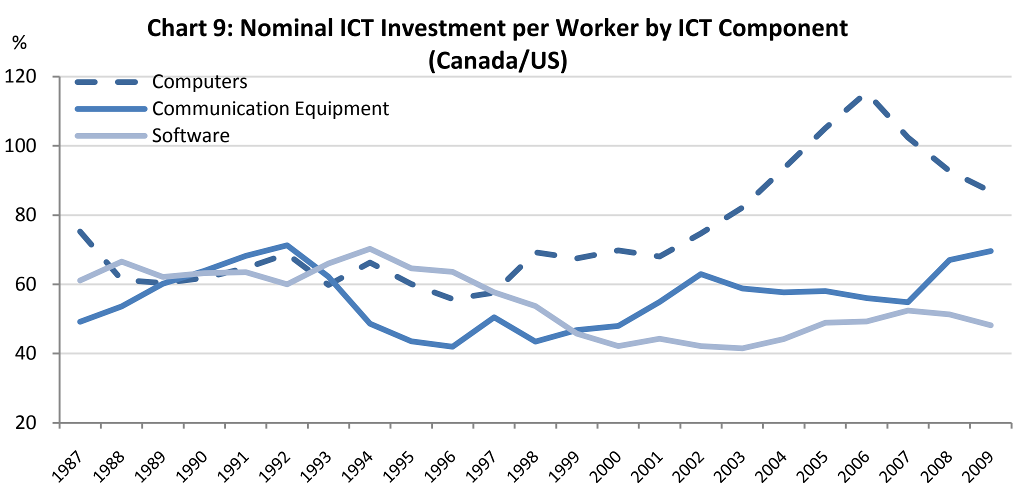
[7] Ideally, the PPP for ICT would be used. However, since Statistics Canada does not calculate an official PPP for ICT series, the PPP for M&E is the best alternative.
[8] For a detailed discussion on how purchasing power parities are calculated by Statistics Canada, see Temple (2007).



Source : CSLS ICT Database, Summary Tables S1 to S16.



Source: CSLS ICT Database, Summary Tables S1, S9 and S13.



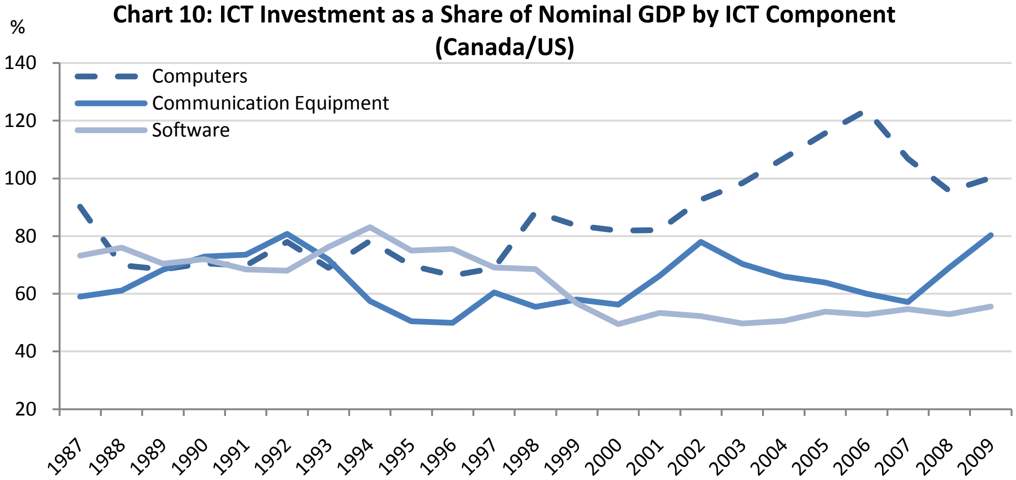
Source: CSLS ICT Database, Summary Tables S1 to S4.

B. Canada-U.S. ICT Investment as a Share of GDP

In 2009, nominal ICT investment as a share of nominal business sector GDP in Canada was 68.8 per cent that of the United States, up from 64.7 per cent in 2008 and 50.8 per cent in 2000 (Charts 7 and 8, Table 3).

Again, the size of the Canada-United States ICT investment/GDP share gap varies greatly by ICT component (Chart 10, Table 3). It is greatest for software, with the software investment/GDP share in Canada being 55.6 per cent that of the United States in 2009, up from 52.9 in 2008 and 49.5 in 2000. The gap is smallest for computers, with the computer investment/GDP share in Canada relative to that of the United States reaching 100.2 per cent in 2009, up from 95.6 in 2008 and 81.8 in 2000, but down from 106.8 in 2007. Communications equipment occupies the middle ground, with Canada's communications equipment investment/GDP share being 80.3 per cent of that of the United States in 2009, up from 69.1 in 2008 and 56.3 in 2000.

Chart 10: ICT Investment as a Share of Nominal GDP by ICT Component (Canada/US)



Source: CSLS ICT Database, Summary Tables S9 to S12.

Table 3: Canada-United States ICT Investment Gap in the Business Sector, 2000-2009

	Total	Computers	Communication Equipment	Software
ICT investment per worker in Canada as a share of ICT investment per worker in the United States, PPP adjusted (%)				
2000	50.8	69.8	48.0	42.2
2007	62.8	102.4	54.8	52.4
2008	62.8	92.7	67.0	51.3
2009	59.5	86.8	69.6	48.2
Percentage points change				
Δ 2008	-0.1	-9.7	12.2	-1.1
Δ 2009	-3.2	-5.9	2.5	-3.1
ICT investment as a share of GDP in Canada as a proportion of that of the United States (%)				
2000	59.5	81.8	56.3	49.5
2007	65.5	106.8	57.1	54.7
2008	64.7	95.6	69.1	52.9
2009	68.7	100.2	80.3	55.6
Percentage points change				
Δ 2008	-0.8	-11.2	12.0	-1.8
Δ 2009	4.0	4.6	11.2	2.7
ICT investment as a share of total investment (Fixed, Non-Res) in Canada as a proportion of that of the United States (%)				
2000	61.6	84.6	58.2	51.1
2007	60.7	98.9	52.9	50.7
2008	61.2	90.4	65.3	50.0
2009	58.0	84.7	67.8	47.0
Percentage points change				
Δ 2008	0.5	-8.6	12.4	-0.6
Δ 2009	-3.1	-5.7	2.5	-3.0

Source: CSLS ICT Database, Summary Tables

Table 4: Purchasing Power Parity (PPP) Estimates for Machinery and Equipment (M&E), 1986-2009

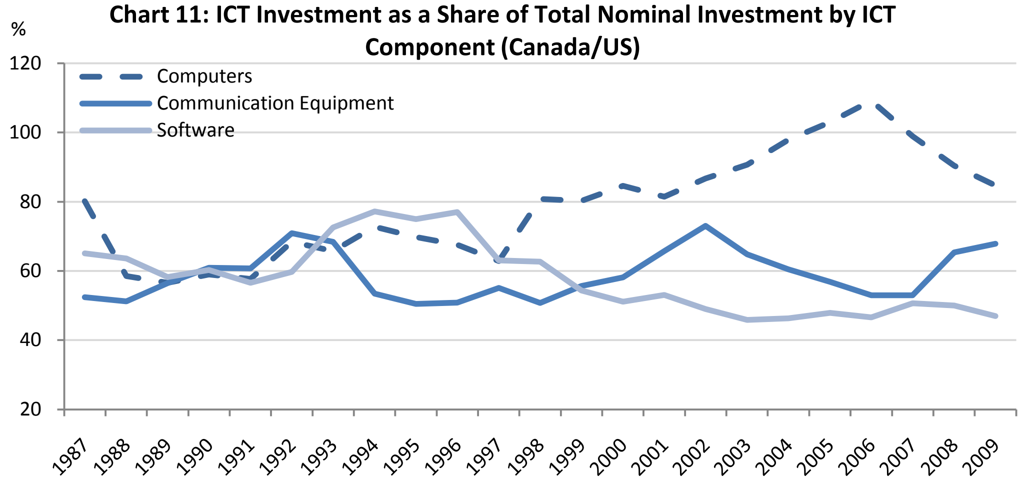
	Canada				United States				PPP for M&E, US dollar per Canadian dollar		
	M&E Investment, millions of current Canadian dollars	**M&E Investment, millions of 2002 chained Canadian dollars**	**Implicit M&E Price Deflator**	**Per Cent Change**	**M&E Investment, millions of current U.S. dollars**	**M&E Investment, millions of 2005 chained U.S. dollars**	**Implicit M&E Price Deflator**	**Per Cent Change**	**Official PPP Values***	**Official PPP Change**	**Implicit PPP Change**
	A	B	C=A/B*100	$D=(C_t/C_{t-1}-1)*100$	E	F	G=E/F*100	$H=(G_t/G_{t-1}-1)*100$	I	$J = (I_t/I_{t-1} - 1)*100$	K=(H-D)
1986	38,647	37,334	103.5		343,300	285,900	120.1		**0.73**	-	-
1987	43,013	42,348	101.6	-1.9	349,900	289,800	120.7	0.6	**0.74**	-	2.4
1988	49,915	49,922	100.0	-1.6	381,000	311,600	122.3	1.3	**0.77**	-	2.8
1989	54,092	54,202	99.8	-0.2	414,000	334,500	123.8	1.2	**0.78**	-	1.4
1990	52,418	52,405	100.0	0.2	419,500	334,600	125.4	1.3	**0.79**	-	1.1
1991	49,140	52,061	94.4	-5.6	414,600	326,000	127.2	1.4	**0.84**	-	7.1
1992	48,676	51,249	95.0	0.6	439,600	349,700	125.7	-1.2	0.83	-	-1.8
1993	48,811	50,233	97.2	2.3	489,400	393,400	124.4	-1.0	0.81	-2.4	-3.3
1994	54,505	54,979	99.1	2.0	544,600	440,300	123.7	-0.6	0.78	-3.7	-2.6
1995	58,370	58,116	100.4	1.3	602,800	493,000	122.3	-1.1	0.78	0.0	-2.5
1996	60,986	61,048	99.9	-0.5	650,800	545,400	119.3	-2.4	0.77	-1.3	-1.9
1997	73,490	73,160	100.5	0.6	718,300	620,400	115.8	-3.0	0.77	0.0	-3.5
1998	80,510	79,211	101.6	1.2	786,000	710,400	110.6	-4.4	0.74	-3.9	-5.6
1999	87,155	87,775	99.3	-2.3	871,000	810,900	107.4	-2.9	0.76	2.7	-0.6
2000	92,085	93,158	98.8	-0.4	950,500	895,800	106.1	-1.2	0.78	2.6	-0.8
2001	91,082	91,340	99.7	0.9	898,100	866,900	103.6	-2.4	0.77	-1.3	-3.2
2002	89,315	89,315	100.0	0.3	842,700	830,300	101.5	-2.0	0.78	1.3	-2.3
2003	90,899	97,748	93.0	-7.0	853,800	851,400	100.3	-1.2	0.82	5.1	5.8
2004	94,931	107,899	88.0	-5.4	916,400	917,300	99.9	-0.4	0.86	4.9	5.0
2005	104,619	123,921	84.4	-4.0	995,600	995,600	100.0	0.1	0.89	3.5	4.1
2006	111,755	137,600	81.2	-3.8	1,071,700	1,069,600	100.2	0.2	0.92	3.4	4.0
2007	114,188	144,098	79.2	-2.4	1,112,600	1,109,000	100.3	0.1	0.95	3.3	2.6
2008	116,605	145,475	80.2	1.2	1,082,900	1,082,000	100.1	-0.2	0.95	0.0	-1.4
2009	107,854	126,942	85.0	6.0	912,800	916,300	99.6	-0.5	**0.89**	-	-6.5

Source: PPP from Statistics Canada, CANSIM Table 380-0057, V13930596; M&E data for Canada from Statistics Canada, CANSIM series v1070249 and v4419816; M&E data for the United States from the Bureau of Economic Analysis, NIPA Tables 5.3.5 and 5.2.3.
* Official PPP values for 1992-2008. For 1987-1991 and 2009, the PPP estimate is obtained by applying the implicit PPP growth rate (US-Canada difference in M&E price deflator growth).

C. Canada-U.S. ICT Investment as a Share of Total Investment

In 2009, nominal ICT investment as a share of business sector investment in Canada was 58.0 per cent that of the United States, down from 61.2 per cent in 2008 and 61.6 per cent in 2000 (Charts 7 and 8, Table 3). In terms of the relative size of all gaps for the three ICT components (Chart 11, Table 3), the pattern that emerges is the same as observed previously, with the largest gap for software investment, the smallest for computer investment and communication equipment investment in the middle.

Chart 11: ICT Investment as a Share of Total Nominal Investment by ICT Component (Canada/US)



Source: CSLS ICT Database, Tables S13 to S16.

IV. Conclusion

In 2009, nominal and real ICT investment growth experienced a sharp decline from the rates observed in 2008 in both Canada and the United States. Canada outperformed the United States in nominal terms (0.6 per cent versus -3.9 per cent), but not in real terms (-3.5 per cent versus 0.7 per cent). This discrepancy is due to the fact that ICT prices rose in Canada (4.1 per cent), ending a long trend of declining prices, but fell in the United States (-4.6 per cent).

The price increase in Canada reflects in part the significant depreciation of the Canadian dollar, which dropped 6.5 per cent in 2009 (from 0.937 USD in 2008 to 0.876 USD, according to average noon exchange rates). Since ICT investment goods are traded internationally, the depreciation of the Canadian dollar translates into increased prices of ICT goods because of the exchange rate pass-through. A weaker currency means that Canadian firms can purchase less ICT investment goods at the same level of planned nominal spending, relative to their American counterparts.

Business sector employment dropped in both countries, but the drop was more pronounced in the United States (-5.5 per cent in the United States versus -2.5 per cent in Canada). Even with this large drop in employment, the United States' performance in terms of nominal ICT investment per worker growth (1.7 per cent) was still worse than Canada's (3.1 per cent), because of Canada's stronger nominal ICT investment growth. In real terms, real ICT investment per worker growth in the United States outpaced Canada's significantly (6.6 per cent versus -1.0 per cent, respectively).

The higher nominal ICT investment per worker growth experienced in Canada relative to that of the United States would imply, *ceteris paribus*, a reduction of the Canada-United States ICT investment per worker gap. However, a sharp 6.5 per cent decline in the purchasing power parity (PPP) for machinery and equipment (M&E) between the two countries in 2009 caused the gap to widen, with the ratio of nominal ICT investment per worker in Canada relative to that of the United States actually falling from 62.8 per cent in 2008 to 59.5 per cent in 2009.

Compared to the 2008 figures, the Canada-United States ICT investment gap widened in 2009 in terms of the nominal ICT investment per worker gap (down from 62.8 per cent in 2009 to 59.5 per cent in 2009) and the nominal ICT investment as a share of total investment gap (down from 61.2 per cent in 2008 to 58.0 per cent in 2009). There was, however, a significant reduction of the nominal ICT investment as a share of GDP gap (up from 64.7 per cent in 2008 to 68.7 per cent in 2009). The only ICT component that experienced a narrowing of the gap according to all three measures was communications equipment.

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VI. Appendix A – Data Aggregation Issues

The purpose of this appendix is to describe the exact procedures used in the CSLS ICT Database to produce aggregate estimates of total ICT investment in *real* terms. Statistics Canada and the Bureau of Economic Analysis provide quantity series for investment in the three ICT components (computers, communications equipment and software) – and also sub-components, in the case of the BEA –, but not for total ICT investment. Consequently, total ICT investment aggregates had to be calculated internally by the CSLS.

Before starting the methodological discussion, the basic terminology used in this appendix must be defined. A *value* series describes the evolution of *nominal* variables over time and is expressed in current dollars. A *quantity series* (also known as a volume series) describes the behaviour of *real* variables. In this appendix, the term *quantity series* refers either to constant dollar or chained dollar series,[9] while the term *quantity index* refers to an index that has no unit of measure and is usually normalized to one at a chosen base/reference period. Although both terms convey the same information regarding the real variable's growth rates over time, it is often more convenient to have the real variable expressed in constant dollars or chained dollars.

In order to convert a quantity index into a constant dollar or a chained dollar series, the quantity index at period *t* must be multiplied by the variable's current dollar value in the base period *b*, in the case of a fixed base series, or by the variable's current dollar value in the reference period *r*, in the case of a chained series. The term *base period* is used when referring to fixed base indexes, and the term *reference period* is used to refer to chained indexes. This distinction is made to avoid confusion and to reinforce the idea that a chained index has no fixed base period.

Aggregation issues arise whenever a large number of price and quantity series must be aggregated into a smaller number of variables. Aggregating value series is straightforward, since the different value series that compose the aggregate just have to be summed (as long, of course, as they are expressed in the same currency). When dealing with quantity series, however, this simple summing procedure does not always yield the best estimates for the aggregated quantity series. The problem of how to best aggregate economic data in general, and ICT investment data in particular, is relevant because different aggregation methods lead to widely different aggregated quantity and price series, each with their own levels and growth rates.

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[9] Constant dollar and chained dollar series are generated using fixed base quantity index formulas and chained quantity index formulas, respectively.

Although there are both price and quantity index formulas, this appendix will focus its discussion on the latter. Three of the most commonly used index number formulas are the Laspeyres, the Paasche and the Fisher formulas. While a Laspeyres quantity index formula uses the base period's prices as weights, the Paasche formula uses current prices as weights. The Fisher quantity index formula is the geometric mean of the Laspeyres and the Paasche formulas. These formulas can be either of the *fixed base* or the *chained* variety. As the name implies, a fixed base formula has a fixed base period which is used as a basis of comparison with all the other periods. A chained formula, however, has no fixed base period, but rather takes into account data from two successive periods.[10]

This appendix is divided into four parts. The first one describes how total ICT investment data were aggregated up to and including the 2009 update of the CSLS ICT Database, the second one how data were aggregated in the 2010 update and the third one discusses the advantages of switching aggregation methods. The last part illustrates the differences between methods by analyzing an actual example.

A. ICT Data Aggregation until the 2009 Update of the CSLS ICT Database

ICT investment can be broken down into three components: computers, telecommunication equipment and software investment. The source of ICT investment data for Canada is Statistics Canada, while for the United States it is the Bureau of Economic Analysis (BEA). These agencies organize data in different ways, and thus different aggregation procedures are required.

Until 2009, CSLS calculated total ICT investment quantity series for Canada simply by summing the three components' quantity series. This was done for total economy, business sector, non-business sector and 2-digit NAICS industries ICT data. The procedure of summing quantity series corresponds to a fixed base Laspeyres quantity index formula with prices normalized to 1 in the base period. More formally:

$$Q_L^t = \frac{\sum_{i=1}^{n} p_i^b\, q_i^t}{\sum_{i=1}^{n} p_i^b\, q_i^b} \tag{1}$$

where Q_L^t is the fixed base Laspeyres quantity index at period *t* (with $t = 1,2,\dots,N$), p_i^b and q_i^b denote the price and quantity series (respectively) for component *i* at the base period *b* and q_i^t denotes the quantity series for component *i* at period *t*. In this particular case, since there are three ICT components, *i*=3. Statistics Canada provides the quantity series q_i^t for

[10] For the actual quantity index formulas, please refer to Appendix B. For a more detailed discussion on index number theory, see Diewert (1993), Landerfeld, Moulton & Vojtech (2003), International Labor Organization (2004) and International Monetary Fund (2004).

each of the ICT components, calculated using a chained Fisher quantity formula. Since Statistics Canada also provides value series for all three components, v_i^t, it is straightforward to calculate their respective price series (which, in this case, are the components' implicit price deflators), p_i^t, by doing:

$$p_i^t = \frac{v_i^t}{q_i^t} \tag{2}$$

Once the total ICT investment quantity index for period *t*, Q_L^t, has been calculated, it can be used to construct a quantity series with base period *b*:

$$CD_L^t = Q_L^t V^b \tag{3}$$

where CD_L^t is the constant dollar value that corresponds to the Laspeyres quantity index at period *t* and $V^b = \sum_{i=1}^{n} v_i^b$ is the aggregate value series in the base period *b*.

Finally, using the quantity series constructed above, one can calculate an implicit price deflator series for total ICT investment, P^t:

$$P^t = \frac{V^t}{CD_L^t} \tag{4}$$

where $V^t = \sum_{i=1}^{n} v_i^t$ is the aggregate value series for period *t*. The main advantage of the fixed base Laspeyres quantity formula is that the aggregated series is the sum of its parts, which is a very transparent and intuitive method of aggregation. Table 1A shows how the aggregation process for Canadian data was handled until the 2009 update of the CSLS ICT Database.

Table 1A – ICT Investment Quantity Series Aggregation for Canada
Up to the 2009 update

	Index	Calculated by
ICT Sub-Components	N.A.	N.A.
ICT Components	Chained Fisher Quantity Index	Statistics Canada
Total ICT	Fixed Base Laspeyres Quantity Index	CSLS

2010 Update

	Index	Calculated by
ICT Sub-Components	N.A.	N.A.
ICT Components	Chained Fisher Quantity Index	Statistics Canada
Total ICT	Chained Fisher Quantity Index	CSLS

In the case of the United States, the CSLS ICT Database does not cover the total economy and the non-business sector, only the business sector and the 2-digit NAICS industries. The business sector aggregation was done in exactly the same way as its Canadian counterpart: by summing the three ICT components. For the industries, however, the situation was more complicated. The industry level data that is readily available at the BEA is either too aggregated for the purposes of the database (Standard Fixed Asset Tables 2.1-2.10 and 4.1-4.10) or too disaggregated (Detailed Fixed Asset Tables). On the one hand, the Standard Fixed Asset Tables 2.1-2.10 have the exact component breakdown needed for the database (computers & peripheral equipment, communication equipment and software), but there is no industry breakdown (the data refers to private fixed assets). Furthermore, the Standard Fixed Asset Tables 4.1-4.10 divide non-residential investment in just two categories (equipment & software and structures) and three large industry groups (farms, manufacturing and nonfarm manufacturing). On the other hand, the Detailed Fixed Asset Tables break down the ICT investment data by 12 sub-components at the 3-digit NAICS industry level.

Thus, in order to obtain numbers for the three ICT components, the ICT sub-components had to be aggregated. The BEA's Detailed Fixed Asset Tables list the following ICT sub-components: mainframes, PCs, DASDs, printers, terminals, tape drives, storage devices, system integrators, communications, pre-packaged software, custom software and own account software. Table 2A shows which ICT sub-components are included in each ICT component category.

Table 2A – Breakdown of ICT Investment by Asset Type

Total ICT	*Computers*	Mainframes
		PCs
		DASDs
		Printers
		Terminals
		Tape drives
		Storage devices
		System integrators
	Telecommunication Equipment	Communications
	Software	Pre-packaged Software
		Custom Software
		Own Account Software

The aggregation of the sub-components was, again, done by simply summing the quantity series. Equation (1) can still be used to calculate each of the ICT components' quantity indexes, with *i* now standing for the number of sub-components. Once the three ICT components' quantity series had been calculated, they could then be summed to produce a total ICT investment quantity series (note that an identical total ICT investment quantity series would be obtained if all the sub-components were summed directly). Both levels of aggregation (sub-components to components and components to total), generate price and quantity series consistent with the fixed base Laspeyres quantity index formula. Table 3A details how the United States ICT data was aggregated at each level.

Table 3A – ICT Investment Quantity Series Aggregation for the United States

Up to the 2009 update

	Index	Calculated by
ICT Sub-Components	Chained Fisher Quantity Index	BEA
ICT Components	Chained Fisher Quantity Index at the Business Sector level	BEA
	Fixed Base Laspeyres Quantity Index at the 2-digit NAICS Industry level	CSLS
Total ICT	Fixed Base Laspeyres Quantity Index	CSLS

2010 Update

	Index	Calculated by
ICT Sub-Components	Chained Fisher Quantity Index	BEA
ICT Components	Chained Fisher Quantity Index at the Business Sector level	BEA
	Chained Fisher Quantity Index at the 2-digit NAICS Industry level	CSLS
Total ICT	Chained Fisher Quantity Index	CSLS

B. ICT Data Aggregation for the 2010 Update of the CSLS ICT Database

In the 2010 update of the CSLS ICT database, significant methodology changes were implemented in how total ICT investment quantity series were calculated. For Canada, total ICT investment quantity series were now calculated using a chained Fisher quantity index formula. The procedure can be summarized in three steps. First, one calculates an *aggregate relative* using the chained Fisher quantity index formula, AR_{CF}^{t}:

$$AR_{CF}^{t} = \sqrt{\left(\frac{\sum_{i=1}^{n} p_i^{t-1}\, q_i^{t}}{\sum_{i=1}^{n} p_i^{t-1}\, q_i^{t-1}}\right)\left(\frac{\sum_{i=1}^{n} p_i^{t}\, q_i^{t}}{\sum_{i=1}^{n} p_i^{t}\, q_i^{t-1}}\right)} \qquad (5)$$

where p_i^{t-1} and p_i^{t} denote price series for component *i* at periods *t-1* and *t* and q_i^{t-1} and q_i^{t} denote quantity series for component *i* at periods *t-1* and *t*. The aggregate relative calculates the per cent quantity change from period *t-1* to period *t*. Equation (5) is a chained formula in the sense that it does not have a fixed base period, but rather takes into account data from two successive periods.

Second, the chained Fisher quantity index can be computed by picking a reference period *r*, setting the quantity index to one in the reference period, and then multiplying AR_{CF}^{t} by the previous period's quantity index. For instance, if the quantity index for the first period in the series is set equal to one (ie. the reference period is *t*=1), then the chained Fisher quantity index would be

$$Q_{CF}^{n} = \prod_{t=2}^{n} AR_{CF}^{t} = AR_{CF}^{2} \times \ldots \times AR_{CF}^{n} \quad (6)$$

where Q_{CF}^{n} is the chained Fisher quantity index for period n, with $n = 2, \ldots, N$ (since for *n*=1, $Q_{CF}^{1} = AR_{CF}^{1} = 1$). Finally, an aggregated quantity series can now be computed using the above quantity index and the chosen reference period *r*:

$$CD_{CF}^{n} = Q_{CF}^{n} V^{r} \quad (7)$$

where CD_{CF}^{n} is the chained dollar value that corresponds to the chained Fisher quantity index in period n. Analogously to Equation (4), the aggregated quantity series constructed above can be used to calculate an implicit price deflator series for total ICT investment, P^{n}, such that:

$$P^{n} = \frac{V^{n}}{CD_{CF}^{n}} \quad (8)$$

For the United States, at the business sector level, the total ICT investment quantity series was also calculated using the chained Fisher quantity index formula. At the industry level, as before, the aggregation procedure was not as straightforward. The initial step was to aggregate the ICT sub-components into ICT components at the 3-digit NAICS industry level using a chained Fisher quantity index formula. Then the 3-digit NAICS industry level ICT components were aggregated into 2-digit NAICS industry level ICT components, again using the chained Fisher quantity index formula. Finally, the aforementioned formula was used one last time to generate a total ICT investment aggregate for each industry.

Ideally, the industry level aggregation would have been done in only one step for each industry, from the 3-digit NAICS industry level ICT sub-components to the 2-digit NAICS industry level ICT components and total ICT investment. However, the level of disaggregation of BEA data made this difficult to implement at the moment, especially for industries that were broken down in several 3-digit NAICS industries. An extreme example would be the manufacturing industry, which was divided into nineteen 3-digit NAICS industries. Since each of the nineteen industries had 12 ICT sub-components, there were a total of 228 price series and 228 quantity series, which would have been hard to handle all at once. The main disadvantage of aggregating the industry level data in three steps is that there is some loss of precision.

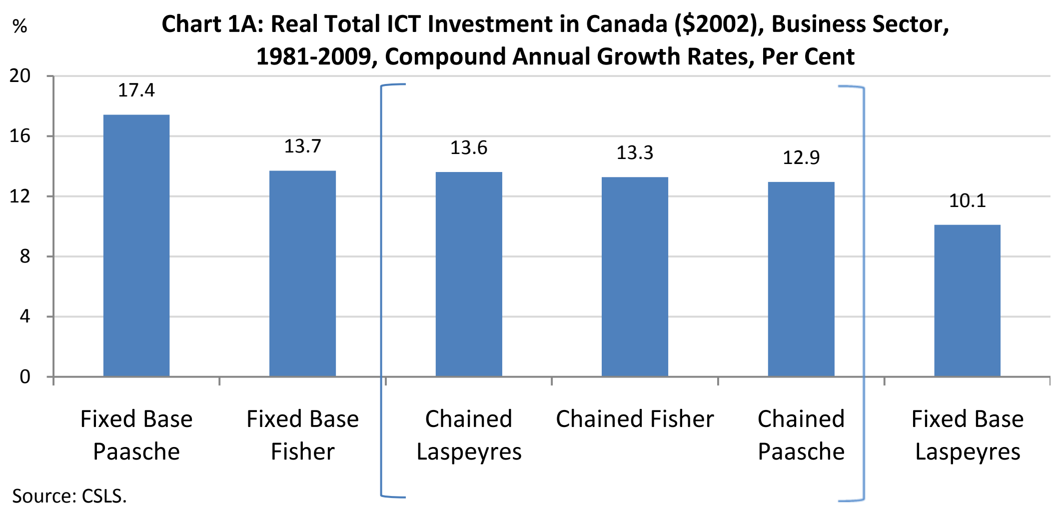
Tables 1A and 3A summarize the changes made to the data aggregation methods.

C. Advantages of Switching Aggregation Methods

The advantages of switching from a fixed base Laspeyres quantity index to a chained Fisher quantity index are twofold. First of all, the Laspeyres and the Paasche quantity index formulas are equally plausible, but generate different results. This suggests that the truth might be somewhere in between, and an average of the two indexes will take this into consideration. The Fisher formula, being the geometric mean of the aforementioned formulas, incorporates both their results. Second (and more importantly), the use of a chained index takes into account how relative prices change over time, whereas fixed base indexes do not, maintaining the relative prices observed on the base period throughout the entire sample period. This is of particular importance in the case of goods that experienced significant relative price changes over the years – as is the case of ICT investment goods. In this sense, the use of chained Fisher quantity index formulas to construct total ICT investment quantity and price series represents a major improvement over the fixed base Laspeyres quantity index formula previously used, providing more accurate estimates of both quantity and price changes (and levels).

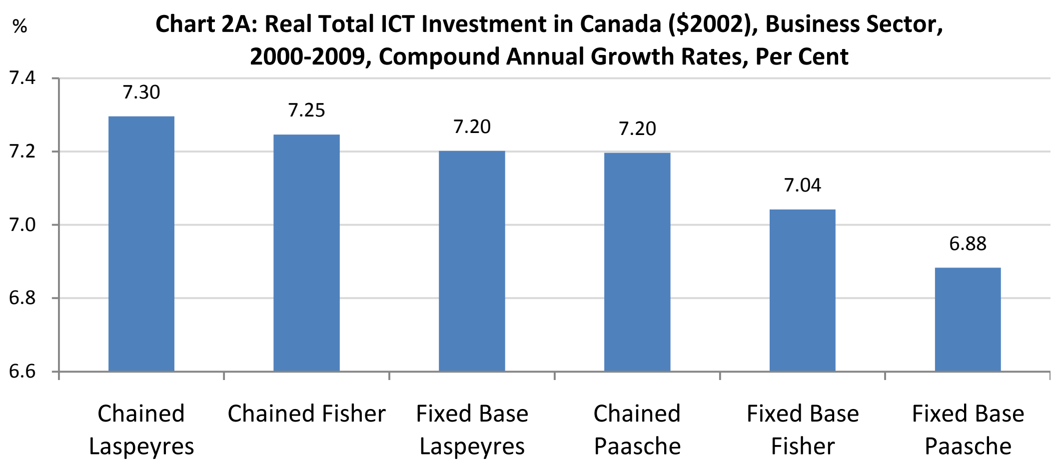
D. Example: Total ICT Investment in Canada, Business Sector

Chart 1A shows the compound annual growth rates (CAGR) of real total ICT investment (expressed in 2002 chained dollars) for the business sector in Canada during the 1981-2009 period according to six different indexes, including the fixed base Laspeyres quantity index and the chained Fisher quantity index. The average annual growth rates of real total ICT investment calculated using the fixed base Laspeyres index was 10.1 per cent per year, against 13.3 per cent per year computed by the chained Fisher, which translates into a difference of 3.2 percentage points. This indicates that the fixed base Laspeyres significantly understated the growth of total ICT investment in real terms over time.



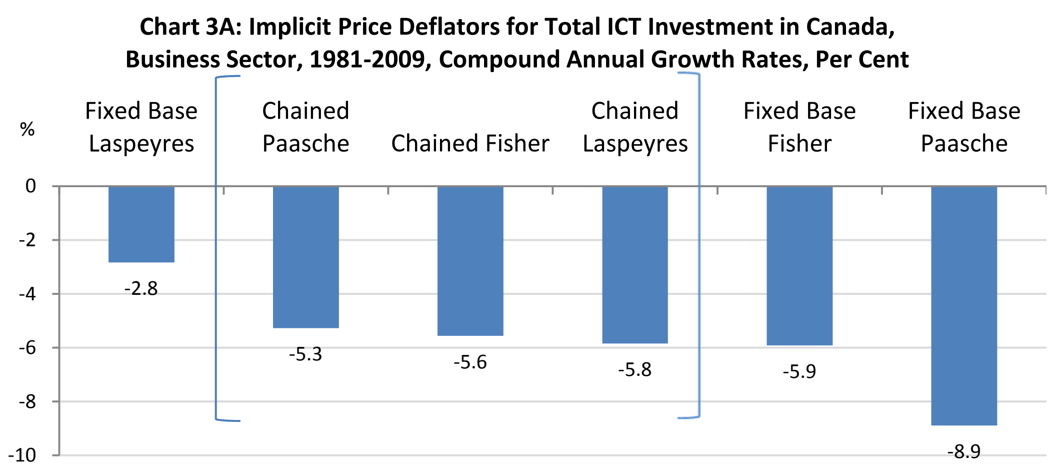
It can also be noted that the fixed base Paasche and the fixed base Laspeyres quantity indexes are situated each at an extreme of the spectrum, with the fixed base Paasche quantity index having the highest CAGR among all the indexes (17.4 per cent per year), and the fixed base Laspeyres quantity index having the lowest. Furthermore, it becomes clear from Chart 1A that the main source of variation does not arise from the choice between a Laspeyres, a Paasche or a Fisher index, but from the choice between a fixed base and a chained index. The spread between the average annual growth rates of the fixed base Paasche and the fixed base Laspeyres quantity index is of 7.3 percentage points, more than ten times the spread for those indexes chained counterparts, which is only 0.7 percentage points. Once again, this underscores the importance of using chained indexes when dealing with goods that experienced significant relative price changes throughout the sample period.

This fact becomes even clearer by looking at Chart 2A, where it can be seen that the spread between the fixed base Laspeyres and the fixed base Paasche quantity indexes gets much closer to the spread of their chained counterparts in the 2000s (0.32 and 0.10 percentage points respectively). The reason for this is basically that, by picking 2002 as a base year, the fixed base indexes capture the relative prices of more recent years much better than that of two decades ago.



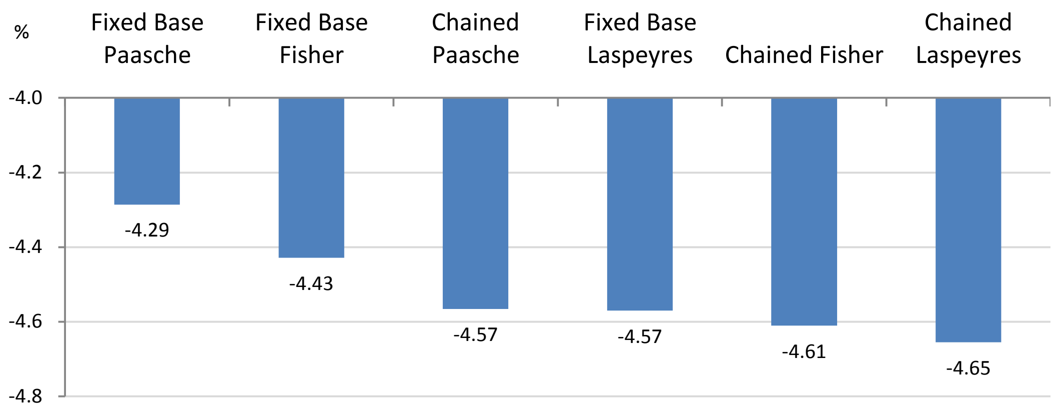
Source: CSLS.

To each of the six quantity indexes discussed above corresponds an implicit price deflator series. Charts 3A and 4A show the compound annual growth rates for those price series, with Chart 3A referring to the 1981-2009 period and Chart 4A to the 2000-2009 period.



Source: CSLS.

Chart 4A: Implicit Price Deflators for Total ICT Investment in Canada, Business Sector, 2000-2009, Compound Annual Growth Rates, Per Cent



Source: CSLS.

It is immediately clear that Charts 3A and 4A are a mirror image of Charts 1A and 2A, respectively. This is expected and can be understood by noting that any value change can be decomposed into quantity changes and price changes. More formally:

$$(1 + Value\ Change) = (1 + Quantity\ Change)(1 + Price\ Change) \qquad (9)$$

Thus, since the average value change over the period is known (and therefore fixed), quantity indexes that estimate higher quantity changes will generate implicit price deflators with lower price increases (or, as is the case here, *higher price decreases*). Unsurprisingly, the same patterns observed in Charts 1A and 2A can be observed in Charts 3A and 4A, but now in reverse. As can be seen in Chart 3A, the fixed base Laspeyres quantity series generates an implicit price deflator series with the highest CAGR among the six price series (-2.8 per cent per year), while the price series that corresponds to the fixed base Paasche is the lowest (-8.9 per cent per year). Again, the spread between the price series that correspond to the fixed base quantity indexes is much higher (6.1 percentage points) than that of the price series that correspond to the chained quantity indexes (0.5 percentage points).

VII. Appendix B – Index Number Formulas

A. Fixed Base Quantity Index Formulas

Fixed Base Laspeyres Quantity Index

$$Q_L^t = \frac{\sum_{i=1}^n p_i^b \, q_i^t}{\sum_{i=1}^n p_i^b \, q_i^b}$$

Fixed Base Paasche Quantity Index

$$Q_P^t = \frac{\sum_{i=1}^n p_i^t \, q_i^t}{\sum_{i=1}^n p_i^t \, q_i^b}$$

where Q_L^t is the fixed base Laspeyres quantity index at period *t* (with $t = 1,2, \dots, N$) and Q_P^t is the fixed base Paasche quantity index at period *t*. p_i^b and q_i^b denote the price and quantity series (respectively) for component *i* at the base period *b*, while p_i^t and q_i^t denote the price and quantity series for component *i* at period *t*.

Fixed Base Fisher Quantity Index

$$Q_F^t = \sqrt{\left(\frac{\sum_{i=1}^n p_i^b \, q_i^t}{\sum_{i=1}^n p_i^b \, q_i^b}\right)\left(\frac{\sum_{i=1}^n p_i^t \, q_i^t}{\sum_{i=1}^n p_i^t \, q_i^b}\right)} = \sqrt{Q_L^t \times Q_P^t}$$

, where Q_F^t is the fixed base Fisher quantity index at period *t* (with $t = 1,2, \dots, N$), Q_L^t is the fixed base Laspeyres index at period *t* and Q_P^t is the fixed base Paasche quantity index at period *t*. p_i^b and q_i^b denote the price and quantity series (respectively) for component *i* at the base period *b*, while p_i^t and q_i^t denote the price and quantity series for component *i* at period *t*.

B. Chained Quantity Index Formulas[11]

Chained Laspeyres Quantity Index

$$Q_{CL}^n = \prod_{t=2}^{n} AR_{CL}^t = AR_{CL}^2 \times \dots \times AR_{CL}^n$$

and

$$AR_{CL}^t = \left(\frac{\sum_{i=1}^n p_i^{t-1} \, q_i^t}{\sum_{i=1}^n p_i^{t-1} \, q_i^{t-1}}\right)$$

[11] The formulas in this section assume that the reference period *r* is the first period in the sample period, *n*=1, and the quantity index for the reference period is set equal to one. If, for some reason, another reference period is desired, then the indexes constructed here have to be rebased. Note that the choice of reference period does not affect in any way each period's quantity change.

where Q_{CL}^{n} is the chained Laspeyres quantity index at period *n* (with $n = 2, \dots, N$, since for *n*=1, $Q_{CL}^{1} = AR_{CL}^{1} = 1$) and AR_{CL}^{t} is the chained Laspeyres aggregate relative at period *t*. p_i^{t-1} and q_i^{t-1} denote the price and quantity series (respectively) for component *i* at the period *t-1*, while q_i^t denotes the quantity series for component *i* at period *t*.

Chained Paasche Quantity Index

$$Q_{CP}^{n} = \prod_{t=2}^{n} AR_{CP}^{t} = AR_{CP}^{2} \times \dots \times AR_{CP}^{n}$$

and

$$AR_{CP}^{t} = \left(\frac{\sum_{i=1}^{n} p_i^t\, q_i^t}{\sum_{i=1}^{n} p_i^t\, q_i^{t-1}} \right)$$

where Q_{CP}^{n} is the chained Paasche quantity index at period *n* (with $n = 2, \dots, N$, since for *n*=1, $Q_{CP}^{1} = AR_{CP}^{1} = 1$) and AR_{CP}^{t} is the chained Paasche aggregate relative at period *t*. p_i^t and q_i^t denote the price and quantity series (respectively) for component *i* at the period *t*, while q_i^{t-1} denotes the quantity series for component *i* at period *t-1*.

Chained Fisher Quantity Index

$$Q_{CF}^{n} = \prod_{t=2}^{n} AR_{CF}^{t} = AR_{CF}^{2} \times \dots \times AR_{CF}^{n}$$

and

$$AR_{CF}^{t} = \sqrt{\left(\frac{\sum_{i=1}^{n} p_i^{t-1}\, q_i^t}{\sum_{i=1}^{n} p_i^{t-1}\, q_i^{t-1}} \right) \left(\frac{\sum_{i=1}^{n} p_i^t\, q_i^t}{\sum_{i=1}^{n} p_i^t\, q_i^{t-1}} \right)} = \sqrt{AR_{CL}^{t} \times AR_{CP}^{t}}$$

where Q_{CF}^{n} is the chained Fisher quantity index at period *n* (with $n = 2, \dots, N$, since for *n*=1, $Q_{CF}^{1} = AR_{CF}^{1}$=1). AR_{CF}^{t}, AR_{CL}^{t} and AR_{CP}^{t} are the aggregate relatives for the chained Fisher, chained Laspeyres and chained Paasche quantity indexes (respectively) at period *t*. p_i^t and q_i^t denote the price and quantity series (respectively) for component *i* at the base period *t*, while p_i^{t-1} and q_i^{t-1} denote the price and quantity series for component *i* at period *t-1*.